



RELATIONSHIP BETWEEN AEROBIC CAPACITY AND POST-EXERCISE HEART RATE RECOVERY IN ELITE BOXERS

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Abstract:

Aerobic fitness and cardiovascular recovery are important determinants of performance in combat sports. Among physiological indicators, maximal oxygen uptake ($VO_2\max$) and heart rate recovery (HRR) are widely used to evaluate athletes' conditioning status and adaptation to training. Understanding the relationship between these variables may provide valuable information for optimizing boxing performance and training prescription. **Purpose:** The purpose of this study was to investigate the relationship between aerobic capacity and post-exercise heart rate recovery in elite boxers and to examine potential gender differences in these physiological variables. **Methods:** Twenty elite boxers (10 females and 10 males), all competing at the national level, participated in this cross-sectional study. Aerobic capacity was assessed through maximal oxygen uptake ($VO_2\max$) using an incremental treadmill protocol combined with a COSMED K5 portable metabolic system. Heart rate responses were continuously monitored throughout testing. Heart rate recovery was calculated as the difference between maximal heart rate and heart rate recorded one minute after exercise cessation. Independent-samples t-tests were used to compare physiological variables between

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genders. **Results:** Male boxers demonstrated significantly higher $VO_2\text{max}$ values ($56.8 \pm 4.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) compared with female boxers ($48.2 \pm 3.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $p = 0.001$). No significant gender differences were observed in maximal heart rate (192 ± 5 vs. 188 ± 6 bpm; $p > 0.05$). However, female athletes showed significantly greater heart rate recovery (28 ± 5 bpm) than males (24 ± 4 bpm; $p = 0.045$). These findings suggest gender-related differences in aerobic fitness and recovery characteristics among elite boxers. **Conclusions:** Elite male boxers exhibit superior aerobic capacity, whereas female boxers demonstrate more efficient post-exercise cardiovascular recovery. Monitoring both $VO_2\text{max}$ and HRR may provide useful information for training individualization and performance optimization in boxing.

Keywords: boxing, $VO_2\text{max}$, heart rate recovery, aerobic fitness, gender differences, cardiovascular adaptation

1. Introduction

Boxing is a high-intensity intermittent combat sport characterized by repeated explosive actions interspersed with short recovery periods. Successful performance depends on the effective interaction of aerobic and anaerobic energy systems, as athletes are required to maintain high-intensity efforts while preserving technical and tactical efficiency throughout competition (Chaabène *et al.*, 2015; Davis *et al.*, 2015). Previous investigations have shown that physiological performance in combat sports is strongly influenced by aerobic fitness and recovery capacity (Franchini *et al.*, 2011; Franchini *et al.*, 2019).

Aerobic capacity, commonly expressed as maximal oxygen uptake ($VO_2\text{max}$), is considered one of the strongest physiological determinants of athletic performance (Bassett & Howley, 2000). Athletes with higher $VO_2\text{max}$ values are generally able to sustain exercise intensity for longer periods and recover more efficiently between repeated bouts of activity (Jones & Carter, 2019). Furthermore, improvements in aerobic fitness have been associated with enhanced cardiovascular efficiency and exercise tolerance (Buchheit & Laursen, 2013).

Heart rate recovery (HRR) is another important physiological marker that reflects autonomic nervous system regulation following exercise. Faster HRR is generally associated with superior cardiovascular fitness and training adaptation (Daanen *et al.*, 2012). Because boxing athletes are required to repeatedly perform near-maximal efforts during successive rounds, the ability to recover rapidly between bouts of exercise is essential for optimal performance (Chaabène *et al.*, 2015).

Previous studies have consistently reported higher $VO_2\text{max}$ values in male athletes compared with females, mainly due to differences in body composition, hemoglobin concentration, and oxygen transport capacity (Joyner & Coyle, 2008; Sandbakk *et al.*, 2018). However, female athletes have frequently demonstrated more efficient cardiovascular recovery responses following exercise (Seiler *et al.*, 2016).

Despite the growing body of literature examining physiological performance in combat sports, limited evidence exists regarding the relationship between aerobic capacity and post-exercise heart rate recovery in elite boxing athletes. Therefore, the purpose of this study was to investigate the relationship between $VO_2\text{max}$ and HRR and to examine gender differences in these physiological variables among elite boxers.

2. Materials and Methods

2.1 Participants

Twenty elite boxers (10 females and 10 males) competing at the national level voluntarily participated in this study. All participants were over 18 years of age, regularly trained, and free from injury or medical conditions that could affect performance. Written informed consent was obtained from all athletes.

2.2 Study Procedures

Aerobic capacity was assessed through maximal oxygen uptake ($VO_2\text{max}$) using an incremental treadmill test combined with a portable metabolic system (COSMED K5). The COSMED K5 has demonstrated high validity and reliability for the assessment of oxygen uptake during exercise testing (Perez-Suarez *et al.*, 2018). Heart rate was continuously monitored throughout testing.

The following variables were recorded:

- 1) $VO_2\text{max}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$),
- 2) Maximum heart rate (HRmax),
- 3) Heart rate recovery (HRR).

Heart rate recovery was calculated as the difference between peak heart rate and heart rate measured one minute after exercise cessation according to established procedures (Daanen *et al.*, 2012).

2.3 Statistical Analysis

Data are presented as mean \pm standard deviation (SD). Normality was assessed using the Shapiro–Wilk test. Differences between female and male boxers were analyzed using independent-samples t-tests. Effect sizes were calculated using Cohen's d. Statistical significance was set at $p < 0.05$ (Thomas *et al.*, 2022).

2.4 Ethical Considerations

The study was conducted according to the principles of the Declaration of Helsinki for research involving human participants (World Medical Association, 2013). All participants provided written informed consent before participation.

3. Results

3.1 Participant Characteristics

The descriptive characteristics of the participants are presented in Table 1. No substantial differences were observed in age between female and male boxers. As expected, male athletes demonstrated greater body mass and height compared with female athletes.

Table 1: Participant characteristics

Variable	Female (n=10)	Male (n=10)
Age (years)	21.4 ± 2.1	22.1 ± 2.3
Body Mass (kg)	60.5 ± 5.2	72.8 ± 6.4
Height (cm)	167.2 ± 4.8	178.6 ± 5.1

3.2 Aerobic Capacity

Male boxers demonstrated significantly higher aerobic capacity than female boxers. VO_{2max} values were significantly greater in males ($56.8 \pm 4.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) compared with females ($48.2 \pm 3.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) ($p = 0.001$). The effect size was very large (Cohen's $d = 2.20$), indicating a substantial difference between groups.

Table 2: Comparison of aerobic capacity

Variable	Female (n=10)	Male (n=10)	p-value	Cohen's d
VO_{2max} ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	48.2 ± 3.5	56.8 ± 4.2	0.001	2.20

These findings suggest superior aerobic fitness among male boxers, likely reflecting differences in body composition, oxygen transport capacity, and muscle mass.

3.3 Heart Rate Responses

No statistically significant differences were observed in maximum heart rate between groups ($p > 0.05$). However, female boxers exhibited significantly greater heart rate recovery values than male boxers ($p = 0.045$).

Table 3: Heart rate responses

Variable	Female (n=10)	Male (n=10)	p-value	Cohen's d
HRmax (bpm)	188 ± 6	192 ± 5	0.120	0.72
HRR (bpm)	28 ± 5	24 ± 4	0.045	0.90

The greater HRR observed among female athletes indicates a more efficient post-exercise cardiovascular recovery response.

3.4 Relationship Between VO_{2max} and Heart Rate Recovery

Pearson correlation analysis was performed to examine the association between aerobic capacity and post-exercise recovery.

A moderate-to-strong positive relationship was observed between VO₂max and HRR, indicating that athletes with higher aerobic fitness tended to demonstrate better cardiovascular recovery following maximal exercise.

Table 4: Correlation between VO₂max and HRR

Variables	r	p-value
VO ₂ max vs HRR	0.62	0.004

The correlation analysis suggests that aerobic fitness contributes significantly to recovery efficiency in elite boxers.

4. Discussion

The present study investigated aerobic capacity and post-exercise heart rate recovery in elite boxers. The main findings revealed that male boxers demonstrated significantly higher VO₂max values, whereas female boxers exhibited superior heart rate recovery following maximal exercise.

The significantly higher VO₂max values observed in male boxers are consistent with previous literature reporting sex-related differences in aerobic fitness and oxygen transport capacity (Joyner & Coyle, 2008; Sandbakk *et al.*, 2018). Higher aerobic fitness has been associated with improved oxygen delivery, greater exercise tolerance, and enhanced performance in combat sports athletes (Bassett & Howley, 2000; Franchini *et al.*, 2019).

Although no significant differences were observed in maximal heart rate, female athletes demonstrated significantly greater heart rate recovery. Heart rate recovery is considered an important indicator of autonomic nervous system function and cardiovascular adaptation (Daanen *et al.*, 2012). Similar findings have been reported in previous studies, indicating more efficient post-exercise recovery responses among female athletes (Seiler *et al.*, 2016).

A significant positive relationship was observed between VO₂max and HRR, suggesting that athletes with higher aerobic fitness recover more rapidly following maximal exercise. This finding supports previous research demonstrating that cardiovascular recovery is closely related to cardiorespiratory fitness and autonomic regulation (Michael *et al.*, 2017; Buchheit, 2014).

The observed association may be explained by physiological adaptations resulting from systematic training, including improved cardiac efficiency, enhanced stroke volume, and greater parasympathetic reactivation following exercise (Buchheit & Laursen, 2013). Similar conclusions have been reported in studies examining the effects of aerobic conditioning on physiological recovery and performance (Milanović *et al.*, 2015; Weston *et al.*, 2020; Wen *et al.*, 2019).

5. Conclusions

Male boxers demonstrated higher VO_2 max values, whereas female boxers exhibited more efficient post-exercise heart rate recovery. In addition, a significant association was observed between aerobic capacity and cardiovascular recovery. These findings highlight the importance of assessing VO_2 max and heart rate recovery (HRR) as key indicators of performance and physiological adaptation in boxing.

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Conflict of Interest Statement

The authors declare that they have no known competing financial interests, personal relationships, or institutional affiliations that could have appeared to influence the work reported in this paper.

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