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Heart rate responses across moderate, heavy, and severe exercise intensity domains during incremental ramp exercise in healthy young males

Sağlıklı genç erkeklerde artan yoğunluklu egzersiz sırasında orta, ağır ve şiddetli egzersiz yoğunluğu alanlarındaki kalp atış hızı cevapları

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Abstract

The lactate threshold (LT) and respiratory compensation point (RCP) are key physiological landmarks that demarcate moderate, heavy, and severe exercise intensity domains. However, detailed heart rate (HR) responses across these three domains during incremental ramp exercise have not been fully characterized.
Fifty healthy young males (age: 21.3±1.3 years, BMI: 22.1±1.6 kg/m^2) performed an incremental ramp exercise test (15 W/min) until tolerance. LT was determined using the V-slope method, and RCP was identified as the point where VE/VCO$_2$ began to increase systematically. HR was recorded beat-to-beat. Delta HR and delta work rate were calculated across three regions: warm-up to LT (<LT), LT to RCP (LT–RCP), and RCP to maximal exercise (RCP–max).
LT occurred at 146±19 W (64±4.1% of Wmax), and RCP occurred at 182±18 W (80±2.8% of Wmax). HR increased progressively: 92.8±12 beats/min at warm-up, 144.9±11 at LT, 162.9±10 at RCP, and 188.6±7 at maximal exercise (94.9±3.8% of predicted HRmax). Delta HR was largest from warm-up to LT (52.1±13.0 beats, $p<0.05$), smaller from LT to RCP (18.0±6.5 beats, $p<0.05$), and moderate from RCP to max (25.6±8.0 beats, $p<0.05$). The work-to-HR ratio did not differ significantly across domains ($p>0.05$). HR increases progressively across moderate, heavy, and severe intensity domains during incremental ramp exercise in healthy young males, with the largest increase occurring below LT. The work-to-HR ratio remains stable across domains, suggesting that the efficiency of work production per heartbeat does not change significantly. These findings support the use of HR as a practical marker for monitoring exercise intensity across different metabolic domains.

Keywords lactate threshold, respiratory compensation point, heart rate, exercise intensity domains, incremental exercise, ramp test

Öz

Laktat eşiği (LE) ve solunumsal kompanzasyon noktası (SKN), egzersiz şiddetinin orta, ağır ve şiddetli alanlarını ayırt eden temel fizyolojik belirteçlerdir. Bununla birlikte, artımlı rampa egzersizi sırasında bu üç egzersiz şiddeti alanı boyunca kalp atım hızı (KAH) yanıtları ayrıntılı olarak henüz tam anlamıyla karakterize edilmemiştir. Elli sağlıklı genç erkek katılımcı (yaş: 21,3±1,3 yıl; BKİ: 22,1±1,6 kg/m^2), tolerans sınırına kadar sürdürülen artımlı rampa egzersiz testine (15 W/dk) katılmıştır. Laktat eşiği V-slope yöntemi kullanılarak belirlenmiş, solunumsal kompanzasyon noktası ise VE/VCO$_2$ oranının sistematik olarak artmaya başladığı nokta olarak tanımlanmıştır. Kalp atım hızı atımdan atıma kaydedilmiştir. Delta KAH ve delta iş yükü üç bölge için hesaplanmıştır: ısınmadan laktat eşiğine kadar olan bölge (<LE), laktat eşiğinden solunumsal kompanzasyon noktasına kadar olan bölge (LE–SKN) ve solunumsal kompanzasyon noktasından maksimal egzersize kadar olan bölge (SKN–maks). Laktat eşiği 146±19 W düzeyinde, maksimal iş yükünün %64±4,1'inde; solunumsal kompanzasyon noktası ise 182±18 W düzeyinde, maksimal iş yükünün %80±2,8'inde gerçekleşmiştir. Kalp atım hızı kademeli olarak artış göstermiştir: ısınma sırasında 92,8±12 atım/dk, laktat eşiğinde 144,9±11 atım/dk, solunumsal kompanzasyon noktasında 162,9±10 atım/dk ve maksimal egzersizde 188,6±7 atım/dk olarak ölçülmüştür. Maksimal egzersizde ulaşılan kalp atım hızı, tahmini maksimal kalp atım hızının %94,9±3,8'ine karşılık gelmiştir. Delta KAH en yüksek ısınmadan laktat eşiğine kadar olan bölgede gözlenmiştir (52,1±13,0 atım; $p<0,05$). Bu artış laktat eşiği ile solunumsal kompanzasyon noktası arasında daha düşük düzeyde gerçekleşmiş (18,0±6,5 atım; $p<0,05$), solunumsal kompanzasyon noktasından maksimal egzersize kadar olan bölgede ise orta düzeyde bulunmuştur (25,6±8,0 atım; $p<0,05$). İş yükü/KAH oranı egzersiz şiddeti alanları arasında anlamlı farklılık göstermemiştir ($p>0,05$). Sağlıklı genç erkeklerde artımlı rampa egzersizi sırasında kalp atım hızı orta, ağır ve şiddetli egzersiz şiddeti alanları boyunca kademeli olarak artmakta; en büyük artış laktat eşiğinin altında meydana gelmektedir. İş yükü/KAH oranının egzersiz şiddeti alanları boyunca stabil kalması, her kalp atımı başına üretilen iş verimliliğinin anlamlı biçimde değişmediğini düşündürmektedir. Bu bulgular, kalp atım hızının farklı metabolik alanlarda egzersiz şiddetinin izlenmesinde pratik bir belirteç olarak kullanılmasını desteklemektedir.

Anahtar Kelimeler: laktat eşiği, solunumsal kompanzasyon noktası, kalp atım hızı, egzersiz şiddeti alanları, artımlı egzersiz, rampa testi.

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INTRODUCTION

The cardiovascular and respiratory systems work closely to maintain homeostasis of the energy metabolic system by regulating blood flow and gas exchange. This regulation is vital at rest and especially during varying degrees of physical exertion (Palange & Ward, 2007; Sietsema et al., 2020). During exercise, increased metabolic demand has a marked impact on cardiac output through coordinated adjustments in heart rate (HR) and stroke volume, while ventilation increases to meet oxygen demand and facilitate carbon dioxide elimination (Ward, 2018; Sietsema et al., 2020).

Exercise intensity is a key determinant of the mechanical stress applied to organs and metabolic systems. Therefore, it is of critical importance in the treatment, monitoring, or recovery of patients, athletes, and healthy individuals in clinical and sports sciences (Whipp, 1996; Ozçelik et al. 2002, Palange et al., 2007; Craighead et al., 2026). Although there is no single widely agreed-upon definition in the scientific community, exercise intensity is generally categorized into different types, such as mild, moderate, heavy, very heavy, and severe (Whipp, 1996; Korzeniewski & Rossiter, 2021).

The concepts of anaerobic threshold (AT) or lactate threshold (LT) were introduced by Wasserman and McIlroy (1964), which simply describe the exercise intensity at which blood lactate begins to increase systematically. Previous studies have demonstrated that the lactate threshold can be measured easily and reliably using respiratory gas exchange parameters (Beaver et al., 1986; Wasserman et al., 1990). According to threshold modeling based on changes in the body's energy metabolism, exercise intensity below the threshold is classified as low to moderate intensity, indicating an aerobic-dominated region (Whipp, 1996).

The exercise intensity between the LT and the respiratory compensation point (RCP) falls within the moderate-to-heavy range. Importantly, this region is mainly dominated by fast oxidative muscle fibers, in which metabolic (lactic) acid production is buffered by the body's buffer system, allowing subjects to continue exercise for approximately one hour. The period during which the increase in metabolic acid is suppressed is defined as the isocapnic buffering period, and its end is defined as the RCP (Sietsema et al., 2020). Exercise intensity above the RCP indicates anaerobic exercise, characterized by fast glycolytic muscle fibers and a progressive increase in metabolic (lactic) acid, representing heavy to severe exercise (Sietsema et al., 2020). An incremental exercise test provides a smooth, consistently increasing workload, allowing assessment of cardiac and respiratory responses to changes in metabolic activity across all three exercise intensities (i.e., moderate, heavy, and severe) (Whipp et al., 1981; Sietsema et al., 2020).

In this study, we aimed to establish heart rate responses in moderate, heavy, and very heavy (severe) exercise zones during incremental exercise testing in healthy male subjects.

MATERIALS AND METHODS

Subjects

A total of 50 male subjects (age: 21.32±1.3 years, BMI: 22.08±1.56 kg/m^2) voluntarily participated in the study. Before enrollment, inclusion and exclusion criteria were applied. Participants with metabolic, cardiac, or respiratory diseases were excluded. Subjects who smoked, consumed alcohol, or used any medication were also excluded. Care was taken to ensure that all subjects were healthy and physically active but not specifically trained athletes. The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Institutional Ethics Committee (approval number and name of institution to be inserted by the author). All subjects provided written informed consent before participation.

Experimental Protocol

Each subject performed an incremental exercise test with a load increment of 15 W/min until the limit of tolerance, between 8:00 AM and 9:00 AM to control for circadian variation. All tests were conducted in a temperature-controlled laboratory (22–24°C).

Before exercise, a twelve-lead ECG was placed on the subjects. Heartbeats were measured and recorded beat-to-beat throughout the study. The cardiac parameter was continuously monitored. During exercise, subjects breathed through a low-resistance turbine volume meter. Respiratory and gas exchange parameters were evaluated breath-by-breath from inhaled and exhaled air. Specifically, O_2 uptake (VO_2) and CO_2 output (VCO_2) were examined.

Determination of Lactate Threshold and Respiratory Compensation Point

Lactate threshold was estimated using the standard V-slope method (Beaver et al., 1986). The respiratory compensation point was defined as the point at which VE/VCO_2 began to increase systematically (Sietsema et al., 2020). During exercise, to avoid pseudo-threshold phenomenon, subjects' warm-up periods were monitored carefully for pre-exercise non-specific hyperventilation (Ozcelik et al., 1999).

Heart rate values were evaluated separately for three regions:

- Warm-up to lactate threshold (<LT)
- Lactate threshold to RCP (LT–RCP)
- RCP to maximal exercise (RCP–max)

Delta HR (ΔHR) and delta work rate (ΔWR) were calculated for each region.

Statistical Analysis

Data are presented as mean ± standard deviation (SD). A one-way repeated-measures ANOVA was used to compare delta HR and delta work rate across the three regions (warm-up–LT, LT–RCP, RCP–max). When a significant main effect was found, post-hoc pairwise comparisons were performed using Tukey's HSD test. Statistical significance was set at $p < 0.05$.

RESULTS

The maximum exercise capacity of the subjects (mean ± SD) was Wmax: 227 ± 23 W. Lactate threshold was observed at 146 ± 19 W, corresponding to 64 ± 4.1% of Wmax. The respiratory compensation point was observed at 182 ± 18 W, corresponding to 80 ± 2.8% of Wmax.

Heart rate was 81.8 ± 11 beats/min during the resting phase and increased to 92.8 ± 12 beats/min during warm-up. At LT, heart rate was 144.9 ± 11 beats/min. At RCP, it increased to 162.9 ± 10 beats/min. At the end of exercise, heart rate was 188.6 ± 7 beats/min, corresponding to 94.9 ± 3.8% of the predicted maximal heart rate (198.6 ± 1.3 beats/min) (Figure 1).

The delta heart rate from warm-up to LT was 52.08 ± 13.0 beats ($p < 0.05$). Between LT and RCP, it was 18.04 ± 6.5 beats ($p < 0.05$), and between RCP and maximal exercise, it was 25.64 ± 8.0 beats ($p < 0.05$) (Figure 2). The delta work rate from warm-up to LT was 125.9 ± 19.8 W ($p < 0.05$). Between LT and RCP, it was 36.6 ± 9.2 W ($p < 0.05$), and between RCP and maximal exercise, it was 44.9 ± 8.3 W ($p < 0.05$).

In addition, the relationship between heart rate and work output (produced work load per heartbeat) was evaluated across three regions. The work-to-heart rate ratio was 2.52 ± 0.56 from warm-up to LT, 2.49 ± 2.08 between LT and RCP, and 2.02 ± 1.22 between RCP and maximal exercise. These differences were not statistically significant ($p > 0.05$).

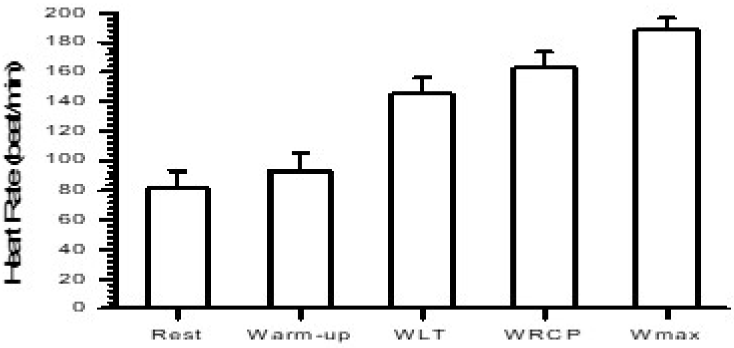

Figure 1: Heart rate (mean ± SD) at rest, warm-up period, at the lactate threshold, at the respiratory compensation point, and at the end of exercise.

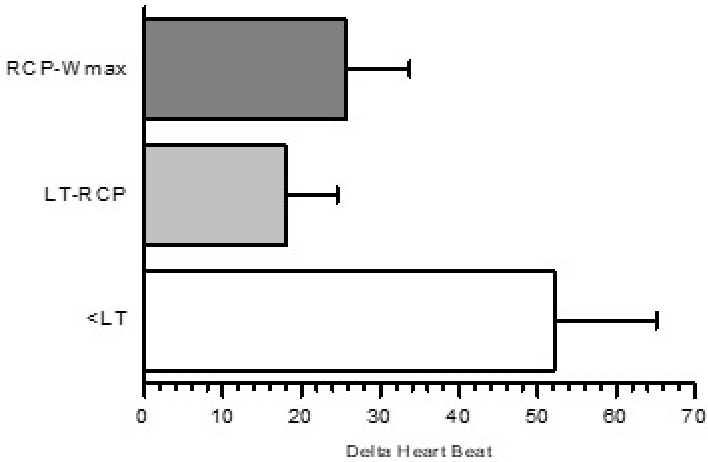

Figure 2: Delta heart rate from warm-up to lactate threshold (<LT), lactate threshold to respiratory compensation point (LT–RCP), and from respiratory compensation point to maximal exercise (RCP–Wmax).

DISCUSSION

The primary finding of this study is that heart rate increases progressively across the moderate (warm-up to LT), heavy (LT to RCP), and severe (RCP to maximal) intensity domains in healthy young males, with statistically significant delta values between each domain ($p < 0.05$). These results confirm that heart rate responses reliably reflect changes in metabolic demand during incremental exercise. Heart rate–work rate relationships have been used to evaluate metabolic response variation (Ozcelik et al., 2004; Algul et al., 2015). Establishing optimal exercise intensity has been widely used in clinical medicine to improve fitness and support treatment (Ozcelik et al., 2015 Kaya and Özdenk 2022).

The heart rate values observed at LT and RCP are consistent with previous literature. In healthy young adults, LT typically occurs at approximately 140–160 beats/min, while RCP occurs around 160–180 beats/min, depending on fitness level (Wasserman et al., 1990; Sietsema et al., 2020). Our findings support these ranges. Furthermore, the work rates at LT (64% of Wmax) and RCP (80% of Wmax) align well with the classical thresholds described by Whipp (1996), where LT is typically observed between 50–70% of VO_2max or Wmax, and RCP between 75–90%.

During incremental exercise, the heart rate response may appear linear or deviate to the right or left, as reported in previous studies (Ozcelik and Kelestimur 2006, Algul et al., 2016). In addition, hypoxic exercise could have significant impact on heart rate and work rate relationship has been shown (Ozcelik and Kelestimur 2004). It has been shown that the effects of weight loss programs on the heart beat-to-workload relationship in obese patients (ozcelik and Colak 2003). The delta heart rate from warm-up to LT was substantially larger than the delta between LT and RCP and between RCP and maximal exercise ($p < 0.05$). This pattern is physiologically expected. In the moderate intensity domain (below LT), the cardiovascular system exhibits a rapid, nearly linear increase in heart rate to meet rising oxygen demand. In contrast, the heavy domain (LT to RCP) shows a slower increase in heart rate, reflecting a more stable cardiodynamic state in which stroke volume and peripheral oxygen extraction contribute significantly to the rise in cardiac output (Korzeniewski & Rossiter, 2021). The renewed increase in delta heart rate in the severe domain (RCP to maximal) likely reflects the additional demand from the recruitment of fast glycolytic fibers and the progressive accumulation of metabolic acids, which stimulate the sympathetic nervous system more strongly (Sietsema et al., 2020).

Interestingly, the work-to-heart rate ratio decreased from warm-up to LT to RCP–maximal exercise, but this difference was not statistically significant ($p > 0.05$). This suggests that while absolute heart rate and work rate both increase significantly across domains, the efficiency of work production per heartbeat does not change dramatically. The large standard deviation in the RCP–maximal interval indicates considerable inter-individual variability in the severe domain, possibly due to differences in motivation, pain tolerance, or anaerobic capacity.

Another important observation is that heart rate reached 94.9 ± 3.8% of the predicted maximum (198.6 ± 1.3 beats/min) at the end of exercise. This indicates that subjects achieved a true maximal or near-maximal effort, confirming the validity of the incremental test protocol (15 W/min ramp). Achieving >90% of age-predicted maximal heart rate is a widely accepted criterion for maximal effort (Craighead et al., 2026).

The delta work rate values between domains also deserve attention. The largest work-rate increase occurred from warm-up to LT, as expected, since this domain covers the transition from rest to moderate exercise. The smaller delta between LT and RCP reflects the narrower work-rate range of the heavy-intensity domain, where the body primarily relies on oxidative metabolism. The delta between RCP and maximal exercise was slightly larger, consistent with the severe domain where work rate increases rapidly but exercise duration is short.

The absence of significant differences in the work-to-heart rate ratio across domains ($p > 0.05$) may seem surprising at first. One possible explanation is that, while heart rate increases linearly with work rate in each domain, the slope of this relationship varies across individuals. Moreover, the ratio approach may be too simplistic to capture the complex interactions between heart rate, stroke volume, and peripheral factors such as O_2 extraction and local blood flow regulation (Palange et al., 2007).

Study Limitations

This study has several limitations. First, only healthy young male subjects were included, so the results cannot be generalized to females, older adults, or clinical populations. Second, lactate threshold and RCP were estimated non-invasively using ventilatory gas exchange methods rather than direct blood lactate measurements, although the V-slope method is well-validated (Beaver et al., 1986). Third, stroke volume and cardiac output were not measured directly; therefore, the contribution of stroke volume versus heart rate to the changes in cardiac output across domains remains unknown. Fourth, the warm-up period included resting values, which may not fully represent the transition from rest to exercise. Future studies should use a standardized warm-up followed by a stable baseline.

CONCLUSION

In conclusion, heart rate increases significantly and progressively across moderate, heavy, and severe intensity domains during incremental ramp exercise in healthy young males. The largest increase occurs from rest to lactate threshold, followed by a smaller increase between LT and RCP, and a moderate increase in the severe domain. However, the efficiency of work production per heartbeat does not change significantly between domains. These findings support the use of heart rate as a practical, non-invasive marker for monitoring exercise intensity across different metabolic domains in healthy populations.

Future studies should investigate the relationships between heart rate and work rate in females, older adults, and patient populations (e.g., heart failure, COPD). Additionally, direct measurement of cardiac output and stroke volume would provide deeper insight into the mechanisms underlying the observed heart rate responses.

Kısaltmalar / Abbreviations

1RM : One Repetition Maximum
HR : Heart Rate (Kalp Atım Hızı)
VO_2 : Oxygen Uptake (Oksijen tüketimi)
VCO_2 : Carbon Dioxide Output (Karbondioksit çıkışı)
VE : Minute Ventilation (Dakika ventilasyonu)
AT : Anaerobic Threshold (Anaerobik eşik)
LT : Lactate Threshold (Laktat eşiği)
RCP : Respiratory Compensation Point (Solunumsal kompansasyon noktası)
Wmax : Maximal Work Rate (Maksimum iş yükü)
WR : Work Rate (İş yükü)
ΔHR : Delta Heart Rate (Kalp atım hızı değişimi)
ΔWR : Delta Work Rate (İş yükü değişimi)
BMI : Body Mass Index (Vücut kitle indeksi)
ECG : Electrocardiogram (Elektrokardiyogram)

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.

During the preparation and writing of this study, scientific, ethical and 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. The study was conducted in accordance with the Declaration of Helsinki.

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

Çalışmanın tasarımı ve planlanması: Ç.Ö., F.A.U.; Veri toplama, analizi ve yorumlanması: Ç.Ö., F.A.U.; Makalenin yazımı: Ç.Ö., F.A.U.; Yazım – özgün taslak, yazım – gözden geçirme ve düzenleme: Ç.Ö., F.A.U. Tüm yazarlar makalenin önemli noktalarını eleştirel olarak gözden geçirmiş ve makalenin son halini onaylamıştır. Yazarlar çalışmaya eşit oranda katkı sağlamıştır.

Design and planning of the study: Ç.Ö., F.A.U.; Data collection, analysis and interpretation: Ç.Ö., F.A.U.; Manuscript preparation: Ç.Ö., F.A.U.; Writing – original draft, writing – review and editing: Ç.Ö., F.A.U. All authors critically reviewed the manuscript and approved the final version. The authors contributed equally to the study.

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