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Effects of speed-power load adaptation on heart rate variability during visuomotor task performance

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Adaptation to physical exercise is a multilevel process that modulates autonomic nervous system (ANS) function, thereby influencing cardiovascular regulation and stress responsiveness. The role of ANS adaptation to physical stressors, especially speed-strength loads, in shaping autonomic responses to visuomotor tasks, remains poorly understood. This study aimed to investigate HRV dynamics in individuals with different levels of adaptation to speed-strength loads under conditions of various visuomotor tasks. The sample comprised 22 trained karate athletes and 26 untrained students, matched for age, body mass, and height. HRV indices (HR, SDNN, RMSSD, pNN$_{50}$, SD$_1$, SD$_2$) were recorded at rest conditions and during a battery of visuomotor tasks of graded complexity: simple visual-motor reaction, visuomotor anticipation, stimulus discrimination, and a tapping test. At rest, trained athletes demonstrated significantly higher RMSSD, pNN$_{50}$, and SD$_1$ values, together with lower HR, indicating enhanced parasympathetic modulation. During task performance, both groups exhibited reductions in heart rate variability (SDNN, SD$_2$), consistent with sympathetic activation, although the magnitude of these changes was greater in the trained group. The most pronounced alterations were observed during the tapping test, where trained athletes showed marked decreases in RMSSD, SD$_1$, and pNN$_{50}$, alongside a pronounced HR increase, reflecting a rapid shift toward sympathetic dominance. These findings suggest that long-term speed-strength training is associated with elevated parasympathetic tone at rest and a more dynamic autonomic reorganization under acute psychophysiological stress. Such modulation may represent a physiological marker of functional readiness, reflecting the ability of trained individuals to mobilize cardiovascular resources during cognitively demanding or emotionally stressful conditions. This study advances understanding of cross-adaptation mechanisms and highlights the relevance of HRV analysis for assessing adaptive responses in physically trained populations.

Keywords: physical loads; simple visual-motor reaction; visuomotor anticipation; go/no-go test; tapping test; karate; students.

Introduction

Adaptation to stress factors, including physical exercise, is a complex multilevel process that ensures optimal functioning of the organism under conditions of external and internal environmental changes (Lu et al., 2021). According to Selye's concept, it is based on a combination of specific and nonspecific adaptive changes (Stanojlović et al., 2022), mediated through central and peripheral pathways. The central pathway has a multilevel structure and integrates the regulatory influences of the cerebral cortex, the hypothalamic-pituitary axis, and the autonomic nervous system (ANS). This pathway provides the integration of vital system functions required to maintain homeostasis under stressor exposure (Lu et al., 2021). Different types of stress are characterized by distinct autonomic patterns determined by the nature of the stress stimulus (Immanuel et al., 2023; Riganello et al., 2023). Psychophysiological stress, similar to physiological stress, activates the hypothalamic-pituitary-adrenal (HPA) axis, yet differs in its mechanisms and demonstrates more variable manifestations (Avramova, 2020; Lu et al., 2021). In modern research, the study of psychophysiological stress responses and their possible modulation through adaptation to physical exercise is considered a promising direction in physiological investigations.

The assumption regarding the modification of organismal responses to psychophysiological stress factors as a result of physical exercise adaptation is based on the concept of cross-adaptation, which explains the interrelation between physiological responses to physical exercise and psychological stressors (Arvidson et al., 2020). Adaptive mechanisms are mediated by the ANS (Daniela et al., 2022; Kupper et al., 2022; Ahmadi et al., 2024) and manifest in the modulation of autonomic tone both at rest and under stressor exposure. At rest, the enhancement of adaptive potential resulting from regular physical activity is expressed as an increase in para-sympathetic tone (Chakraborty et al., 2023; Korsak et al., 2023; Sammito et al., 2024). These changes rely on both peripheral and central mechanisms. Peripheral mechanisms include, in particular, an increase in stroke volume and enhanced capillarization of muscle tissue (Hornby-Foster et al., 2024). Central mechanisms involve adaptations in central nervous system structures (Lee et al., 2020; Fournié et al., 2021), modifications in the "central command" system (Wan et al., 2023), and direct influences of higher brain centers on ANS structures (van der Mee et al., 2022). During stress exposure, decreased parasympathetic activity and enhanced sympathetic activation are observed, reflecting a shift in regulatory balance toward mobilization of the organism's functional reserves (Tyshchenko, 2020; Casanova-Lizón et al., 2022). It is well established that repeated exposure to constant exercise intensity leads to a reduction in magnitude of ANS responses and accelerates recovery processes (van der Mee et al., 2022).

Heart rate variability (HRV) is a widely used non-invasive indicator of ANS activity, reflecting autonomic regulatory balance and serving as an informative marker of cardiovascular responses to physical and psychophysiological stressors (Bhattacharya et al., 2023; Peabody et al., 2023; Tekin et al., 2025). HRV reflects beat-to-beat variations in cardiac cycle duration (Matuz et al., 2021; Sammito et al., 2024), which arise from both autonomic tone fluctuations and hormonal or neuropsychological influences (Fournié et al., 2021). HRV analysis enables an objective evaluation of the divisions of ANS activity (Toyofuku et al., 2024). During exercise, sympathetic activation typically increases, which is reflected by a reduction in HRV (Daniela et al., 2022; Wan et al., 2023). In the context of stress, the standard deviation of NN intervals (SDNN) and the long axis of the Poincaré plot (SD$_2$) are considered informative indicators; their reduction reflects increased sympathetic activity (Lackner et al., 2020; Ishaque et al., 2021). Meanwhile, reductions in the root mean square of successive differences (RMSSD), the percentage of successive RR intervals differing by more than 50 ms (pNN$_{50}$), and the short axis of the Poincaré plot (SD$_1$) indicate diminished parasympathetic activity (Immanuel et al., 2023; Shushkovska et al., 2023). Some studies have also identified associations between changes in SDNN, RMSSD, and pNN_{50} and cognitive task performance (Van Cutsem et al., 2022; Arakaki et al., 2023).

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. It is well established that adaptation to cyclic exercise is accompanied by HRV changes reflecting enhanced parasympathetic tone of the ANS at rest (Chakraborty et al., 2023; Korsak et al., 2023; Sammito et al., 2024). Recent reviews underscore that different exercise modalities exert distinct effects on heart rate variability (HRV), a key marker of ANS function, with high-intensity interval training (HIIT) showing the most pronounced improvements in time- and frequency-domain indices (Yang et al., 2024). Moreover, HRV has emerged as a valuable tool for monitoring recovery and training adaptation, though its application is hindered by methodological inconsistencies and inter-individual variability (Storniolo et al., 2025). Longitudinal analyses also reveal a lack of standardized protocols and baseline values, complicating efforts to generalize findings across populations (Sundas et al., 2025). These insights highlight the need to explore how chronic physical training influences ANS dynamics beyond physical exertion. Although the autonomic benefits of endurance training are well established (Immanuel et al., 2023), the regulation of 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). 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.

Only a limited number of investigations have examined the influence of exercise adaptation on HRV responses to cognitive and emotional stimuli (Chatterjee et al., 2022; Akbari Niaz Abadi et al., 2023; Bhattacharya et al., 2023; 2025). Analysis of these studies reveals both common trends and inconsistencies in the reported data (Souza et al., 2021), forming a basis for further exploration of cross-adaptation phenomena to psychophysiological and cognitive stressors under the influence of regular physical training. 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 adaptations, the impact of long-term physical training on ANS responses to non-physical stressors, particularly cognitive and emotional challenges, remains insufficiently characterized. Existing studies have primarily focused on HRV changes during physical exercises, while responses to cognitive load in trained individuals remain underexplored, especially in speed-strength disciplines. This gap limits our ability to fully characterize the systemic effects of regular physical activity beyond its direct physiological outcomes. Addressing this gap, the present study examines HRV dynamics during the performance of complex visual-motor reaction tasks in individuals with varying degrees of adaptation to speed-strength training. We hypothesize that trained participants will exhibit distinct task-related autonomic modulation compared to untrained controls.

Materials and methods

The study involved male students of Ivan Boberskyi Lviv State University of Physical Culture. The trained (T) group consisted of 22 highly skilled karate athletes (black belts, masters of sport, with a minimum of five years of training experience). Their mean age was 19.14 ± 2.25 years, height 179.18 ± 4.67 cm, and body mass 73.95 ± 12.65 kg. The untrained (UT) group comprised 26 students who did not engage in systematic physical activity. Their mean age was 18.31 ± 0.68 years, height 179.21 ± 7.14 cm, and body mass 73.50 ± 11.00 kg. Groups did not differ significantly in age and anthropometric parameters. None of the participants reported a history of cardiovascular disease or other medical conditions that could influence the outcomes. All participants had normal or corrected-to-normal vision and normal color perception. Written informed consent was obtained from each participant prior to inclusion in the study. The research protocol was conducted in accordance with the ethical standards of the Declaration of Helsinki and the fundamental bioethical principles outlined in the Council of Europe Convention on Human Rights and Biomedicine (Council of Europe, 1997; World Medical Association, 2013). The study was approved by the Ethics Committee of Ivan Bobersky Lviv State University of Physical Culture (protocol No. 29/2025, June 29, 2025).

Physiological data were collected during the first half of the day under conditions of comfortable ambient temperature and absence of external disturbances, in line with international recommendations for the standardization of HRV assessment (Damoun et al., 2024). At baseline, a five-minute HRV record was performed in a seated position at relative rest. Participants then performed a battery of visuomotor tests of varying complexity: simple visual-motor reaction (SVMR), visuomotor anticipation tasks (VAT), stimulus discrimination tasks (SDT or Go/No-Go test), and the tapping test (TT). All tasks were administered using the NS-Psychotest.NET (Neurosoft, russian federation, 2016) software-hardware system.

The SVMR was assessed with a visual–motor analyzer that presented a red visual stimulus (0.2 s duration) with a total of 70 stimuli. In the VAT test, participants pressed a button when a red marker moving clockwise reached a green mark (50 stimuli). During the SDT test, circles of various colors and sizes appeared randomly on the monitor; participants were instructed to respond as quickly as possible to the appearance of a red circle with a yellow border (70 stimuli). The TT test lasted 30 seconds, during which participants pressed the Enter key with the index finger of the dominant hand at maximal frequency.

Throughout all tests, HRV was recorded using Polar RS800 heart rate monitors (Polar Electro Oy, Finland, 2012), and data were processed with the software Polar Pro Trainer 5.40.172 (Polar Electro Oy, Finland, 2012). The following indices were analyzed: heart rate (HR), the standard deviation of normal-to-normal intervals (SDNN), the root mean square of successive differences (RMSSD), the percentage of successive NN intervals differing by more than 50 ms (pNN_{50}, %), the short axis of the Poincaré plot (SD_1), and the long axis of the Poincaré plot (SD_2), expressed in milliseconds.

Statistical analysis was conducted using the software package OriginPro 2018, version b9.5.0.193 (OrirginLab Corporaton, USA) and JASP 0.95.1 (Jasp Team, Netherlands, 2025). Normality of data distribution was verified with the Shapiro-Wilk test. Differences between two independent samples were assessed using Student's t-test or the Mann–Whitney U test (for non-normally distributed data). Repeated Measures ANOVA was used to evaluate multiple within-subject effects and interactions. Post hoc comparisons were conducted using the Holm correction, effect sizes were calculated using Cohen's d, and 95% confidence intervals were reported to provide estimates of the precision and practical significance of observed effects. Relative changes in HRV indices were expressed as percentages of baseline values (taken as 100%). The significance of these changes was evaluated using the one-sample t-test or the One-Sample Wilcoxon Signed Rank Test (for non-normal distributions).

Results

At rest, significant intergroup differences were observed in HR, SDNN, SD_1, RMSSD, and pNN_{50} (Table 1). HRV indices in the trained group (T) were 11.80–43.01% higher compared with the untrained group (UT), whereas HR was 7.40% lower in T ($P < 0.05$).

Table 1
The HRV indices of trained (T, x ± SD, n = 22) and untrained (UT, x ± SD, n = 26) persons

HRV indices	Group	Rest	SVMR	VAT	SDT	TT
HR, bpm	T	75.9 ± 10.0	74.7 ± 10.4	76.4 ± 9.5	77.8 ± 12.2	113.9 ± 14.3
	UT	82.1 ± 10.8*	81.5 ± 14.2*	79.4 ± 9.0	80.9 ± 12.3	106.7 ± 13.2*
SDNN, ms	T	87.3 ± 25.5	64.9 ± 15.8	61.4 ± 18.4	52.6 ± 9.7	38.9 ± 15.7
	UT	73.9 ± 26.1*	55.9 ± 18.2*	58.8 ± 24.7	51.6 ± 26.5	44.6 ± 25.6*
SD_1, ms	T	42.5 ± 13.0	39.9 ± 11.5	32.7 ± 9.9	30.9 ± 10.6	8.5 ± 4.4
	UT	35.5 ± 15.9*	33.9 ± 12.5$^{\#}$	29.5 ± 9.6	32.3 ± 18.4	11.5 ± 7.8*
SD_2, ms	T	118.0 ± 33.9	80.1 ± 20.3	79.1 ± 27.2	67.0 ± 13.0	54.9 ± 22.9
	UT	105.5 ± 38.3	71.4 ± 24.3$^{\#}$	77.5 ± 35.5	64.5 ± 33.4	62.4 ± 33.1
RMSSD, ms	T	54.3 ± 19.0	54.8 ± 17.5	47.3 ± 13.6	43.7 ± 14.9	11.3 ± 6.0
	UT	41.9 ± 21.7*	46.4 ± 18.9$^{\#}$	41.7 ± 13.6$^{\#}$	44.8 ± 23.9	15.9 ± 10.9*
pNN_{50}, %	T	12.5 (8.3; 16.3)	19.1 (12.7; 23.0)	12.9 (6.9; 17.9)	6.0 (12.0; 15.1)	0.0 (0.0; 0.9)
	UT	5.9 (3.8; 13.0)*	12.0 (6.9; 15.6)*	10.9 (4.5; 17.4)	4.2 (8.6; 16.3)	0.0 (0.0; 2.8)*

Note: SVMR – simple visual-motor reaction, VAT – visuomotor anticipation tasks, SDT – stimulus discrimination tasks, TT – tapping test (TT); level of significance of differences between groups: * – $P < 0.05$; $^{\#}$ – $P < 0.10$; for pNN_{50}, data are presented as Q2 (Q1; Q3).

Repeated measures ANOVA (Table 2) showed that all studied heart indices changed significantly depending on testing conditions ($P < 0.001$), indicating a pronounced physiological response to experimental influences. The strongest effects were observed for heart rate (HR), $\eta^2p = 0.83$, as well as for SD_1 ($\eta^2p = 0.66$) and RMSSD ($\eta^2p = 0.64$), highlighting the high sensitivity of these indices to changes in conditions. The interaction between testing conditions and group membership was statistically significant for most indices: HR, SDNN, SD_1, RMSSD, and pNN_{50}, indicating different dynamics of HRV changes between the studied groups. The between-group effect was statistically significant only for pNN_{50}, suggesting that, while resting HRV is higher in athletes, group differences are most marked when stressors (tasks) are introduced rather than in all conditions.

Analysis of changes in HRV indices during the SVMR, VAT, SDT, and TT tests compared to the resting state (Table 3) revealed varying response dynamics depending on the type of indicator. In UT group the heart rate (HR) showed a statistically significant change only during the TT test ($P_{holm} < 0.01$; d = –2.63), indicating a pronounced increase in heart rate. Other conditions did not demonstrate statistically significant changes. For the SDNN and SD_2 indices, which reflect overall heart rate variability, a decrease was observed across all test conditions. This is supported by positive Cohen's d values (SDNN: d = 0.66–1.12; SD_2: d = 0.83–1.34) and statistically significant P-values ($P_{holm} < 0.01$). The confidence intervals did not include zero, confirming the statistical significance of these changes. In the UT group the indicators of short-term heart rate variability (SD_1, RMSSD, and pNN_{50}) showed a decrease only during the TT test In other conditions, changes were either minor or not statistically significant.

In the T group the comparison of HR between the resting state and test conditions (Table 3) revealed a statistically significant increase only during TT ($P_{holm} < 0.01$; Cohen's d = –3.44; CI: –47.45 to –26.74). The SDNN index showed a significant reduction across all test conditions compared to rest. The most pronounced decrease in SDNN was observed during TT, suggesting the highest level of physiological load under this condition. The SD_1 index showed significant reductions during VAT, SDT, and TT compared to rest, supported by significant P-values and large effect sizes. The greatest reduction in SD_1 occurred during TT. The SD_2 index demonstrated significant reductions across all test conditions relative to rest. The RMSSD and pNN_{50} indices showed a significant decrease only during TT, accompanied by a large effect and a confidence interval that excluded zero.

Table 2
Results of repeated measures ANOVA for heart rate variability indices

HRV index	Type of effect	df	F	P	η^2p
HR	test type	4	183.85	< 0.01	0.83
	test × group interaction	4	3.67	0.01	0.09
	group	1	0.27	0.61	0.01
SDNN	test type	4	27.52	< 0.01	0.39
	test × group interaction	4	2.76	0.03	0.06
	group	1	0.58	0.45	0.01
SD_1	test type	4	75.87	< 0.01	0.66
	test × group interaction	4	2.96	0.02	0.07
	group	1	1.28	0.27	0.03
SD_2	test type	4	28.17	< 0.01	0.40
	test × group interaction	4	0.70	0.59	0.02
	group	1	0.06	0.81	0.00
RMSSD	test type	4	69.85	< 0.01	0.64
	test × group interaction	4	3.21	0.01	0.07
	group	1	1.89	0.18	0.05
pNN_{50}	test type	4	43.47	< 0.01	0.49
	test × group interaction	4	2.65	0.04	0.06
	group	1	3.97	0.05	0.08

Note: df – degrees of freedom, η^2p – partial eta squared, measure of effect size.

Table 3
HRV index comparisons between rest and test conditions: results of post hoc analysis

HRV Indices	Post hoc analysis	UT group				T group			
		SVMR	VAT	SDT	TT	SVMR	VAT	SDT	TT
HR	P_{holm}	1	1	1	< 0.01	1	1	1	< 0.01
	Cohen's d	–0.01	0.05	0.08	–2.63	0.08	–0.07	–0.08	–3.44
	95% CI	–6.22	–4.78	–4.35	–37.95	–4.66	–6.46	–6.36	–47.45
		6.11	5.72	5.93	–17.52	6.47	5.03	4.65	–26.74
SDNN	P_{holm}	< 0.01	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Cohen's d	0.83	0.66	0.93	1.12	1.30	1.50	2.01	2.90
	95% CI	4.53	0.74	6.03	7.60	6.61	5.83	17.51	32.18
		36.19	31.77	39.54	47.24	38.24	45.98	51.89	68.11
SD_1	P_{holm}	1	0.24	0.34	< 0.01	0.83	0.02	< 0.01	< 0.01
	Cohen's d	0.01	0.53	0.44	1.93	0.21	0.93	1.03	3.22
	95% CI	–8.86	–3.44	–4.54	9.59	–6.24	–0.38	1.02	25.26
		9.19	15.53	14.62	34.58	10.71	19.90	20.59	42.03
SD_2	P_{holm}	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Cohen's d	1.11	0.83	1.24	1.34	1.50	1.47	2.03	2.54
	95% CI	15.10	5.13	17.20	19.64	14.11	8.68	25.90	36.29
		59.70	51.18	66.44	70.69	55.58	59.54	68.42	81.63
RMSSD	P_{holm}	0.65	1	1	< 0.01	0.73	0.33	0.16	< 0.01

HRV Indices	Post hoc analysis	UT group				T group			
		SVMR	VAT	SDT	TT	SVMR	VAT	SDT	TT
	Cohen's d	–0.34	0.08	0.07	1.53	–0.18	0.46	0.62	2.82
	95% CI	–17.64 6.48	–11.14 13.69	–11.33 13.74	9.64 40.97	–15.11 9.80	–6.07 19.73	–4.08 22.65	29.89 54.33
pNN_{50}	P_{holm}	0.43	0.75	1	< 0.01	0.19	0.83	0.83	< 0.01
	Cohen's d	–0.41	–0.29	–0.20	1.03	–0.56	–0.19	0.10	1.72
	95% CI	–7.31 1.77	–6.02 2.11	–5.77 3.15	2.14 11.68	–9.65 1.66	–6.44 3.75	–3.43 4.78	7.63 16.73

Note: P_{holm} – Holm-corrected P-values, Cohen's d – effect sizes, 95% CI – confidence intervals.

The data of Table 3 confirms the preliminary conclusions from the ANOVA analysis (Table 2) and revealed pronounced differences in physiological responses between the UT and T groups during the performance of SVMR, VAT, SDT, and TT tests. The most significant changes were observed in the T group, which showed a deeper changes in both heart rate (HR) and heart rate variability indices. The effect sizes were substantially larger in the T group, indicating a stronger HRV response.

Analysis of the relative changes in HRV indices as percentages of baseline values (taken as 100%) reveals that during the SVMR test, HR, SD_1, and RMSSD did not change significantly in either group (Table 4). By contrast, SDNN decreased by 24–25% and SD_2 by 28–29% ($P < 0.001$), while pNN_{50} increased by 32–37% ($P < 0.05$). These changes reduced intergroup differences in SD_1 and RMSSD to trend level ($P < 0.1$) and introduced a tendency toward differences in SD_2 ($P < 0.1$). Overall, the HRV response during SVMR reflected similar reductions in overall variability in both groups, without changes in mean HR. The increase in pNN_{50}, together with the trend toward higher RMSSD, may indicate enhanced short-term rhythm fluctuations underconditions of focused attention without psychophysiological stress. Performance of the VAT test was not accompanied by significant changes in HR or pNN_{50} in either group, although a trend was noted in UT (Tables 1 and 2). Both groups demonstrated significant decreases in SDNN (by 28% in T and 17% in UT; $P < 0.001$), SD_1 (by 17% and 7%, respectively; $P < 0.05$), and SD_2 (by 29% and 23%, respectively; $P < 0.001$). In T, but not in UT, RMSSD decreased significantly by 6% ($P < 0.05$). Thus, VAT performance was associated with reductions in overall HRV in both groups, with more pronounced effects in T, particularly regarding parasympathetically mediated indices (RMSSD, SD_1).

During the SDT test, HR and pNN_{50} showed no significant changes in either group (Tables 1 and 2). RMSSD remained unchanged in UT but decreased by 18% in T ($P < 0.01$). Both groups exhibited reductions in SDNN (by 38% and 28%, respectively; $P < 0.01$), SD_1 (by 24% and 12%, respectively; $P < 0.05$), and SD_2 (by 39% and 37%, respectively; $P < 0.001$).

Table 4
Significance of changes (%) in HRV indices under the influence of sensorimotor tests in the trained group (T, x ± SD, n = 22) and untrained group (UT, x ± SD, n = 26)

HRV indices	Group	SVMR		VAT		SDT		TT	
		%	P_{T-UT}	%	P_{T-UT}	%	P_{T-UT}	%	P_{T-UT}
HR	T	99.33 ± 10.43	>0.1	100.50 ± 10.98	<0.1	103.45 ± 10.49	<0.05	151.86 ± 22.78***	<0.01
	UT	99.75 ± 10.46		97.52 ± 10.09#		97.87 ± 7.91		134.99 ± 18.97***	
SDNN	T	75.39 ± 18.71***	>0.1	71.88 ± 22.19***	<0.1	62.45 ± 17.98**	<0.1	45.72 ± 17.05***	<0.01
	UT	75.53 ± 23.31***		82.85 ± 34.43***		72.45 ± 27.88**		71.29 ± 49.07***	
SD_1	T	100.27 ± 31.58	>0.1	82.29 ± 31.40**	>0.1	77.85 ± 30.71***	<0.1	20.47 ± 9.27***	<0.01
	UT	104.46 ± 43.07		93.21 ± 31.78*		88.22 ± 41.93*		37.12 ± 27.57***	
SD_2	T	70.92 ± 19.60***	>0.1	70.64 ± 25.48***	>0.1	60.62 ± 18.74***	>0.1	47.29 ± 23.78***	<0.01
	UT	72.35 ± 25.95***		77.41 ± 33.26***		63.42 ± 25.73***		62.64 ± 33.70***	
RMSSD	T	111.61 ± 46.44	>0.1	94.09 ± 22.10*	<0.05	82.07 ± 26.98**	<0.05	21.59 ± 9.29***	<0.01
	UT	125.11 ± 57.20		116.92 ± 53.47		109.56 ± 50.55		47.87 ± 38.31***	
pNN_{50}	T	137.08 (89.91; 214.75)*	>0.1	99.08 (71.01; 118.32)	<0.05	106.8 (76.9;124.9)	<0.05	12.60 (6.00; 15.31)***	<0.01
	UT	132.26 (84.31; 258.69)*		134.32 (74.58; 207.98)#		119.4 (75.0;170.9)		49.65 (10.00; 86.49)*	

Note: HRV values at rest were taken as 100%; level of significance of changes compared to rest: *** – $P < 0.001$; ** – $P < 0.01$; * – $P < 0.05$; # – $P < 0.10$; P_{T-UT} – significance of differences in changes (%) between groups.

Thus, SDT performance was associated with pronounced reduction in HRV indices in both groups, particularly in SDNN and SD_2. The decreases in SDNN and RMSSD were more pronounced in T than in UT. Moreover, reductions in SD1 in both groups indicated diminished parasympathetic modulation, with stronger effects in T, where this was accompanied by significant decreases in another vagally mediated parameter, RMSSD.

The most pronounced changes were observed during the 30-second tapping test (Table 4). Significant between-group differences ($P < 0.05$) were found in all indices except SD_2. Averaged relative changes showed that HR increased by 52% in T and 35% in UT ($P < 0.001$), with a greater increase in T compared with UT ($P < 0.01$). Several HRV indices decreased markedly during this test. SDNN decreased by 54% in T and 28% in UT ($P < 0.001$), and RMSSD decreased by 78% and 52%, respectively ($P < 0.001$), indicating a stronger effect of the test on trained individuals ($P < 0.01$). SD_1 decreased by 79% in T ($P < 0.001$) and 63% in UT ($P < 0.001$), confirming significant intergroup differences ($P < 0.01$). SD_2 reductions were smaller (by 53% and 37%, respectively; $P < 0.001$) but still demonstrated intergroup effects. The most pronounced changes were observed in pNN_{50}, which decreased by 87% in T ($P < 0.001$) and by 51% in UT ($P < 0.05$). Taken together, HRV alterations during the tapping test demonstrate profound changes in ANS regulatory activity, characterized by a marked shift toward sympathetic dominance. These responses were significantly more pronounced in individuals adapted to speed-strength training.

Discussion

At rest, we observed differences in HRV parameters between individuals systematically engaged in speed-strength training and their untrained counterparts. Specifically, trained participants demonstrated higher RMSSD, pNN_{50}, and SD_1 values, indicating enhanced parasympathetic activity under baseline conditions. These results are consistent with previous reports (Souza et al., 2021; Chakraborty et al., 2023; Immanuel et al., 2023; Korsak et al., 2023; Sammito et al., 2024), which confirmed the association between endurance training and increased parasympathetic modulation of the ANS at rest. Such shifts in autonomic balance appear to be a hallmark of long-term adaptation to various forms of physical activity. For example, comparable changes have been described in team-sport athletes, where basketball players and swimmers exhibited higher RMSSD values and lower resting heart rates relative to sedentary individuals (Chakraborty et al., 2023). Although combat sports remain less thoroughly investigated, Bhattacharya et al. (2023) reported a similar trend: young karate athletes displayed higher HF power and lower LF/HF ratios compared with non-athletic controls, suggesting parasympathetic predominance. Collectively, these findings support the hypothesis that ANS adaptation to exercise may involve shared mechanisms across different sport disciplines, including the speed-strength ones.

At the central level, adaptive responses may involve stimulation of neuroplasticity within the paraventricular nucleus (PVN) and the rostral ventrolateral medulla (RVLM). These processes are mediated by increased expression of BDNF and TrkB and are associated with reduced sympathetic outflow (Lee et al., 2020). Training has also been shown to preserve vagal neurons in the nucleus ambiguus (NA) and the dorsal motor nucleus of the vagus (DMV), thereby reinforcing parasympathetic control (Korsak et al., 2023). Moreover, adaptations extend to the central autonomic network (CAN) (Fournié et al., 2021). HRV fluctuations are functionally linked to activity within the prefrontal cortex, anterior cingulate cortex, amygdala, hippocampus, and other CAN structures, which collectively mediate flexible adjustments to internal and external stimuli (Fournié et al., 2021; Mee et al., 2022; Wan et al., 2023).

At the peripheral level, regular physical activity enhances baroreflex sensitivity by improving vascular compliance (Hornby-Foster et al., 2024). Sammito et al. (2024) further demonstrated that endurance training elicits molecular adaptations, including altered expression of ion channel proteins in the sinoatrial node, which modulate HRV by reducing its variability indices.

Cognitive and emotional stress is typically reflected characterized in reductions of long-term HRV indices such as SDNN and SD_2, while short-term parasympathetic markers (RMSSD, pNN_{50}) may vary depending on task complexity and individual fitness level (Shushkovska et al., 2023, Immanuel et al., 2023; Riganello et al., 2023). Our results corroborate these observations, revealing a reduction in SDNN and SD_2 values during task performance in both groups, with the most pronounced changes detected during the tapping test. Effect size analysis using Cohen's d shows that the T group exhibited more pronounced changes across SDNN and SD_2 parameters. It is well established that SDNN and SD_2 reflect overall (long-term) heart rate variability, whereas RMSSD, pNN_{50}, and SD_1 primarily index high-frequency parasympathetic modulation (Lackner et al., 2020). In most tasks, a reduction in RMSSD (% from the baseline) was observed in the trained group, whereas in untrained participants significant decreases in this parameter were only evident during the tapping test. Conversely, an increase in pNN_{50} was detected during less complex tasks requiring sustained attention (SVMR, and VAT) in the untrained group. During the tapping test, which demands maximal motor frequency and rapid sensorimotor coordination, pNN_{50} values declined sharply in both groups. The phenomenon of increased pNN_{50} during relatively simple cognitive tasks has also been reported by other authors (Ahmadi et al., 2024), and is typically interpreted as a sign of reduced sympathetic activation and effective autonomic regulation under moderate cognitive load (Riganello et al., 2023). However, findings across studies remain inconsistent. For instance, Van Cutsem et al. (2022) observed increased RMSSD and pNN_{50} during prolonged task performance, likely reflecting fatigue-related disengagement, while Chakraborty et al. (2023) and Hansen et al. (2004) reported minimal changes in these indices during shorter cognitive challenges. These discrepancies may be attributed to differences in task duration, complexity, and baseline fitness levels. Further research is needed to clarify the specific autonomic dynamics elicited by various cognitive task types and their modulation by physical training status.

The concurrent decrease in SDNN and SD_2, alongside increases in RMSSD and pNN_{50}, may reflect selective suppression of long-term variability due to diminished baroreflex or sympathetic modulation, while short-term vagal responses are preserved or even enhanced. Such dynamics are characteristic of focused attention in the absence of emotional arousal and have been observed during well-practiced visuomotor or cognitive tasks (Lackner et al., 2020). In this context, further investigation of the interplay between short- and long-term HRV indices under different modes of stimulation is warranted. Addressing this hypothesis requires spectral analysis, which is not feasible with ultra-short recordings.

Our findings also highlight differences in the impact of visuomotor tasks on HRV indices between individuals with varying levels of adaptation to speed-power loads. In tasks requiring complex information processing (VAT and SDT), changes in multiple HRV parameters (HR, SDNN, RMSSD, pNN_{50}) were more pronounced in the trained group. These differences became particularly evident during the tapping test, which strongly activates the sympathetic branch of the ANS. In this test, all analyzed HRV parameters demonstrated substantially greater changes in participants adapted to speed-strength training compared with untrained controls.

Overall, the influence of adaptation to physical loads on HRV responses to cognitive load remains insufficiently characterized, and available findings are inconsistent (Hansen et al., 2004; Luque-Casado et al., 2013; Chakraborty et al., 2023). For instance, Shushkovska et al. (2023) reported greater resilience to stressors in individuals with a vagotonic regulatory profile, particularly among trained athletes. Similarly, Tekin et al. (2025) demonstrated that trained individuals exhibited more pronounced parasympathetic responses to sensorimotor load, characterized by higher RMSSD and pNN_{50} values and reduced LF/HF ratios, reflecting more efficient autonomic regulation. Luque-Casado et al. (2013) likewise found that less physically fit individuals showed a progressive decline in HRV parameters (RRi, RMSSD) during serial cognitive testing, whereas participants with higher fitness levels maintained considerably more stable values. Their data suggested that fitter individuals tended to preserve higher RRi, SDNN, and RMSSD during testing, although these differences did not reach statistical significance. In contrast, Hansen et al. (2004) reported no substantial group differences in HRV during task performance; however, post-task HF power, an indicator of parasympathetic activity, was significantly higher in trained individuals. Some findings remain contradictory: for example, Chakraborty et al. (2023) documented resting differences in HR, RMSSD, and HF power between athletes (basketball players and swimmers) and untrained participants, but found no significant group differences during cognitive testing.

While our findings confirm several patterns reported in earlier research, they also uncover inconsistencies that suggest the need for further investigation. First, our results agreed with prior observations of increased sympathetic activation of the ANS during psychoemotional and cognitive load (van der Mee et al., 2022; Shushkovska et al., 2023), as well as the dependence of these changes on task complexity. However, unlike other authors, we analyzed relative changes in HRV parameters as percentage from baseline values. This approach enabled us to detect larger changes in the number of HRV parameters during certain tasks in trained individuals compared with untrained controls. These results suggest that one manifestation of adaptation to speed-strength training is a more rapid and pronounced reorganization of ANS activity toward sympathetic dominance under psychoemotional load.

Conclusion

Based on the obtained results, we established that several HRV indices (HR, SDNN, SD_1, RMSSD, and pNN_{50}) differed significantly at rest between research groups, consistent with higher parasympathetic activity in athletes, adapted to speed-strenght training. The ANOVA results reveal distinct dynamics in the changes in HR, SDNN, SD_1, RMSSD, and pNN_{50} between trained and untrained individuals during visuomotor tests performance. During tests both groups demonstrated a reduction in overall HRV (SDNN, SD_2) with more pronounced changes in group of trained individuals. This effect was particularly evident during the tapping test, where marked decreases in SDNN, RMSSD, SD_1, and pNN_{50} indicated a strong shift toward sympathetic dominance in both groups, with more pronounced changes in the trained group. Such responses may reflect adaptations to speed-strength training, leading to a more dynamic autonomic response to psychophysiological stress. Whether this represents enhanced functional readiness or greater reactivity requires further investigation.

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