Cardio-electrical and blood pressure characteristics during recovery following very intense exercise in martial arts athletes

Características cardioeléctricas y de la presión arterial durante la recuperación tras un ejercicio muy intenso en atletas de artes marciales

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Abstract

Background. Martial arts, characterized by intermittent high-intensity efforts, generate specific cardiovascular constraints. Few studies have examined post-exercise cardio-electrical and hemodynamic responses in this context, particularly during the recovery phase.

Objective. This study aimed to analyze variations in heart rate (HR), blood pressure (systolic: SYS, diastolic: DIAS), oxygen saturation (SpO_2), and electrocardiographic parameters (PR, QT, QRS, QTc, RV5, SV1) in martial arts practitioners before, immediately after, and up to 30 minutes following an intense bout of exercise.

Methods. Twenty-four male athletes performed a high-intensity session simulating competition (≥85% HRmax). Physiological measurements were collected at four time points (rest, end of exercise, and 15- and 30-minute recovery). A repeated-measures ANOVA and a factorial analysis were performed.

Results. Significant post-exercise hypotension was observed (SYS: −11.33% at 30 min; DIAS: −14.63% at end of exercise). HR doubled at the end of effort (138 bpm), with partial recovery by 30 minutes. QT interval shortened and then progressively normalized. SpO_2 showed a slight decrease (−1.28%) before rising again. Factorial analysis identified clusters of interrelated variables.

Conclusion. Martial arts induce specific transient cardio-electrical responses. These findings highlight the importance of individualized recovery monitoring for both performance optimization and cardiovascular prevention.

Keywords

Martial arts, heart rate, electrocardiogram, post-exercise hypotension, recovery, oxygen saturation.

Resumen

Antecedentes. Las artes marciales, caracterizadas por esfuerzos intermitentes de alta intensidad, generan restricciones cardiovasculares específicas. Pocos estudios han examinado las respuestas cardioeléctricas y hemodinámicas post-ejercicio en este contexto, particularmente durante la fase de recuperación.

Objetivo. Este estudio tuvo como objetivo analizar las variaciones en la frecuencia cardíaca (FC), la presión arterial (sistólica: PAS, diastólica: PAD), la saturación de oxígeno (SpO_2) y los parámetros electrocardiográficos (PR, QT, QRS, QTc, RV5, SV1) en practicantes de artes marciales antes, inmediatamente después y hasta 30 minutos tras un esfuerzo intenso.

Métodos. Veinticuatro atletas masculinos realizaron una sesión de alta intensidad que simulaba una competición (≥85% de la FC máxima). Se recogieron mediciones fisiológicas en cuatro momentos temporales (reposo, final del ejercicio, y recuperación a 15 y 30 minutos). Se realizó un ANOVA de medidas repetidas y un análisis factorial.

Resultados. Se observó una hipotensión post-ejercicio significativa (PAS: −11,33 % a los 30 min; PAD: −14,63 % al final del ejercicio). La FC se duplicó al final del esfuerzo (138 lpm), con una recuperación parcial a los 30 minutos. El intervalo QT se acortó y luego se normalizó progresivamente. La SpO_2 mostró una ligera disminución (−1,28 %) antes de volver a aumentar. El análisis factorial identificó grupos de variables interrelacionadas.

Conclusión. Las artes marciales inducen respuestas cardioeléctricas transitorias específicas. Estos hallazgos resaltan la importancia de un monitoreo individualizado de la recuperación tanto para la optimización del rendimiento como para la prevención cardiovascular.

Palabras clave

Artes marciales, frecuencia cardíaca, electrocardiograma, hipotensión post-ejercicio, recuperación, saturación de oxígeno.

Introduction

Martial arts—including disciplines such as karate, judo, taekwondo, and mixed martial arts (MMA)—are characterized by intermittent and explosive efforts combining aerobic and anaerobic components, placing substantial demands on the cardiovascular system. These efforts, involving rapid movements such as strikes (e.g., *Oi-zuki*) and throws, elicit heart rate (HR) peaks approaching 95–100% of the theoretical maximum (220 – age), along with marked blood pressure fluctuations driven by the intensity and intermittent nature of combat (Andreato et al., 2017; Imamura et al., 1999)”. The post-exercise recovery phase is crucial for restoring homeostasis, preserving myocardial integrity, and optimizing future performance, yet remains insufficiently studied in martial arts settings.

Scientific literature shows that intense exercise elicits complex physiological responses. Post-exercise hypotension (PEH), defined as a prolonged reduction in systolic (SYS) and diastolic (DIAS) blood pressure, results from peripheral vasodilation mediated by nitric oxide and prostaglandins, as well as baroreflex resetting (Minson & Halliwill, 2017). A meta-analysis reported an average SYS decrease of 5.3 mmHg following aerobic exercise, with larger reductions after high-intensity efforts (Casonatto et al., 2016). Electrocardiographic (ECG) parameters such as QT interval shortening reflect accelerated ventricular repolarization under sympathetic activation (Zorzi et al., 2018). HR rises sharply during exercise and decreases progressively during recovery due to vagal reactivation, a marker of cardiovascular fitness (Stanley et al., 2013). Oxygen saturation (SpO_2) may exhibit slight desaturation—exercise-induced arterial hypoxemia (EIAH)—due to ventilation–perfusion mismatch (Dempsey & Wagner, 1999). These responses are well documented in endurance or resistance sports, but remain underexplored in martial arts characterized by intermittent efforts ≥85% HRmax.

In real-world settings, martial arts practitioners often reach HR levels close to their theoretical maximum, with substantial blood pressure fluctuations due to the explosive nature of techniques, followed by short rest intervals (2–3 minutes) insufficient for complete recovery (Andreato et al., 2017). This dynamic increases cardiac stress, as illustrated by reported cardiovascular complications among MMA fighters (Bledsoe et al., 2005)”. International federations such as the International Judo Federation (IJF) and the International Union of Martial Arts (IUAM) emphasize the need for protocols to minimize cardiovascular risks, though specific standards for cardio-electrical and blood pressure recovery remain poorly established (IJF, 2023) . In sports cardiology, guidelines stress monitoring post-exercise responses to prevent cardiac decompensation, particularly in athletes repeatedly exposed to intense bouts (Pelliccia et al., 2021)

Existing studies show several limitations. First, they focus mainly on endurance or strength sports, overlooking martial arts with their intermittent effort patterns (Imamura et al., 2016 ; James et al., 2013). Second, protocols lack standardization regarding intensity and duration, limiting comparability (Casonatto et al., 2016). Third, few investigations analyze recovery beyond 15 minutes, restricting understanding of homeostatic restoration (Fecchio et al., 2020). Finally, the absence of factorial approaches to explore interactions among ECG parameters (e.g., PR, QT, QRS), hemodynamic variables (SYS, DIAS), and SpO_2 represents a major methodological gap (Carvalho et al., 2021) . These limitations are critical because incomplete recovery may result in chronic fatigue, performance decline, and increased cardiovascular risk (Bledsoe et al., 2005).

This study aims to address these gaps by characterizing variations in cardio-electrical parameters (HR, PR, QT, QRS intervals), hemodynamic measures (SYS, DIAS), and SpO_2 in 24 martial arts practitioners before, during, and up to 30 minutes after an intense competition-simulated effort. Factorial analysis (Varimax rotation) will be used to identify specific parameter patterns, providing a holistic understanding of their interactions. Findings may guide coaches in optimizing recovery timing (e.g., 2–3-minute intervals between rounds), support clinicians in screening for abnormalities (e.g., vagally mediated atrioventricular blocks), and contribute to the development of international standards for combat-sport safety, aligning with IJF (2023) and Pelliccia et al. (2021) recommendations.

Method

Participants

The sample consisted of 24 male martial arts practitioners, aged 19.42 ± 2.78 years, with a body mass index (BMI) of 22.12 ± 3.69. All were engaged in regional or national competitions, with an average training experience of 4.42 ± 3.80 years, and trained 4 to 5 times per week. Inclusion criteria were: regular sports practice for at least two years, absence of diagnosed cardiovascular pathologies, and signed informed consent. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the local institutional ethics committee.

Procedure

Measurements and Instruments

Each participant completed a 30-minute high-intensity exercise session performed in a controlled laboratory environment, using a martial-arts-specific circuit simulating high-intensity sequences typical of combat sports (striking combinations, projection-like movements, intermittent effort phases without direct contact). Exercise intensity targeted ≥ 85% of theoretical maximal heart rate, confirmed through continuous heart-rate monitoring (Polar Team2 Pro, Polar Electro Oy, Finland).

Participants performed no cognitive or technical tasks outside the physical protocol. During recovery periods, they were required to remain supine, refraining from speaking or moving, to minimize parasympathetic or metabolic interference on cardiovascular measurements (Lucía et al.,; Stanley et al., 2013).

Measurements were taken at four key time points:

- Rest (supine, 10 minutes of quiet),
- End of exercise (immediately post-effort),
- Recovery at 15 minutes,
- Recovery at 30 minutes (supine position).

Measurements and Instruments

Measured variables included:

- Heart rate (HR), in beats per minute (bpm);
- Systolic (SYS) and diastolic (DIAS) blood pressure (mmHg), assessed using an electronic sphygmomanometer (OMRON M6 Comfort, HEM-7321-E, Japan);
- Oxygen saturation (SpO_2), via digital oximeter (Nonin Onyx® Vantage 9590, USA);
- Twelve-lead electrocardiogram (ECG), recorded using a Cardioline Cube ECG device, allowing analysis of:

– PR, QRS, QT, and TC intervals (ms),

– P and T waves (ms),

– RV5 and SV1 amplitudes (mV),

– RV5+SV1 product (mV).

All measurements were conducted by the same trained technician under standardized conditions (temperature, posture, silence).

Data analysis

Data were analyzed using IBM SPSS Statistics v.26 (IBM Corp., Armonk, NY). Intra-subject variations across the four time points (rest, end of exercise, 15- and 30-min recovery) were assessed using repeated-measures ANOVA, followed by Bonferroni-corrected post hoc tests. Effect sizes were reported as partial η^2, and percentage changes (%Δ) were calculated for each significant difference.

An exploratory factor analysis (EFA) using principal component extraction (Varimax rotation) was performed to examine the structure of relationships between ECG and blood-pressure parameters across phases. The objective was to identify physiological variable clusters potentially related to post-exercise recovery profiles in martial arts practitioners..

Results

Blood Pressure

The results presented in Table 1 illustrate the variations in the mean values of blood pressure parameters across the four measurement points (rest, end of exercise, 15 min, and 30 min of recovery). Systolic values (SYS) show an average of 131.54 mmHg at rest, 129.00 mmHg at the end of exercise, 119.79 mmHg at 15 min of recovery, and 116.63 mmHg at 30 min of recovery. The ANOVA indicates a significant difference ($p = .001$, $\eta^2 = .575$), with a moderate effect size. Post-hoc comparisons reveal significant differences between rest and 15 min ($p = .001$), rest and 30 min ($p = .001$), and between end of exercise and 30 min ($p = .006$). The variation in SYS from rest to 15 min recovery is approximately ((119.79 – 131.54) / 131.54) × 100 ≈ –8.93 %, and from rest to 30 min is ≈ –11.33 %.

1.Tests are adjusted for all pairwise comparisons within each row using Bonferroni correction. 2.p: probability of significance at 5%; Eta squared: effect size.

Table 1. Variation in the Mean Values of Electrocardiographic and Blood Pressure Parameters at Rest and During Post-Exercise Recovery

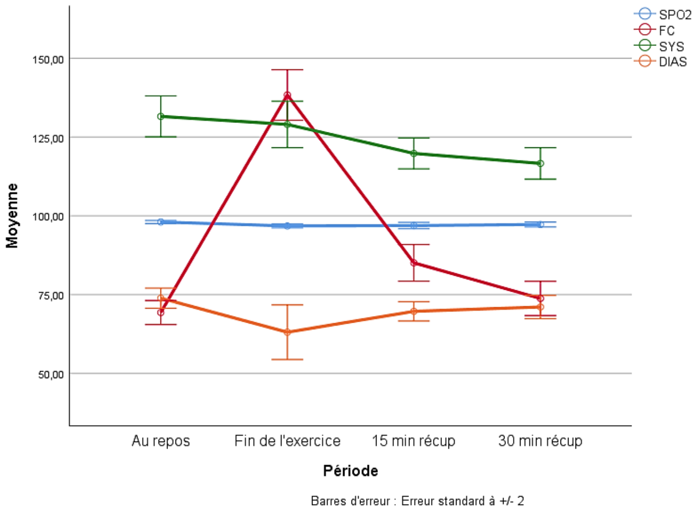
Parameter	At Rest		End of Exercise		15 min Recovery		30 min Recovery		ANOVA	
	(A)		(B)		(C)		(D)		p value	éta
	Mean	±sd	Mean	±sd	Mean	±sd	Mean	±sd		
SPO2	98,04	1,20	96,79	1,50	96,92	2,45	97,25	1,89	.000 (p)	.582 (Eta)
FC	69,33	9,31	138,33 A C D	19,64	85,08 A	14,25	73,79	13,31	.000	0.938
SYS	131,54 C D	15,92	129,00 D	18,05	119,79	12,00	116,63	12,25	.001	.575
DIAS	73,88 B	7,80	63,08	21,23	69,71	7,49	71,08	9,05	.018	.387
PR	158,14	21,89	159,04	21,58	161,03	20,43	156,83	22,38	ns	
QT	364,46 B C	21,98	326,38	20,82	344,79 B	20,74	355,04 B	26,98	.000	.819
TC	389,92	19,48	414,96 A C D	18,93	394,04	22,87	391,08	28,54	.000	.623
P	40,63	25,41	53,71	34,72	48,54	28,34	51,63	28,00	ns	
QRS	58,50	20,39	58,46	23,59	57,79	32,85	56,08	22,85	ns	
T	43,88	16,26	49,79	8,78	45,54	12,58	40,61	26,96	ns	
RV5	1,76	,68	1,93	,58	2,00	,52	1,76	,87	ns	
SV1	1,21	,51	1,22	,61	1,12	,53	1,09	,65	.010	.429
AmpRV5.SV1	2,98	,96	3,15	,83	3,11	,77	2,85	1,10	.055	.309

*Significant differences, p< .05

Results are based on two-tailed tests assuming equal variances. For each significant pair, the key of the smallest category appears in the category with the highest mean.Significance level for uppercase letters (A, B, C): .051.

Mean diastolic values (DIAS) are 73.88 mmHg at rest, 63.08 mmHg at the end of exercise, 69.71 mmHg at 15 min, and 71.08 mmHg at 30 min of recovery. ANOVA shows a significant difference ($p = .018$, $\eta^2 = .387$), with a small-to-moderate effect size. A post-hoc comparison indicates a significant variation between rest and 15 min Recovery ($p = .029$), representing a decrease of ((63.08 – 73.88) / 73.88) × 100 ≈ –14.63 %.

Figure 1. Variation of Blood Pressure and Oxygen Saturation Parameters (SPO_2, HR, SYS, DIAS).



In Figure 1,SPO_2 (blue): remains stable around 98–100% at rest, decreases slightly to approximately 96.79% at end of exercise, then rises to 97.25% after 30 min of recovery, with low variability (small error bars). HR (Red): increases sharply from ~69 bpm at rest to ~138 bpm at end of exercise, decreases to ~85 bpm after 15 min, and to ~74 bpm after 30 min, with greater variability during effort (larger error bars). SYS (green): declines from ~132 mmHg at rest to ~129 mmHg at end of exercise, then drops to ~120 mmHg at 15 min and ~117 mmHg at 30 min, with noticeable variability. DIAS (orange): falls from ~74 mmHg at rest to ~63 mmHg at end of exercise, then increases to ~70 mmHg during recovery, with moderate variability.

Oxygen Saturation (SPO_2)

As shown in Table 1, SPO_2 is measured at 98.04% at rest, 96.79% at end of exercise, 96.92% at 15 min, and 97.25% at 30 min of recovery. ANOVA indicates a significant overall difference ($p < .001$, $\eta^2 = .582$), with a moderate effect size. Post-hoc comparisons indicate a significant difference between rest and end of exercise ($p < .001$), corresponding to $((96.79 − 98.04) / 98.04) × 100 ≈ −1.28$ %.

Electrocardiogram (ECG)

The electrocardiographic data in Table 1 and the statistical comparisons in Table 2 enable a detailed analysis of cardiac responses across the different phases. Electrocardiographic analysis reveals marked adaptations in heart rate (HR) and conduction intervals. HR increases sharply from rest (69.33 ± 9.31 bpm) to end of exercise (138.33 ± 19.64 bpm), with progressive reduction to 85.08 ± 14.25 bpm at 15 min, then 73.79 ± 13.31 bpm at 30 min ($p < .001$; $\eta^2 = .938$). The amplitude of this variation indicates maximal sympathetic system solicitation, followed by progressive parasympathetic reactivation. The QT interval decreases significantly, from 364.46 ± 21.98 ms at rest to 326.38 ± 20.82 ms at end of effort ($p < .001$), before lengthening to 344.79 ± 20.74 ms at 15 min and 355.04 ± 26.98 ms at 30 min ($\eta^2 = .819$), indicating transient shortening of cardiac repolarization under stress. Total conduction time (TC) follows an inverse pattern: 389.92 ± 19.48 ms at rest, 414.96 ± 18.93 ms at end of effort ($p = .001$), 394.04 ± 22.87 ms at 15 min, and 391.08 ± 28.54 ms at 30 min ($\eta^2 = .623$), reflecting temporary prolongation of intraventricular conduction. In contrast, PR intervals (approximately 158–161 ms), QRS (≈ 58 ms), and P and T waves show no statistically significant variations. These results suggest stability in atrial and ventricular conductions despite the intensity of the effort.

Table 2. Post Hoc Statistical Comparisons (Inter-Periods) for Repeated Measures ANOVA

Variable	(I) Period	At Rest	End of Exercise	15 min Recovery
SPO2	At Rest	1	.000	ns
	End of Exercise	.000	1	ns
	15 min Recovery	Ns	ns	1
	30 min Recovery	Ns	ns	ns
FC	At Rest	1	.000	ns

	End of Exercise	.000	1	.000
	15 min Recovery	Ns	.000	1
	30 min Recovery	Ns	ns	.000
SYS	At Rest	1	ns	.001
	End of Exercise	Ns	1	.030
	15 min Recovery	.001	.030	1
	30 min Recovery	.001	.006	ns
DIS	At Rest	1	ns	.029
	End of Exercise	Ns	1	ns
	15 min Recovery	.029	ns	1
	30 min Recovery	Ns	ns	ns
PR	At Rest	1	ns	ns
	End of Exercise	Ns	1	ns
	15 min Recovery	Ns	ns	1
	30 min Recovery	Ns	ns	ns
QT	At Rest	1	.000	.000
	End of Exercise	.000	1	.000
	15 min Recovery	.000	.000	1
	30 min Recovery	ns	.000	ns
TC	At Rest	1	.001	ns
	End of Exercise	.001	1	.000
	15 min Recovery	ns	.000	1
	30 min Recovery	ns	.007	ns
P	At Rest	1	ns	ns
	End of Exercise	ns	1	ns
	15 min Recovery	ns	ns	1
	30 min Recovery	ns	ns	ns
QRS	At Rest	1	ns	ns
	End of Exercise	ns	1	ns
	15 min Recovery	ns	ns	1
	30 min Recovery	ns	ns	ns
T	At Rest	1	ns	ns
	End of Exercise	ns	1	ns
	15 min Recovery	ns	ns	1
	30 min Recovery	ns	ns	ns
RV5	At Rest	1	ns	ns
	End of Exercise	ns	1	ns
	15 min Recovery	ns	ns	1
	30 min Recovery	ns	ns	ns
SV1	At Rest	1	ns	ns
	End of Exercise	ns	1	.019
	15 min Recovery	ns	.019	1
	30 min Recovery	ns	ns	ns
mpRV5.SV1	At Rest	1	ns	ns
	End of Exercise	ns	1	ns
	15 min Recovery	ns	ns	1
	30 min Recovery	ns	ns	ns

Regarding amplitudes, RV5 remains relatively constant across phases. SV1 shows a significant decrease from end of exercise (1.22 ± 0.61 mV) to 15 min (1.12 ± 0.53 mV; $p = .010$; $\eta^2 = .429$), with a trend toward normalization at 30 min. The combined amplitude RV5 + SV1 (≈ 3 mV) decreases slightly without reaching significance ($p = .055$), reducing its discriminative value in this context. Continuing from the described results, the temporal dynamics observed for heart rate, oxygen saturation, as well as systolic and diastolic pressures are visually represented in the corresponding graphs (see Figure 1). These curves confirm the marked evolution of heart rate, which peaks at the end of exercise, as well as the transient decrease in SpO_2 and the prolonged decrease in blood pressure, reinforcing the observations in Table 1. Furthermore, the graphical representation of electrocardiographic intervals (Figure 2) clearly visualizes the reduction in QT and prolongation of TC at different measurement times, confirming the statistical variations noted. These trends are supported by the results in Table 2, which synthesizes the post hoc comparisons between measurement periods.

Figure 2. Variations in Electrocardiographic Intervals and Amplitudes (PR, QT, TC, QRS, RV5, SV1).

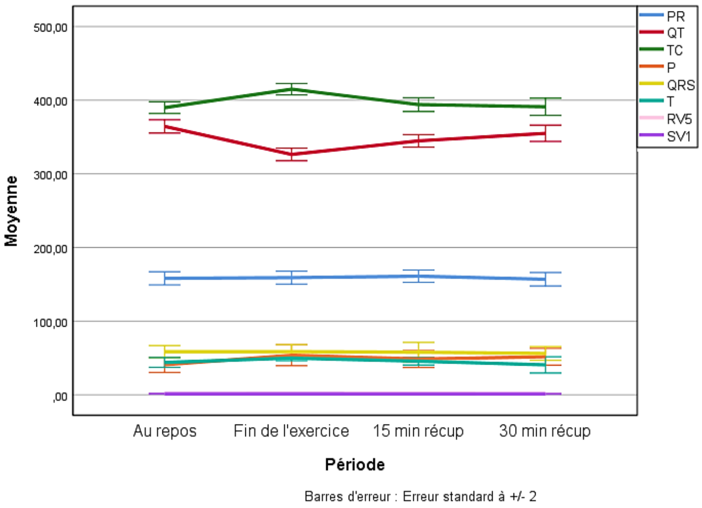


Table 3. Regression Estimates of Parameters at End of Exercise and After 30 min Recovery.

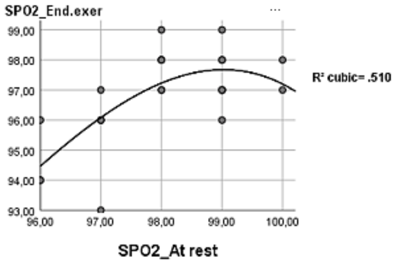
Dependent Variable	Period	Model Summary						Coefficient Estimates			
		Equation	R2	F	ddl1	ddl2	Sig.	Constnte	b1	b2	b3
SPO2	End	Cubique	,508	10,849	2	21	,001	-2192,170	34,676	,000	-,001
	Recovery	Qudrtique	,346	5,549	2	21	,012	1245,573	-24,168	,127	
HR	End	S	,191	5,201	1	22	,033	5,389	-32,013		
	Recovery	Linéire	,086	2,075	1	22	,164	46,265	,199		
SYS	End	Qudrtique	,483	9,805	2	21	,001	176,314	-1,494	,009	
	Recovery	S	,301	9,458	1	22	,006	5,220	-59,143		
DIS	End	Qudrtique	,128	1,542	2	21	,237	303,030	-7,323	,055	
	Recovery	Qudrtique	,229	3,115	2	21	,065	73,067	-,646	,009	
PR	End	S	,670	44,600	1	22	,000	5,834	-119,993		
	Recovery	Linéire	,476	19,971	1	22	,000	43,062	,715		
QT	End	Qudrtique	,401	7,034	2	21	,005	655,956	-2,374	,004	
	Recovery	Qudrtique	,150	1,853	2	21	,182	1568,936	-7,953	,013	
TC	End	Qudrtique	,015	,162	2	21	,852	-275,782	3,435	-,004	
	Recovery	Linéire	,081	1,926	1	22	,179	213,584	,428		
P	End	Linéire	,117	2,909	1	22	,102	34,740	,467		
	Recovery	Cubique	,130	,995	3	20	,416	30,382	,034	,005	-2,216E-6
SV1	End	Cubique	,739	18,881	3	20	,000	,636	-,683	1,262	-,273
	Recovery	Cubique	,893	55,782	3	20	,000	,020	,248	,794	-,221
QRS	End	Cubique	,900	60,141	3	20	,000	-47,444	3,830	-,049	
	Recovery	Cubique	,576	8,603	3	19	,001	19,321	,032	,016	-9,618E-5
T	End	Linéire	,073	1,733	1	22	,202	43,393	,146		
	Recovery	Qudrtique	,007	,070	2	21	,933	-27,169	2,697	-,026	
RV5	End	Cubique	,432	5,075	3	20	,009	1,868	-,935	,596	-,053
	Recovery	Cubique	,494	6,505	3	20	,003	-,065	1,542	-,650	,167
SV1_End.exer	End	Cubique	,739	18,881	3	20	,000	,636	-,683	1,262	-,273
	Recovery	Linéire	,877	157,535	1	22	,000	,257	,886		
mpRV5-SV1	End	Qudrtique	,597	15,578	2	21	,000	2,594	-,302	,149	
	Recovery	Cubique	,738	18,740	3	20	,000	8,212	-6,601	2,104	-,180

End: End of exercise; Recovery: After 30 min of exercise

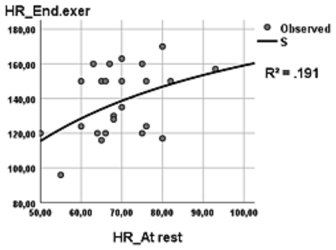
Conversely, certain models, such as those applied to T wave duration ($R^2 = 0.007$) or total conduction time (TC) ($R^2 = 0.015$), proved non-significant. Their low explanatory power reflects either substantial interindividual variability or heightened sensitivity to factors not accounted for in the current models (e.g., hydration status, electrolytes, or post-exercise oxidative stress levels). Figure 3 graphically confirms these results by illustrating the fitted trend curves: a clear inflection in the curves is visible for SpO_2 and SYS, while HR and QT follow patterns of progressive decrease or normalization.

Figure 3: Regression Curves for SPO2, FC, and SYS The regression curves illustrate the following predictive relationships

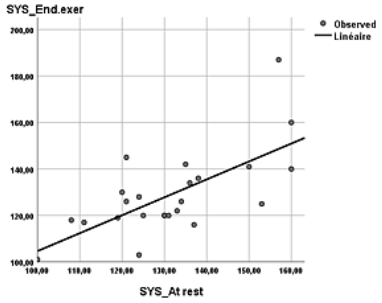
- SPO2 : Y:−2192,170+34,676X−0,001X3 Y : -2192,170 + 34,676X - 0,001X^3 Y:−2192,170+34,676X−0,001X3 ($p < 0,001$, F : 10,849).
- FC : Y:5,389−1/X Y : 5,389 - 1/X Y:5,389−1/X (p : 0,033, F : 5,210).
- SYS : Y:27,57+0,771X Y : 27,57 + 0,771X Y:27,57+0,771X (F : 18,914, $p < 0,001$, R^2 : 0,438)



Y: -2192,170+34,676.X - 0,001. X^3 , ($p<0.001$, F:10 ;849)



Y: 5.389-1/X ; ($p<0.033$, F:5.210)



Y:27.57+0.771.X ; Linéire
(F:18.914, $p>.000$) R^2: .438. **r^2 : .680**

Discussion

Blood Pressure

The results demonstrate a significant decrease in systolic blood pressure (SYS) following intense exercise, declining from 131.54 mmHg at rest to 119.79 mmHg at 15 minutes (-8.93%) and 116.63 mmHg at 30 minutes (-11.33%) of recovery. Diastolic blood pressure (DIAS) drops from 73.88 mmHg at rest to 63.08 mmHg at the end of exercise (-14.63%), then rises to 69.71 mmHg at 15 minutes and 71.08 mmHg at 30 minutes. This post-exercise hypotension (PEH) arises from peripheral vasodilation mediated by nitric oxide and prostaglandins, as well as baroreflex resetting that reduces sympathetic tone (Chen & Bonham, 2010; Halliwill et al., 2013). Increased vascular compliance also contributes to this response (MacDonald, 2002). These observations align with the meta-analysis by Borges et al. (2016) , which reports an average SYS reduction of 4.8 mmHg following aerobic exercise, although our decrease is more pronounced, likely due to the high intensity (≥85% HRmax) of martial arts training. Sales et al. (2016) observed a similar SYS reduction (-14.2 mmHg) after a karate session, and Prado et al. (2022) noted a significant decline following Muay Thai training. However, in contrast to MacDonald (2002), who reports an increase in SYS during exercise, we observed stabilization at the end of effort, possibly related to the intermittent nature of the exercise. Pescatello et al. (2015) confirm that PEH is more pronounced after intense efforts, and van de Walle et al. (2021) highlight a marked effect in interval-based exercises. The absence of continuous blood pressure measurements limits the analysis of real-time hemodynamic dynamics, and the small sample size (n=24) reduces generalizability (Carvalho et al., 2021) . The cited studies often feature small cohorts (Sales et al., 2016) and heterogeneous protocols (Borges et al., 2016) , complicating comparisons. Future research could incorporate ambulatory measurements and a control group to quantify long-term PEH in martial arts.

Oxygen Saturation (SpO_2)

SpO_2 decreases slightly from 98.04% at rest to 96.79% at the end of exercise (-1.28%), then recovers to 97.25% at 30 minutes of recovery ($p < .001$, $\eta^2 = .582$). This transient desaturation, termed exercise-induced arterial hypoxemia (EIAH), results from increased oxygen demand by skeletal muscles that temporarily exceeds blood transport capacity, along with ventilation/perfusion mismatch (Dominelli &

Sheel, 2019) . The relative stability of SpO_2 indicates efficient respiratory and circulatory adaptations in martial arts practitioners. These results are consistent with Oliveira et al. (2019), who report a modest SpO_2 decline (97.1 ± 3.2%) at peak exercise, and with the systematic review by Ramos et al. (2015), which notes minor desaturation during intense exercises. However, unlike Nielsen et al. (2018), who observed more marked desaturation in untrained individuals, our participants maintained $SpO_2 \geq 95\%$, likely due to improved alveolo-capillary diffusion. Johnson et al. (2021) emphasize interindividual variability in SpO_2 responses, consistent with our data. The use of pulse oximetry may overestimate arterial saturation, and the lack of ventilatory or blood gas measurements limits interpretation (Oliveira et al., 2019). The cited studies often lack blood gas analyses (Ramos et al., 2015), reducing precision. Future studies could integrate pCO_2 measurements to assess EIAH in martial arts practitioners.

Electrocardiogram (ECG)

ECG analysis reveals an increase in heart rate (HR) from 69.33 ± 9.31 bpm at rest to 138.33 ± 19.64 bpm at the end of exercise, followed by a decrease to 85.08 ± 14.25 bpm at 15 minutes and 73.79 ± 13.31 bpm at 30 minutes ($p < .001$, $\eta^2 = .938$). This response reflects acute sympathetic activation and parasympathetic withdrawal during effort, followed by vagal re-innervation during recovery (Carter et al., 2003; Daanen et al., 2012). The QT interval shortens from 364.46 ± 21.98 ms at rest to 326.38 ± 20.82 ms at the end of effort ($p < .001$), then lengthens to 344.79 ± 20.74 ms at 15 minutes, due to accelerated ventricular repolarization and sympathetic stimulation (Arrowood et al., 1993; Schwartz & Crotti, 2011). Total conduction time (TC) increases from 389.92 ± 19.48 ms at rest to 414.96 ± 18.93 ms at the end of effort ($p = .001$), suggesting temporary myocardial fatigue (Kashou et al., 2020). The stability of PR and QRS intervals indicates resilience in atrioventricular conduction. These results are consistent with Carter et al. (2003) for HR and Schwartz & Crotti (2011) for QT. However, unlike Drezner et al. (2017), who report QRS modifications in athletes, our data show stability, possibly due to exercise duration. Fananapazir et al. (1983) note a direct sympathetic effect on QT, supporting our observations. The slight decrease in SV1 amplitude at 15 minutes ($p = .010$) remains unexplained, possibly related to thoracic artifacts. Limitations: The absence of QTc correction and HR variability analysis limits interpretation (Cohen et al., 2021). The cited studies often focus on athletes (Drezner et al., 2017), restricting applicability to diverse populations. Future research could include biochemical measures (e.g., adrenaline) to explore sympathetic links.

Predictive Modeling

Regression models reveal significant relationships for SpO_2 ($R^2 = 0.508$), SYS ($R^2 = 0.483$), and SV1 ($R^2 = 0.877$ at 30 minutes). The cubic model for SpO_2 reflects nonlinear dynamics, consistent with EIAH (Wasserman et al., 2011). The quadratic decrease in SYS indicates progressive vascular relaxation (Pescatello et al., 2015). The strong SV1 fit suggests predictable electrophysiological recovery (Kashou et al., 2020). In contrast, models for T wave ($R^2 = 0.007$) and TC ($R^2 = 0.015$) are non-significant, likely due to uncontrolled factors such as hydration or electrolytes (Lee et al., 2021). These results align with Wasserman et al. (2011) for SpO_2 but contrast with Surawicz and Knilans (2008), who do not report predictive dynamics for TC, possibly due to absent electrolyte data. Brown et al. (2020) note similar relationships for SYS in quadratic models. The small sample size affects statistical power, and the absence of variables like electrolytes limits interpretation (Brown et al., 2020). The cited studies lack data on confounding factors (Surawicz & Knilans, 2008). Future studies could use continuous measurements and include biomarkers to validate models. Implications and Perspectives These results suggest that martial arts practitioners exhibit robust cardiovascular adaptations, with marked PEH, stable SpO_2, and expected ECG modifications. For coaches, adjusting recovery intervals based on HR (e.g., 15-minute pause to reach ~85 bpm) can optimize performance. For clinicians, monitoring QT could aid in detecting anomalies in athletes. Future research should explore chronic PEH, EIAH across martial arts styles, and correlations between parameters via factor analysis to identify physiological axes (e.g., cardiorespiratory vs. cardioelectrical).

Conclusions

This study characterized cardio-electrical and blood pressure responses in 24 martial arts practitioners (karate and judo, aged 20-30 years) at rest, at the end of intense exercise (≥85% of maximum heart rate), and at 15 and 30 minutes of recovery. The primary results show notable post-exercise hypotension, with a systolic blood pressure decrease of 8.93% at 15 minutes and 11.33% at 30 minutes, and a diastolic pressure drop of 14.63% at the end of exercise, followed by partial recovery. Heart rate increases from 69.33 to 138.33 beats per minute, then decreases progressively, indicating efficient restoration of cardiovascular balance. The QT interval shortens significantly at the end of effort, reflecting transient electrophysiological adaptation. Oxygen saturation exhibits a slight desaturation of 1.28%, consistent with metabolic constraints of explosive efforts. A factor analysis revealed interactions among these parameters, suggesting adaptations specific to martial arts. These results offer practical applications for coaches, who can adjust recovery pauses (e.g., 2-3 minutes to reach ~85 beats per minute) to optimize performance. For clinicians, monitoring the QT interval can help detect anomalies, enhancing athlete safety in combat sports. However, the study is limited by the small sample size, absence of continuous measurements, and a laboratory protocol that does not fully reflect real competition conditions. Future research should explore long-term adaptations, integrate biomarkers such as lactate to better understand physiological mechanisms, and use wearable technologies for real-time measurements. An in-depth factor analysis could identify physiological patterns unique to martial arts, informing training strategies and safety standards.

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