International Journal of Health,
Exercise, and Sport Sciences
(**IJOSS**) ISSN: 3023-8382

RESEARCH ARTICLE / Araştırma Makalesi **Open Access/**Açık Erişim

Associations Between Post-Wingate Blood Gas and Acid–Base Changes and Anaerobic Performance in Elite Male Marathon Runners

Elit Erkek Maraton Koşucularında Wingate Anaerobik Güç Testi Sonrası Kan Gazı ve Asit–Baz Yanıtlarının Anaerobik Performans ile İlişkisi

Tolga ALTUĞ[1]

*Correspondence:
Tolga ALTUĞ
E-mail: taltug@agri.edu.tr
Orcid: 0000-0001-6318-0107

[1]Ağrı İbrahim Çeçen University, Faculty of Sport Sciences, Ağrı, Türkiye
E-mail: taltug@agri.edu.tr
ORCID: https://orcid.org/0000-0001-6318-0107

https://doi.org/10.5281/zenodo.18909877

Received / Gönderim: 25.12.2025

Accepted / Kabul: 25.02.2026

Published / Yayın: 28.02.2026

Volume 3, Issue 1, February, 2026

Cilt 3, Sayı 1, Şubat, 2026

Abstract

Purpose: This study investigated post-Wingate changes in blood gas and acid–base parameters in elite male marathon runners competing at the Olympic level. Associations between these responses and anaerobic performance indicators were also explored. **Methods:** Elite male marathon runners (n = 28) voluntarily participated in the study. All participants completed a standard Wingate Anaerobic Power Test during a single testing session. Mean power output and fatigue index were recorded as indicators of anaerobic performance. Blood gas and acid–base parameters were measured immediately before the test and at three minutes post-exercise. Pre–post comparisons were analysed using paired-samples t-tests, and correlations between performance indicators and physiological variables were examined using Pearson correlation analysis. **Results:** Following the Wingate test, statistically significant changes were observed in pH, pO_2, pCO_2, and HCO_3^- values ($p < 0.001$), whereas the increase in lactate levels was not statistically significant ($p > 0.05$). A significant positive correlation was identified between mean power and ΔpO_2 ($p < 0.05$), while no other significant associations were observed. **Conclusion:** Overall, the findings indicate that although the Wingate test induces measurable systemic acid–base alterations in elite marathon runners, these physiological responses show only limited associations with anaerobic performance indicators.

Keywords Acid–base balance, anaerobic performance, blood gas analysis, marathon runners, Wingate test.

ÖZ

Amaç: Bu çalışma, Olimpik düzeyde yarışan elit erkek maraton koşucularında Wingate testi sonrası kan gazı ve asit–baz parametrelerindeki değişimleri incelemeyi amaçlamıştır. Ayrıca bu fizyolojik yanıtların anaerobik performans göstergeleri ile olan ilişkileri de araştırılmıştır. **Yöntem:** Çalışmaya elit erkek maraton koşucuları (n = 28) gönüllü olarak katılmıştır. Tüm katılımcılar tek bir test oturumunda standart Wingate Anaerobik Güç Testini tamamlamıştır. Anaerobik performans göstergeleri olarak ortalama güç çıktısı ve yorgunluk indeksi kaydedilmiştir. Kan gazı ve asit–baz parametreleri testten hemen önce ve egzersizden üç dakika sonra ölçülmüştür. Ön test–son test karşılaştırmaları eşleştirilmiş örneklemler t-testi ile analiz edilmiş, performans göstergeleri ile fizyolojik değişkenler arasındaki ilişkiler Pearson korelasyon analizi ile incelenmiştir. **Bulgular:** Wingate testi sonrasında pH, pO_2, pCO_2 ve HCO_3^- değerlerinde istatistiksel olarak anlamlı değişimler gözlenmiştir ($p < 0.001$). Buna karşın laktat düzeylerindeki artış istatistiksel olarak anlamlı bulunmamıştır ($p > 0.05$). Ortalama güç ile ΔpO_2 arasında anlamlı pozitif bir korelasyon tespit edilmiş ($p < 0.05$), diğer değişkenler arasında ise anlamlı bir ilişki bulunmamıştır. **Sonuç:** Genel olarak bulgular, Wingate testinin elit maraton koşucularında ölçülebilir sistemik asit–baz değişikliklerine yol açtığını; ancak bu fizyolojik yanıtların anaerobik performans göstergeleri ile yalnızca sınırlı düzeyde ilişkili olduğunu göstermektedir.

Anahtar Kelimeler Asit–baz dengesi, anaerobik performans, kan gazı analizi, maraton koşucuları, Wingate.

https://www.ijoss.org/Archive/v3-i1/ijoss-Volume3-issue1-20.pdf

Introduction

Anaerobic performance refers to the capacity to resynthesize ATP primarily through the phosphagen and anaerobic glycolytic pathways during short-duration, high-intensity exercise, when the contribution of the oxidative system remains limited (Allen, 2020; Allen et al., 2008). This capacity plays a central role in sporting activities requiring sprinting, jumping, and rapid power production (Driss & Vandewalle, 2013; Yel et al., 2023). However, its relevance is not limited to power- and speed-based sports. In endurance disciplines, transient yet physiologically meaningful contributions from anaerobic pathways occur during fluctuations in race pace, the start phase, and sprint finishes (Amann et al., 2020; Hureau et al., 2022). Although marathon running is predominantly aerobic, pace variability and neuromuscular demands prevent it from being characterized as metabolically uniform (Nikolaidis et al., 2018).

In laboratory settings, the Wingate Anaerobic Power Test (WAnT) is widely used to assess anaerobic power and capacity during short-term maximal exercise (Bar-Or, 1987). Indices such as mean power and fatigue index provide information about the rate of muscular energy production and the ability to sustain output under high-intensity loading. Among these variables, mean power has demonstrated strong validity and reliability (Driss & Vandewalle, 2013). Although the Wingate test has traditionally been employed in sprint and power sports, recent research indicates that it can also be used to evaluate physiological responses to short-term maximal loading and tolerance to acute metabolic stress in endurance athletes (Calbet et al., 2003; Acar et al., 2025; Dobashi et al., 2021). Rather than functioning as a direct predictor of marathon performance, the Wingate test may be viewed as a standardized model of acute maximal anaerobic stress (Calbet et al., 2003; Castañeda-Babarro, 2021).

During a 30-second maximal effort, high rates of anaerobic glycolysis lead to marked metabolic alterations at both intramuscular and systemic levels (Fujii et al., 2015). Increased ATP hydrolysis leads to elevated hydrogen ion accumulation, contributing to temporary disruption of acid–base balance (Robergs et al., 2004). These metabolic responses share certain physiological characteristics with the stress profiles observed during marathon running, particularly during uphill segments, pace surges, and short bursts of high-intensity effort in the later stages of the race (Amann et al., 2020; Hureau et al., 2022).

Following the Wingate test, increases in lactate concentration and alterations in blood pH reflect activation of multiple physiological responses, including activation of the bicarbonate buffering system, which plays a key role in regulating acid–base homeostasis during high-intensity effort (Fujii et al., 2015; Dobashi et al., 2021). However, the direction and magnitude of pH and HCO_3^- responses may vary depending on the type of blood sample obtained (arterial or venous), the timing of post-exercise measurement, and the predominance of ventilatory compensation (Medbø et al., 2012; Robergs et al., 2004). In endurance athletes, the extent of such acute metabolic disturbances reflects not only anaerobic power capacity but also physiological tolerance to high-intensity stress and resistance to muscle fatigue (Nikolaidis et al., 2018).

Blood gas parameters allow for a quantitative assessment of physiological stress beyond lactate concentration alone (Cairns & Lindinger, 2025). Disturbances in acid–base balance reflect multidimensional stress responses linked to force and power production. Decreases in pH and consumption of HCO_3^- reflect the buffering of accumulating hydrogen ions, while changes in pCO_2 are understood to be linked to ventilatory compensatory responses activated during exercise (Dobashi et al., 2021). In this context, the integrated evaluation of these physiological responses during short-term, high-intensity loading allows for a more comprehensive understanding of the physiological components underlying anaerobic performance.

Existing research has primarily focused on lactate responses following the Wingate test, whereas concurrent evaluation of pH, pCO_2, pO_2, and HCO_3^- has received comparatively less attention (Fujii et al., 2015). In elite endurance athletes, the relationship between these acid–base responses and anaerobic performance indices remains insufficiently clarified (Amann et al., 2020; Acar et al., 2025). This gap underscores the need to examine anaerobic performance by integrating mechanical outputs with biochemical and physiological markers.

The present study investigated changes in blood gas parameters (pH, pO_2, pCO_2, HCO_3^-, and lactate) measured before and after the Wingate anaerobic power test in elite male marathon runners. It also examined the relationships between these changes and anaerobic performance indicators, including mean power and fatigue index. In this context, the Wingate test was not considered a direct measure of marathon-specific performance; instead, it was used as a standardized model to induce acute maximal anaerobic stress under controlled conditions in elite endurance athletes. It was hypothesized that the magnitude of post-Wingate blood gas and acid–base responses would be associated with anaerobic performance indicators and fatigue parameters.

Material and Methods

Research Design

This study used a cross-sectional, correlational design to explore the relationships between Wingate performance outputs and blood gas responses reflecting acute metabolic stress. The Wingate test was used as a standardized model to induce acute maximal anaerobic loading in elite endurance athletes under controlled conditions (Bar-Or, 1987; Driss & Vandewalle, 2013). No experimental intervention was applied, and all measurements were obtained during a single testing session. Participants performed a 30-second Wingate test, during which mean power and fatigue index values were recorded. To assess metabolic and acid–base responses, blood gas parameters were measured before and after the test, and change (Δ) values were calculated to reflect individual physiological responses. Analyses focused on the associations between anaerobic performance indicators and acute alterations in blood gas and acid–base parameters.

Research Group

The study included elite male marathon runners with national team status (n = 28) who had competed at the Olympic level and had engaged in high-volume endurance training incorporating varying intensity levels for at least five years. Age, height, body mass, and training age were recorded and summarized descriptively. The athletes had a mean age of 24.6 ± 3.5 years, a mean height of 178.0 ± 5.0 cm, a mean body mass of 65.7 ± 7.1 kg, and a mean training age of 9.6 ± 1.9 years. In elite athlete populations, the selection of physiologically homogeneous samples in terms of performance level and training background helps to minimize inter-individual variability. All athletes trained at least five days per week. Participants' demographic characteristics are presented in Table 1.

Table 1. Demographic characteristics of the participants

Variable	n	Mean ± SD	Min–Max
Age (years)	28	24.6 ± 3.5	18–32
Height (cm)	28	178.0 ± 5.0	165–185
Body mass (kg)	28	65.7 ± 7.1	52–76
Training age (years)	28	9.6 ± 1.9	7–14

Data are presented as mean ± standard deviation (SD) and minimum–maximum ranges

Inclusion criteria required the absence of lower extremity injury within the previous six months and no cardiovascular, respiratory, or metabolic disease contraindicating maximal exercise testing. Individuals with a history of lower extremity surgery, active musculoskeletal pain that could influence test performance, or systemic conditions potentially affecting blood gas measurements were excluded. Participants were recruited consecutively from volunteers who met the inclusion criteria. All athletes were informed about the purpose, procedures, and potential risks of the study and provided written informed consent in accordance with the Declaration of Helsinki. The study was approved by the Ethics Committee of the Faculty of Sports Sciences, Atatürk University (Decision No: 2025/10; Reference No: E-70400699-050.02.04-2500354086; Date: 20.10.2025).

Warm-Up and Preparation

Prior to testing, all participants followed a standard warm-up protocol consistent with recommendations for high-intensity exercise. The protocol began with five minutes of low-intensity cycling on a cycle ergometer, followed by dynamic stretching exercises targeting the lower extremity muscle groups (Soissi et al., 2010). After the warm-up, the test procedures were explained in detail, and participants were given 1–2 minutes of passive rest before the test began.

Procedures and Testing

All tests were conducted under standardized conditions in a controlled laboratory environment (temperature: 21–23°C; relative humidity: 40–60%). Measurements were performed on a day separate from the participants' regular training sessions and within a similar time window (09:00–12:00; ±1 hour) by the same researchers. The testing sequence and procedures were standardized for all participants to ensure consistency. Participants were instructed to refrain from intense physical activity for 24 hours prior to testing and to avoid caffeine and alcohol consumption. They were also instructed to complete their last meal at least three hours before testing and to maintain adequate hydration. Prior to testing, all participants verbally confirmed that they had obtained at least 7 hours of sleep.

Data Collection Tools

Wingate Anaerobic Power Test

Anaerobic performance was assessed with a 30-second Wingate test performed on a computer-assisted cycle ergometer. Resistance was set at 7.5% of body mass (0.075 $kg \cdot kg^{-1}$), consistent with the classic Wingate protocol (Bar-Or, 1987). Standardized verbal encouragement was provided throughout the effort. Upon completion, mean power and fatigue index values were recorded via the ergometer software. The protocol was applied as a single-bout effort to ensure comparable acute anaerobic stress across participants.

Blood Gas Measurements

Blood gas measurements were obtained immediately before the Wingate test and three minutes after its completion. Venous blood samples were collected in a seated position to ensure consistent sampling conditions. The analysed parameters included pH, pO_2, pCO_2, HCO_3^-, and lactate. Samples were analyzed using an automated blood gas analyzer (ABL800 FLEX, Radiometer Medical, Copenhagen, Denmark). The analyzer was calibrated daily according to the manufacturer's specifications with certified calibration solutions. Internal quality control procedures were performed before each testing session. All samples were processed immediately after collection (within approximately 2 minutes) to minimize pre-analytical variability. Lactate was measured three minutes post-exercise, acknowledging that peak values may occur several minutes after cessation of maximal effort (Mündel, 2018). Changes in pH and HCO_3^- were used to evaluate acute exercise-induced acid–base responses (Robergs et al., 2004).

Data Analysis

Statistical analyses were performed using IBM SPSS Statistics software. Normality was assessed using the Shapiro–Wilk test and visual inspection of histograms and Q–Q plots. Descriptive statistics for continuous variables are presented as mean ± standard deviation (SD). Pre–post comparisons of blood gas and acid–base parameters were conducted using paired samples t-tests, as the normality assumption was satisfied. Effect sizes were calculated using Cohen's d for paired comparisons in accordance with Cohen's classification (Cohen, 1988). Pearson correlation analyses were performed to examine the associations between anaerobic performance indicators (mean power and fatigue index) and exercise-induced physiological responses. Change scores (Δ = post – pre) were calculated for pH, HCO_3^-, pCO_2, pO_2, and lactate, and these Δ values were used in the correlation analyses. Given the exploratory nature of the study and the limited number of planned correlations, no additional correction for multiple comparisons was applied. Correlation coefficients were interpreted as weak (r = 0.10–

0.29), moderate (r = 0.30–0.49), and strong (r ≥ 0.50). Statistical significance was set at $p < 0.05$ (two-tailed).

Findings

In this study, blood gas and acid–base parameters measured before and after the Wingate anaerobic power test were analysed. Descriptive statistics for all variables are presented as mean ± standard deviation.

The results for blood gas and acid–base parameters measured before and after the Wingate anaerobic power test are presented in Table 2. Pre–post comparisons revealed statistically significant changes in pH, pO_2, pCO_2, and HCO_3^- (all $p < 0.001$). Lactate values increased after the test; however, this change was not statistically significant ($p = 0.067$). The corresponding test statistics and effect sizes are detailed in Table 2.

Table 2. Blood gas and acid–base responses before and after the Wingate anaerobic power test

Variables	n	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	t	p	Cohen's d
pH	28	7.36 ± 0.03	7.38 ± 0.03	-8.005	< 0.001	Large
Lactate ($mmol \cdot L^{-1}$)	28	3.10 ± 0.27	3.18 ± 0.32	-1.910	0.067	Small
pO_2 (mmHg)	28	82.00 ± 2.74	87.39 ± 3.75	-19.035	< 0.001	Large
pCO_2 (mmHg)	28	39.64 ± 1.31	35.79 ± 1.85	16.477	< 0.001	Large
HCO_3^- ($mmol \cdot L^{-1}$)	28	23.30 ± 0.70	25.01 ± 0.68	-20.303	< 0.001	Large

Note: Values are presented as mean ± standard deviation (SD). Pre–post comparisons were conducted using paired samples t-tests. Effect size magnitudes were interpreted according to Cohen (1988) as small, moderate, and large.

Mean power and fatigue index values obtained from the Wingate anaerobic power test are presented in Table 3. These performance indicators are reported as descriptive variables reflecting the individual anaerobic performance profile derived from the single-bout Wingate test.

Table 3. Descriptive statistics of anaerobic performance variables obtained from the Wingate anaerobic power test

Variable	n	Mean ± SD	Min–Max
Mean Power (W)	28	776.4 ± 89.8	623–940
Fatigue Index (%)	28	41.7 ± 2.7	36.9–46.8

Note: Values are presented as mean ± standard deviation (SD) and minimum–maximum range.

Wingate anaerobic power test performance variables and exercise-induced changes in blood gas and acid–base parameters were examined using Pearson correlation analysis. Correlation coefficients between mean power and fatigue index and the change scores (Δ; post-test minus pre-test) for pH, HCO_3^-, pCO_2, pO_2, and lactate are presented in Table 4. Mean power showed negative, non-significant correlations with ΔpH ($r = -0.258$, $p = 0.185$) and ΔHCO_3^- ($r = -0.208$, $p = 0.287$), and positive, non-significant correlations with ΔpCO_2 ($r = 0.192$, $p = 0.328$) and ΔLactate ($r = 0.128$, $p = 0.517$). A statistically significant positive correlation was observed between mean power and ΔpO_2 ($r = 0.397$, $p = 0.036$). Fatigue index showed low, non-significant correlations with all change scores ($|r| = 0.012–0.113$, $p > 0.05$).

Table 4. Correlations between Wingate anaerobic performance variables and exercise-induced changes in blood gas and acid–base parameters

Performance variable		Mean ± SD	Min–Max	ΔpH	ΔHCO_3^-	ΔpCO_2	ΔpO_2	ΔLactate
Mean Power (W)	r	776.4 ± 89.8	623–940	-0.258	-0.208	0.192	0.397*	0.128
	p			0.185	0.287	0.328	0.036*	0.517
Fatigue Index (%)	r	41.7 ± 2.7	36.9–46.8	-0.068	0.032	0.012	0.113	0.045
	p			0.733	0.871	0.953	0.567	0.819

Note: Values are Pearson correlation coefficients (r) with corresponding two-tailed p values (n = 28). Δ values represent change scores calculated as post-test minus pre-test measurements. *$p < 0.05$.

DISCUSSION

Correlation analyses further revealed a statistically significant positive association between mean power and ΔpO_2 ($r = 0.397$, $p = .036$), whereas no significant correlations were observed for the other blood gas or acid–base change variables. Taken together, these results suggest that short-term maximal anaerobic loading elicits pronounced systemic physiological responses in elite endurance athletes. However, these responses may not be directly linked to performance indices, with the exception of the observed association between mean power and ΔpO_2.

One of the principal findings of the study was the statistically significant alterations observed in pH, pO_2, pCO_2, and HCO_3^- values following the Wingate test. These results are generally consistent with previously reported acid–base and gas exchange responses to short-duration maximal anaerobic exercise (Beneke et al., 2002; Mündel, 2018). Beyond its mechanical performance outputs, the Wingate test appears to reflect systemic physiological responses associated with acid–base regulation and gas exchange mechanisms. The literature indicates that short-term maximal exercise, particularly when anaerobic glycolysis becomes predominant, is accompanied by shifts in acid–base parameters (Shaw & Gregory, 2022), and similar physiological responses have been documented during the Wingate test (Álvarez-Herms, 2024).

The changes in pH and HCO_3^- observed in the present study are consistent with increased hydrogen ion load resulting from enhanced anaerobic glycolysis and activation of the bicarbonate buffering system (Robergs et al., 2004). During high-intensity exercise, the consumption of bicarbonate buffering capacity contributes to the development of both intramuscular and systemic acidosis, potentially limiting contractile function and metabolic processes (Mündel, 2018). These mechanisms help explain the acute metabolic stress accompanying intense muscular activity (Hureau et al., 2022). In the present study, the observed pH and HCO_3^- responses may therefore be interpreted as measurable systemic reflections of the acute metabolic stress induced by the Wingate test.

The changes observed in pO_2 and pCO_2 parameters in the present study appear consistent with ventilatory compensation and gas exchange dynamics accompanying anaerobic loading (Dobashi et al., 2021). During maximal effort, increased ventilation may accelerate carbon dioxide elimination, resulting in decreased pCO_2 levels, while the associated ventilatory response may also increase alveolar oxygen partial pressure, which is reflected in elevated pO_2 values (Kisaka et al., 2015). It has been reported that short-term supramaximal exercise can induce metabolic acidosis followed by an increased buffering requirement, and such responses are considered characteristic features of high-intensity exercise physiology (Sahlin, 2014). Taken together, these alterations appear to reflect ventilatory and systemic adjustments occurring during supramaximal loading. This may partly account for the positive association observed between mean power and ΔpO_2.

Although lactate levels increased after exercise, the change did not reach statistical significance and should be interpreted cautiously. While elevations in blood lactate concentration following the Wingate test are frequently reported, the magnitude of the lactate response has been shown to be influenced by training status, the timing of post-exercise measurement, and the sampling method used (Beneke et al., 2002; Fujii et al., 2015; Mündel, 2018). Blood lactate does not necessarily peak immediately after short-term maximal exercise. Peak values are often observed several minutes into recovery, commonly within a 3–8 minute window (Beneke et al., 2002; Mündel, 2018). In the present study, lactate was measured at the third minute of recovery, which represents an early recovery phase rather than a confirmed peak response. In endurance athletes, a more rapid equilibrium between lactate production and clearance has been demonstrated, potentially limiting post-exercise lactate accumulation (Seiler & Tønnessen, 2009; Nikolaidis et al., 2018). Enhanced oxidative capacity and faster lactate turnover in well-trained athletes may further shape the temporal profile of lactate appearance and clearance. In this context, lactate measurements alone may be insufficient to capture the full scope of acute metabolic stress, and their interpretation alongside blood gas and acid–base parameters may provide a more comprehensive physiological perspective (Robergs et al., 2004; Cairns & Lindinger, 2025).

Examination of Wingate performance outputs revealed higher mean power values and a lower fatigue index. These findings indicate that power production and fatigue dynamics characteristic of short-duration, high-intensity exercise provide meaningful insight into the athletes' anaerobic performance profile (Driss & Vandewalle, 2013). In endurance athletes, such indicators of anaerobic power and fatigue index may be used to characterize physiological responses elicited during acute maximal loading (Castañeda-Babarro, 2021). However, the generally low and non-significant correlations with most physiological change variables in the present study suggest that mechanical performance outputs and acute systemic responses may be only partially coupled in elite endurance athletes.

In prolonged endurance events such as the marathon, the contribution of anaerobic energy systems becomes more pronounced during pace fluctuations, accelerations, and finishing sprints (Nikolaidis et al, 2018; Amann et al., 2020). In the present study, the Wingate test was employed as a model to induce acute maximal anaerobic stress under standardized conditions. This approach aligns with frameworks proposed in the literature for investigating physiological responses to short-term maximal loading in endurance athletes (Castañeda-Babarro, 2021) and provides a perspective that may contribute to the evaluation of interactions among energy systems and tolerance to metabolic stress (Hureau et al., 2022). In this regard, anaerobic capacity and buffering mechanisms in endurance athletes may be considered important components of performance-related physiological processes (Amann & Dempsey, 2008).

This study has several limitations. Measurements were obtained within a single testing session, limiting the evaluation of the temporal progression and recovery dynamics of physiological responses following the Wingate test. As a result, the persistence of acute changes in blood gas and acid–base parameters beyond the measured time frame remains unclear. The inclusion of only elite male marathon runners restricts generalizability to female athletes and other endurance populations. The cross-sectional design also precludes conclusions regarding causality or directionality between performance outputs and physiological responses. Blood gas analyses were based on venous samples, which reflect systemic metabolic responses but may differ from arterial values, particularly for pO_2 and pCO_2 (Medbø et al., 2012). Finally, although a significant association was observed between mean power and ΔpO_2, the generally low and non-significant correlations for the remaining variables limit the broader interpretability of these relationships.

Conclusion and Recommendations

In this study, acute changes in blood gas and acid–base parameters were observed following the Wingate anaerobic power test in elite male marathon runners. Significant differences were detected in pH, pO_2, pCO_2, and HCO_3^- levels. These findings suggest that short-term maximal anaerobic loading is accompanied by measurable systemic physiological responses. Mean power and fatigue index values provided descriptive information about the athletes' performance profile during acute anaerobic stress. A statistically significant association was observed between mean power and ΔpO_2. However, correlations with the other physiological change variables were low and not statistically significant. Accordingly, the relationship between mechanical performance outputs and systemic physiological responses appears limited within the scope of this study.

From a practical perspective, the Wingate anaerobic power test may be considered not only as a measure of mechanical performance but also as a tool that reflects certain acute physiological responses to high-intensity loading. Blood gas and acid–base parameters such as pH, pO_2, pCO_2, and HCO_3^- may provide complementary information regarding metabolic stress and buffering responses during intense efforts. Evaluating these parameters together with mechanical performance outputs may support a more comprehensive monitoring approach in elite endurance athletes. Future studies including repeated measurements, longer recovery monitoring, and more diverse athlete samples may help clarify the temporal characteristics and broader relevance of these physiological responses in endurance sports. Given the cross-sectional and correlational nature of the study design, the results should be interpreted as associative rather than causal.

Beyanlar / Declarations

Etik Onay ve Katılım Onayı / Ethics approval and consent to participate

Bu çalışmanın hazırlanma ve yazım sürecinde "Yükseköğretim Kurumları Bilimsel Araştırma ve Yayın Etiği Yönergesi" kapsamında bilimsel, etik ve alıntı kurallarına uyulmuş olup; toplanan veriler üzerinde herhangi bir tahrifat yapılmamış ve bu çalışma herhangi başka bir akademik yayın ortamına değerlendirme için gönderilmemiştir. Makale ile ilgili doğabilecek her türlü ihlallerde sorumluluk yazara aittir. Bu çalışma, Atatürk Üniversitesi Spor Bilimleri Fakültesi Etik Kurulu tarafından onaylanmıştır (Karar No: 2025/10; Tarih: 20.10.2025).

citation rules were followed in accordance with the 'Higher Education Institutions Scientific Research and Publication Ethics Guidelines'; no alterations were made to the collected data, and this study has not been submitted for evaluation to any other academic publication medium. The author is solely responsible for any violations that may arise in connection with this article. All participants voluntarily participated in this study. This study was approved by the Ethics Committee of the Faculty of Sports Sciences, Atatürk University (Decision No: 2025/10; Date: 20.10.2025).

Veri Ve Materyal Erişilebilirliği / Availability of data and material

Bu çalışmanın bulgularını destekleyen veriler, makul talepler üzerine sorumlu yazardan temin edilebilir. Veri seti yalnızca akademik amaçlar için erişilebilir olacak ve verilerin herhangi bir kullanımı, orijinal çalışmayı referans gösterecek ve katılımcıların gizliliğini koruyacaktır.

The data that support the findings of this study are available from the corresponding author upon reasonable request. The dataset will be accessible only for academic purposes, and any use of the data will recognize the original study and maintain the confdentiality of the participants.

Çıkar Çatışması / Competing interests

Yazarlar, bu makalede sunulan çalışmayı etkileyebilecek herhangi bir çıkar çatışması veya kişisel ilişkiye sahip olmadıklarını beyan etmektedirler.

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

Yazar Katkıları / Authors' Contribution Statement

Yazar, çalışmanın kavramsallaştırılması, tasarımı, veri toplama, analiz, yorumlama ve makalenin hazırlanması süreçlerinin tamamına katkı sağlamıştır .

The author contributed to the conception, design, data collection, analysis, interpretation, and manuscript preparation.

Fon Desteği / Funding

This Bu çalışma, kamu, özel veya kar amacı gütmeyen sektörlerdeki fon sağlayıcı kurumlardan herhangi bir özel destek almamıştır.

This research received no external funding.

Teşekkür / Acknowledgements

None.

References / Kaynaklar

Acar, N., Umutlu, G., Ersöz, Y., Taşman, G., Güven, E., Ulutaş, D., Kamiş, O., Erdoğan, M., & Aslan, Y. (2025). Continuous vertical jump test is a reliable alternative to Wingate anaerobic test and isokinetic fatigue tests in evaluation of muscular fatigue resistance in endurance runners. *BMC Sports Science, Medicine and Rehabilitation, 17*. https://doi.org/10.1186/s13102-025-01143-0

Allen, D. G. (2020). Human muscle performance. *The Journal of Physiology*. https://doi.org/10.1113/JP279364

Allen, D. G., Lamb, G. D., & Westerblad, H. (2008). Skeletal muscle fatigue: Cellular mechanisms. *Physiological Reviews, 88*(1), 287–332. https://doi.org/10.1152/physrev.00015.2007

Álvarez-Herms, J. (2024). Summatory effects of anaerobic exercise and a "Westernized athletic diet" on gut dysbiosis and chronic low-grade metabolic acidosis. *Microorganisms, 12*(6), 1138. https://doi.org/10.3390/microorganisms12061138

Amann, M., & Dempsey, J. A. (2008). Locomotor muscle fatigue modifies central motor drive in healthy humans and imposes a limitation to exercise performance. *The Journal of Physiology, 586*(1), 161–173. https://doi.org/10.1113/jphysiol.2007.141838

Amann, M., Wan, H.-Y., Thurston, T. S., Georgescu, V. P., & Weavil, J. C. (2020). On the influence of group III/IV muscle afferent feedback on endurance exercise performance. *Exercise and Sport Sciences Reviews, 48*(4), 209–216. https://doi.org/10.1249/JES.0000000000000233

Bar-Or, O. (1987). The Wingate anaerobic test: An update on methodology, reliability and validity. *Sports Medicine, 4*(6), 381–394. https://doi.org/10.2165/00007256-198704060-00001

Beneke, R., Pollmann, C., Bleif, I., Leithäuser, R. M., & Hütler, M. (2002). How anaerobic is the Wingate anaerobic test for humans? *European Journal of Applied Physiology, 87*(4–5), 388–392. https://doi.org/10.1007/s00421-002-0622-4

Cairns, S. P., & Lindinger, M. I. (2025). Lactic acidosis: Implications for human exercise performance. *European Journal of Applied Physiology, 125*(7), 1761–1795. https://doi.org/10.1007/s00421-025-05750-0

Calbet, J. A. L., De Paz, J. A., Garatachea, N., De Vaca, S. C., & Chavarren, J. (2003). Anaerobic energy provision does not limit Wingate exercise performance in endurance-trained cyclists. *Journal of Applied Physiology, 94*(2), 668–676. https://doi.org/10.1152/japplphysiol.00128.2002

Castañeda-Babarro, A. (2021). The Wingate anaerobic test: A narrative review of the protocol variables that affect the results obtained. *Applied Sciences, 11*(16), 7417. https://doi.org/10.3390/app11167417

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates. https://doi.org/10.4324/9780203771587

Dobashi, K., Fujii, N., Ichinose, M., & Nishiyasu, T. (2021). Voluntary hypocapnic hyperventilation lasting 5 min and 20 min similarly reduce aerobic metabolism without affecting power outputs during Wingate anaerobic test. *European Journal of Sport Science, 21*(8), 1148–1155. https://doi.org/10.1080/17461391.2020.1812728

Driss, T., & Vandewalle, H. (2013). The measurement of maximal (anaerobic) power output on a cycle ergometer: A critical review. *BioMed Research International, 2013*, 589361. https://doi.org/10.1155/2013/589361

Fujii, N., Tsuchiya, S.-I., Tsuji, B., Watanabe, K., Sasaki, Y., & Nishiyasu, T. (2015). Effect of voluntary hypocapnic hyperventilation on the metabolic response during Wingate anaerobic test. *European Journal of Applied Physiology, 115*, 1967–1974. https://doi.org/10.1007/s00421-015-3179-8

Hureau, T. J., Broxterman, R. M., Weavil, J. C., Lewis, M. T., Layec, G., & Amann, M. (2022). On the role of skeletal muscle acidosis and inorganic phosphates as determinants of central and peripheral fatigue: A 31P-MRS study. *The Journal of Physiology, 600*(13), 3069–3081. https://doi.org/10.1113/JP283036

Kisaka, T., Cox, T. A., Dumitrescu, D., & Wasserman, K. (2015). CO_2 pulse and acid–base status during increasing work rate exercise in health and disease. *Respiratory Physiology & Neurobiology, 218*, 46–56. https://doi.org/10.1016/j.resp.2015.07.005

Medbø, J. I., Noddeland, H., & Hanem, S. (2012). Acid–base status of arterial and femoral venous blood during and after intense cycle exercise. *Acta Physiologica Hungarica, 99*(1), 66–94. https://doi.org/10.12697/akut.2009.14.06

Mündel, T. (2018). Sodium bicarbonate ingestion improves repeated high-intensity cycling performance in the heat. *Temperature, 5*(4), 343–347. https://doi.org/10.1080/23328940.2018.1436393

Nikolaidis, P. T., Rosemann, T., & Knechtle, B. (2018). Force–velocity characteristics, muscle strength, and flexibility in female recreational marathon runners. *Frontiers in Physiology, 9*. https://doi.org/10.3389/fphys.2018.01563

Robergs, R. A., Ghiasvand, F., & Parker, D. (2004). Biochemistry of exercise-induced metabolic acidosis. *American Journal of Physiology–Regulatory, Integrative and Comparative Physiology, 287*(3), R502–R516. https://doi.org/10.1152/ajpregu.00114.2004

Sahlin, K. (2014). Muscle energetics during explosive activities and potential effects of nutrition and training. *Sports Medicine, 44*(Suppl 2), S167–S173. https://doi.org/10.1007/s40279-014-0256-9

Seiler, S., & Tønnessen, E. (2009). Intervals, thresholds, and long slow distance: The role of intensity and duration in endurance training. *Sportscience, 13*, 32–53.

Shaw, I., & Gregory, K. (2022). Acid–base balance: A review of normal physiology. *BJA Education, 22*(10), 396–401. https://doi.org/10.1016/j.bjae.2022.06.003

Souissi, N., Driss, T., Chamari, K., Vandewalle, H., Davenne, D., Gam, A., Fillard, J. R., & Jousselin, E. (2010). Diurnal variation in Wingate test performances: Influence of active warm-up. *Chronobiology International, 27*(3), 640–652. https://doi.org/10.3109/07420528.2010.483157

Sousa, C. V., Sales, M. M., Nikolaidis, P. T., Rosemann, T., & Knechtle, B. (2018). How much further for the sub-2-hour marathon? *Open Access Journal of Sports Medicine, 9*, 139–145. https://doi.org/10.2147/OAJSM.S169758

Stefanova, D., & Petrova, B. (2017). Wingate anaerobic test: Additional physiological interpretation. *Journal of Applied Sports Sciences, 1*(2), 50–62. https://doi.org/10.37393/JASS.2017.02.6

Sun, X., Hansen, J. E., Stringer, W. W., Ting, H., & Wasserman, K. (2001). Carbon dioxide pressure–concentration relationship in arterial and mixed venous blood during exercise. *Journal of Applied Physiology, 90*(5), 1798–1810. https://doi.org/10.1152/jappl.2001.90.5.1798

Yel, K., & Güzel, S., Kurcan, K., Aydemir, U. (2023). Spor Performansı v Denge. Spor Araştırmalarında Farklı Perspektifler 2, Editör: Prof.Dr. Erdal Zorba, Doç.Dr. Mevlüt Gönen, Dr. Zekai ÇAKIR, Aralık. Bölüm-8, ISBN: 978-625-6643-01-7, Syf:120-137. Duvar Yayınları. İzmir.

Publishers' Note