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# Investigation of Heart Rate Variability of 14-18 Aged Swimmers: Loading and Recovery in Different Swimming Styles in Short Distance (50 M)

# 14-18 Yaş Yüzücülerin Kalp Atım Hızı Değişkenliklerinin İncelenmesi: Kısa Mesafe (50 M) Farklı Yüzme Stillerinde Yüklenme ve Toparlanma

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# INVESTIGATION OF HEART RATE VARIABILITY OF 14-18 AGED SWIMMERS: LOADING AND RECOVERY IN DIFFERENT SWIMMING STYLES IN SHORT DISTANCE (50 M)


## ABSTRACT

The present study aimed to compare the effects of different swimming styles (freestyle, backstroke, breaststroke, butterfly) on heart rate variability (HRV) before, during and after 50m sprint performance. In the literature, some studies directly compare the differences in recovery time depending on swimming distance. However, to our knowledge, no study investigates the differences in recovery time according to swimming style; this study aims to fill this gap. Swimmers participated in the study as volunteers (mean age 15.4±1.2 years; height 175.3±6.8 cm; weight 64.9±7.6 kg). The study was implemented with a randomized crossover design and each participant completed the HRV measurements by swimming 50 m at maximum speed in four different swimming styles. Time-domain (RR-SDNN-RMSSD) and frequency-domain (VLF-LF-HF) data of HRV were collected before (Pre-test), during (Test), and immediately after (Post-test) the 50m swim with the Polar V800 device. The data were analyzed by two-way ANOVA test (3-time x 4-intervention). From the time domain data of the participants, the interaction of time and style RR (Fs*t=2.670, =0.08), SDNN (Fs*t=2.251, =0.07) was found to have a statistically significant difference, but RMSSD (Fs*t=0.746, =0.01) was found to have no statistically significant difference. From the frequency domain data, time and style interaction of VLF (Fs*t=2.590, =0.08), LF (Fs*t=4.271, =0.13), HF (Fs*t3.156, =0.10) were found to have statistically significant differences. The differences in the results vary depending on the technical requirements of the swimming styles and their demands on the energy systems. The fact that each style utilizes different muscle groups and metabolic pathways to different degrees is one of the main reasons for these variations in recovery. In short-distance (50m) swimming performance in freestyle, backstroke, breaststroke, and butterfly swimming styles, the HRV before, during, and after swimming at maximum speed may have different effects on time and frequency domain parameters. In conclusion, the swimming style's technical challenges and predominant energy systems should be considered during training planning, ensuring an appropriate balance of loading and rest that accounts for recovery time and the physiological demands of each style.


***Keywords:*** Heart Rate Variability, Recovery, Swimming**.**

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# 14-18 YAŞ YÜZÜCÜLERİN KALP ATIM HIZI DEĞİŞKENLİKLERİNİN İNCELENMESİ: KISA MESAFE (50 M) FARKLI YÜZME STİLLERİNDE YÜKLENME VE TOPARLANMA

## ÖZ

Bu çalışmanın amacı, farklı yüzme stillerinin (serbest, sırtüstü, kurbağalama, kelebek) 50m kısa mesafe performansı öncesi, sırasında ve sonrası kalp atım hızı değişkenliğine (KAHD) etkilerini karşılaştırmaktır. Literatürde, yüzme mesafesine bağlı olarak toparlanma süresindeki farklılıkları doğrudan karşılaştıran çalışmalar bulunmaktadır, ancak bildiğimiz kadarıyla yüzme stillerine göre toparlanma süresindeki farklılıkları araştıran bir çalışma bulunmamaktadır, bu çalışma bu boşluğu doldurmayı amaçlamaktadır. Araştırmaya yüzücüler gönüllü olarak katılmıştır (ortalama yaş 15,4±1,2 yıl; boy 175,3±6,8 cm; vücut ağırlığı 64,9±7,6 kg). Çalışma, rastgele çaprazlama tasarımıyla uygulanmış ve her katılımcı, dört farklı yüzme stilinde 50m mesafeyi maksimum hızda yüzerek KAHD ölçümlerini tamamlamıştır. Polar V800 cihazı ile 50m yüzme öncesinde (Ön-test), sırasında (Test) ve hemen sonrasında (Son-test) olarak, KAHD'nin Zaman-Alan (RR-SDNN-RMSSD) ve Frekans-Alan (VLF-LF-HF) verileri toplanmıştır. Elde edilen Veriler, çift yönlü varyans analizi (Anova) testi (3-zaman x 4-stil) ile analiz edilmiştir. Katılımcıların Zaman-alan eksenli verilerinden; RR değerlerinin Zaman ve stil etkileşimi RR ($F_{s*t}$=2.670, =0.08), SDNN değerlerinin zaman ve stil etkileşimi ($F_{s*t}$=2,25, =0,07) arasında istatistiksel olarak anlamlı fark bulunurken, RMSSD değerlerinde zaman ve stil etkileşimi ($F_{s*t}$=0,746, =0,01) arasında anlamlı bir fark tespit edilmemiştir. Frekans-Alan Eksenli Değerlerinden; VLF verilerinin Zaman ve stil etkileşimi ($F_{s*t}$=2,590, =0,08). LF verilerinin Zaman ve stil etkileşimi ($F_{s*t}$=4,271, =0,13). HF verilerinin Zaman ve stil etkileşimi, ($F_{s*t}$3,156, =0,10) verileri arasında istatiksel olarak anlamlı sonuç tespit edilmiştir. Sonuçlardaki farklılıklar, yüzme stillerinin teknik gereksinimlerine ve enerji sistemleri üzerindeki taleplerine bağlı olarak değişir. Her stilin farklı kas gruplarını ve metabolik yolları farklı derecelerde kullanması, toparlanmadaki bu farklılıkların ana nedenlerinden biridir. Serbest, sırtüstü, kurbağalama ve kelebek yüzme stillerinde kısa mesafe (50m) yüzme performansında, maksimum hızda yüzme öncesi, sırası ve sonrasındaki KAHD, zaman ve frekans alanı parametreleri üzerinde farklı etkilere sahip olabilir. Sonuç olarak, antrenman planlaması yapılırken yüzme stilinin teknik zorlukları ve baskın enerji sistemleri göz önünde bulundurulmalı, her stilin gerektirdiği toparlanma süresi ve fizyolojik talepler dikkate alınarak uygun yük ve dinlenme dengesi sağlanmalıdır.

***Anahtar Kelimeler:*** Kalp Atım Hızı Değişkenliği, Toparlanma, Yüklenme, Yüzme.

## INTRODUCTION

Swimming is one of the most popular competitive and recreational sports worldwide that includes four different styles: freestyle, backstroke, breaststroke, and butterfly (Moser et al., 2020). Individual and specialized training is important for swimmer performance (Ieno et al., 2021). To prepare training programs according to the individual needs of athletes, it is important to evaluate their current situation in detail. There are many physical-physiological indicators of swimming success. One of the most important but least scientifically studied indicators is heart rate variability (HRV), which gives us information about the autonomic nervous system (ANS). Although in the literature, there are heart rate variability (HRV) studies at different distances, there is a lack of comprehensive research on different swimming styles. Recent studies have used HRV parameters as an indicator of loading, fatigue, and recovery. In this context, HRV is one of the main criteria used to assess the adaptive capacity of athletes to high-level training and frequent competitions (Kamandulis et al., 2020).

The brain, one of the most complex and complicated structures of the organism, exhibits an asymmetrical organization in terms of the anatomical structures and functions of its two hemispheres, this asymmetric structure affects the interactions between different parts of the brain and its overall functionality (Erdil et al., 2016). This dynamic structure of the brain is directly related to the ANS, and the functionality of this system plays an important role in determining the physiological and psychological states of individuals. HRV is a biomarker that allows the assessment of autonomic nervous system activity by measuring the time differences between heartbeats. HRV has an important role in understanding physiological and psychological states by reflecting the balance and functionality of the parasympathetic and sympathetic branches of the autonomic nervous system (Wang et al., 2022). HRV measurements are performed by methods such as time and frequency domain analysis, and these methods are used to understand the effects of factors such as stress, sleep, cardiovascular diseases, and exercise performance on the ANS (Agorastos et al., 2023).

In terms of modern sports sciences, HRV is considered a fundamental parameter for analyzing athletes' cardiovascular system responses and assessing autonomic nervous system functionality (Escorihuela et al., 2020). The changes that occur in the organism because of physical loads are reflected in enzymatic activities such as heart rate, respiration, ventilation amount, oxygen consumption, and lactic acid production (Küçük, 2018). HRV is a prominent biomarker that provides information on training load, recovery processes, and performance optimization, especially for high-endurance sports such as swimming (Proietti et al., 2017). Recent studies show that HRV is an effective assessment method for monitoring training intensity, fatigue level, and recovery processes (Escorihuela et al., 2020). This study fills an important gap in the literature by examining HRV parameters during and after short-distance (50 m) swimming. While existing research usually focuses on long-distance swimming or other sports, this study contributes to individualized training strategies by evaluating the effects of anaerobic loading on HRV based on specific swimming styles.

In the post-exercise recovery process, maintaining the balance of the ANS is critical for maintaining sports performance (Güngör et al., 2022). In recent years, heart rate variability (HRV) has gained attention as an important tool in the assessment of training frequency, the recovery process, and overall performance in training. By reflecting ANS components, HRV provides information about unit stress levels and recovery status. Lactate measurements are a direct indicator of muscle fatigue and metabolic stress. The combined use of these two parameters allows for a more effective loading and recovery strategy (Merati et al., 2015). For example, it was reported that there was a positive relationship between anaerobic threshold and anaerobic power in terms of the LF/HF ratio, one of the heart rate variability parameters. This finding supports the usability of HRV parameters for the evaluation of recovery processes after intense physical activities such as swimming (Alparslan et al., 2023).

There are many tools to measure HRV. However, thanks to technological advances, the popularity of smartwatches based on artificial intelligence is increasing due to their ease of use in sports, their obtaining different data, and their practical evaluation by coaches and sports scientists (Jerath et al., 2023). The techniques and race distances used in swimming are important factors in determining the cardiac responses of athletes (Esco, 2016; Flatt, 2017). Especially short-distance swimming races, such as 50 meters, cause sudden and significant changes in the heart rate of athletes because they require high anaerobic energy demand and intense physical effort (Matuz et al., 2022).

The role of HRV in the recovery process enables optimization of individual loading (Shaffer & Ginsberg, 2017). In this context, examining the HRV changes of different swimming styles on short-distance performance offers a valuable research area to better understand the physiological adaptation capacities of young athletes (Proietti et al., 2017). The evaluation of HRV according to swimming styles plays an important role in optimizing athletes' performance by contributing to the development of individualized training strategies (Esco & Flatt, 2014).

The present study aimed to compare the effects on heart rate variability before, during, and after a 50 m sprint performance of freestyle, backstroke, breaststroke, and butterfly swimming performed by swimmers aged between 14-18 years old. It is anticipated that the findings of the study will contribute to a deeper understanding of the physical-physiological adaptation processes of young swimmers. It is expected that the findings of the study will contribute to a deeper understanding of the physiological adaptation processes of young swimmers. It aims to make a unique contribution to the sports science literature by guiding the development of style-based personalized training and recovery strategies for coaches and athletes. We hypothesize that 1) four swimming styles will differently affect HRV, also 2) pre- during- and post-swimming HRV parameters are varied.

## METHOD

### Research Group

This study was carried out in a quasi-experimental randomized controlled crossover design between October 1 and December 31, 2thew the participation of a total of 30 volunteer boys and girl swimmers who actively participated in national competitions at the Istanbul Metropolitan Municipality Sports Club affiliated with the Turkish Swimming Federation. During the interventions, 7 volunteers were excluded for various reasons. The final sample group consisted of 23 swimmers aged 14-18 years (8 girls, 15 boys). The mean age of the volunteers was 15.4 ± 1.2 years, the mean height was 175.3 ± 6.8 cm and the mean weight was 64.9 ± 7.6 kg. For the sample size calculation of the study, the ANOVA: repeated measures, within-between interaction method from the F test family was used with the G*Power 3.1.9.7 program. In this calculation, $f = 0.4$, $\alpha = 0.05$, and $\beta = 0.80$ values were used, and a minimum of 20 subjects were foreseen to be included in the study. However, considering that participants may drop out of the study due to reasons such as lack of interest, changes in their thoughts, physical problems, illness, medication use that may affect the study, lack of self-efficacy, lack of time, or inability to adapt to the exercise program, it was planned to include 50% more participants than the minimum sample size specified in the power analysis. Therefore, the study was started with a larger sample group.

Inclusion criteria are followed: 1) Participating in regular swimming training at moderate or high intensity at least 3 d/week for at least two years, 2) Not having muscle and joint injuries in the last three months, 3) Not using drugs or stimulants regularly for at least six months, 4) Actively participating in national competitions, 5) Not being in menstrual period for female volunteers, 6) Not reporting a value below 16 as a result of the assessment of the degree of difficulty perceived during swimming with the Borg Rating of Perceived Exertion 6-20 Scale (RPE), 7) To minimize instrumentation bias, swimmers had to use heart rate monitors during training sessions one week before starting the interventions of the study.

In cases of a lack of motivation, individuals often do not fully comprehend the relationship between their actions and their consequences, and this can lead to a reduced sense of efficacy (Ceylan et al., 2022). In addition, considering that anxiety states that may occur may affect the HRV, all participants were informed about the procedures to be applied, and they were constantly supported and motivated by their coaches to avoid a lack of motivation. The participants voluntarily participated in the study by signing the written consent form. The coaches of the athletes were also informed about the methodological processes of the study and signed the consent forms. The study was approved by the Istanbul Gelisim University Ethics Committee (dated 03.06.2022 and numbered 221014).

## Data Collection

The present study was conducted during the competition period of the swimmers' training program in which they performed two swimming training sessions per day, six days a week, averaging 90 min /day. In addition, the participants continued dry-land resistance exercises for 30 minutes/ day, six days a week. The experimental trials of the study were completed within 7 days for each participant. Before 48 hours and during this time, the volunteers did not participate in any exhaustive workouts. Participants were assigned to different swimming styles using a randomized crossover design. The participants performed trials in a randomized order. The randomization process was performed by the researcher by manually dividing the participants randomly into groups. In this process, each participant was randomly assigned to a swimming style sequence and all participants were assessed in all four swimming styles on different days. This method was applied to avoid possible systematic errors and to minimize the effect of individual differences. The HRV was determined by swimming 50 m at maximum speed in four different swimming styles (freestyle, backstroke, breaststroke, and butterfly) using a Polar V800 Heart rate device. HRV was determined before (Pretest), during (Test), and after (Post-test) swimming. HRV was collected before swimming for 5 minutes in the passive rest supine position of participants. After that, subjects performed a warm-up (10 min), with no collected HRV (Behm & Chaouachi, 2011). The warm-up included jogging, calisthenics exercises, and static-dynamic stretching. The subject wore the Polar V800 device and a chest strap with an embedded sensor and performed a 50 m. swimming (freestyle, backstroke, breaststroke, or butterfly) at maximum effort, and immediately after swimming went into rest position (5 minutes) and collected HRV. In this study, SDNN and RMSSD calculations of HRV parameters were performed using time domain analysis. SDNN (standard deviation) refers to the standard deviation of all normal-normal (NN) intervals and is calculated by the formula: the sum of the squares of the differences from the mean of each NN interval obtained during the measurement period divided by the total number of NN intervals and taking the square root. This parameter indicates the total variability of the autonomic nervous system in general. RMSSD (root mean square difference) is calculated as the square root of the mean of the squares of the differences between consecutive NN intervals. This metric is considered an important indicator, especially in the assessment of parasympathetic nervous system activity (Koenig et al., 2014). The intensity of loading during swimming was assessed using heart rate values and the Borg RPE6-20 Scale**.** To minimize potential device bias, swimmers were familiarized with the device by wearing devices during training one week before the measurement week.

The analyzed HRV parameters were as follows; time domains - RR (time interval between successive heartbeats), RMSSD (Root mean square of successive differences), SDNN (Standard deviation of all NN intervals), and frequency domains - VLF (Very-low frequency 0.005-0.04Hz), LF (Low frequency 0.04-0.15 Hz), HF (High frequency 0.15-0.4 Hz). These parameters are important indicators of ANS function and cardiovascular health and constitute the basic analysis data of the study (Liu et al., 2020).

The study was carried out in a 50 m indoor swimming pool. To minimize the influence of biological rhythms on performance, measurements were taken between 06.00-08.00 in the morning of non-consecutive days, when participants' hormonal cycles are considered similar (Sato et al., 2019; Maier et al., 2022; Schönke et al., 2023). During the measurements, it was preferred to keep the ambient temperature (26-27°C) and water temperature (25-26°C) close to each other. This preference is due to the potential for the effects of water temperature on bradycardia to affect the experimental results (Xu & Chen, 2021).

## Data Collection Tools

Body Composition: The height of the participants was measured in swimsuits. Total body weight, basal metabolic rate, fat ratio (%), fat amount (kg), lean mass (kg), and total body fluid (kg) were analyzed using the TANITA BC-418MA (Tokyo, Japan) Segmental Body Analysis Monitor.

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Heart Rate Variability: HRV parameters were collected with a Polar V800 monitor and a from H7 chest strap (Polar Electro, Kempele, Finland). Data were transferred to the Polar Flow sync program using Kubios HRV Premium 3.5.0 software (Kuopio, Finland). In this study, the Polar V800 watch and h-7 chest strap device and Kubios HRV software were used to analyze HRV data. The normalization process was performed to improve signal quality and minimize artifacts. First, the RR intervals recorded by the Polar V800 device were preprocessed in Kubios software, missing or erroneous beats were identified, and automatic correction algorithms were applied. Then, low and high outliers were identified in the data set and normalized with detrending methods. This process aims to improve the reliability of time domain (SDNN, RMSSD) and frequency domain analysis. Although the Polar V800 has high accuracy on land, there are some limitations to its use in the underwater environment. The signal transmission of the optical sensors may be reduced underwater, making it difficult for the device to measure HRV without the use of a chest strap. In addition, water conductivity and pressure changes can affect electrode signals. However, research shows that with proper placement and data cleaning, Polar V800 can achieve acceptable levels of accuracy in HRV measurements underwater.

Borg RPE 6-20 Scale: It is a widely used tool to measure the perceived difficulty of exercise and consists of a score range from 6 to 20. It is based on the participant expressing the fatigue felt during exercise in a range from 6 to 20 (6 is nothing…….20 is exhaustion). This indicates a high linear relationship between perceived effort and heart rate during exercise. It is used in swimming as an effective method for athletes of different age groups (Borg, 1998; Scherr et al., 2013). The Borg RPE scale was administered after the participants completed each style and distance before being given the post-test, and volunteers who scored below 16 were excluded from the study.

## Analysis of Data

SPSS for Windows 29 (SPSS Inc, Chicago, USA) software was used for the statistical analysis of the collected data. The Shapiro-Wilk test was used to verify data normality. The data were analyzed by Two-Way ANOVA (3 time periods x 4 swimming interventions) test. For pairwise time and group comparisons, the Bonferroni test was used. The value was used to determine the effect size (ES). To interpret the ES: ≤0.01 indicated small, 0.06 indicated medium, and 0.14 indicated large effects. The significance value was set at $p<0.05$ (Cohen, 2013).

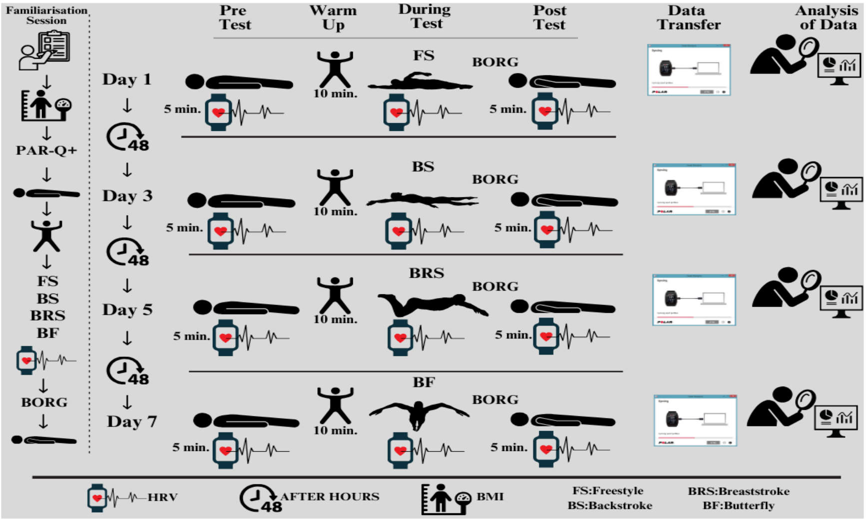


**Figure 1**. Experimental procedure flow diagram.

## FINDINGS

Demographic and physical variables are shown in Table 1. Tables 2 and 3 present parameters mean values of 4 swimming styles before, during, and after swimming.

**Table 1.** Descriptive characteristics of the participants.

| Variables | $\bar{X}$ | Sd | Min | Max |
|---|---|---|---|---|
| **Age (years)** | 15.4 | 1.2 | 14 | 18 |
| **Height (cm)** | 175.3 | 6.8 | 161.0 | 185.0 |
| **Weight (kg)** | 64.9 | 7.6 | 48.9 | 80.9 |
| **BMI (kg/m²)** | 20.5 | 1.8 | 17.7 | 23.3 |
| **Fat (%)** | 15.7 | 6.3 | 8.9 | 27.0 |
| **FM (kg)** | 9.9 | 4.1 | 5.4 | 19.1 |
| **FFM (kg)** | 52.8 | 8.3 | 38 | 69 |
| **MM (kg)** | 50.22 | 7.9 | 36.2 | 65.9 |
| **Tbw (kg)** | 38.8 | 4.9 | 28.0 | 50.7 |
| **Tbw %** | 60.8 | 5.2 | 49.7 | 66.6 |

The mean BMI values of the participants were determined as 20.54 ± 1.76 kg/$m^2$, fat percentage was 15.70% ± 6.28%, fat mass (FM) was 9.85 ± 4.06 kg, and the mean fat-free body mass (FFM) was 52.78 ± 8.29 kg. The mean muscle mass (MM) of the participants was recorded as 50.15 ± 7.94 kg, total body water (TBW) was determined as 38.80 ± 4.98 kg in kilograms and 60.76 ± 5.20 % in percentage.

**Table 2.** Comparisons of time domain parameters mean values according to four swimming styles before, during and after swimming

| Variable | STYLE | Pre-test | Test | Post-test | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **$\bar{X}$ ± Sd** | **$\bar{X}$ ± Sd** | **$\bar{X}$ ± Sd** | **$F_t$** | | **$F_{s*t}$** | |
| **RR /ms** | **FS** | 835.8±82.3#† | 626.0±116.9† | 521.2±112.7 | 101.9* | .822 | **2.670*** | 0.08 |
| | **BS** | 829.3±89.8#† | 650.7±468.8† | 573.3±120.3 | 35.3* | .616 | | |
| | **BRS** | 843.5±96.2#† | 602.5±157.2† | 596.3±119.3 | 44.5* | .669 | | |
| | **BF** | 807.1±150.5#† | 627.5±120.6† | 637.8±118.9 | 14.3* | .395 | | |
| **SDNN / ms** | **FS** | 52.7±13.4#† | 31.3±7.0† | 60.7±20.0 | 20.4* | .481 | **2.251*** | 0.07 |
| | **BS** | 44.3±13.3#† | 25.7±6.8† | 40.8±10.4 | 21.7* | .496 | | |
| | **BRS** | 48.8±18.1#† | 26.6±4.8† | 44.6±13.2 | 18.2* | 453 | | |
| | **BF** | 49.0±14.1#† | 27.4±8.0† | 41.6±10.7 | 23.7* | .518 | | |
| **RMSSD /ms** | **FS** | 26.4±11.4#† | 26.7±7.3† | 25.8±8.2 | 0.5 | .002 | 0.746 | 0.01 |
| | **BS** | 23.0±8.7#† | 26.2±8.5† | 22.1±8.0 | 1.4 | .059 | | |
| | **BRS** | 22.9±10.1#† | 27.8±10.1† | 22.9±6.4 | 2.3 | .116 | | |
| | **BF** | 25.5±12.2#† | 27.9±6.7† | 20.8±6.8 | 3.5 | .139 | | |

#: There is a statistically significant difference according to the Test and Post-test ($p<0.05$), †: There is a statistically significant difference according to Pre-test and Post-test ($p<0.05$). Pre-test: Before swimming, Test: During swimming, Post-test: After swimming, FS: freestyle; BS: backstroke; BRS: breaststroke; BF: butterfly

The interaction of time and style ($F_{s*t}$ = 2.670) of the RR values was found to have a statistically significant difference and medium effect size ( = 0.08). The interaction of SDNN values with time and style ($F_{s*t}$ =2.251) was found to have a statistically significant difference and medium effect size ( = 0.07). However, the interaction of RMSSD values with style and time (=0.746) found no statistically significant difference and small effect size ( = 0.07).

**Table 3.** Comparisons of frequency domain parameters mean values according to four swimming styles before, during and after swimming

| Variable | STYLE | Pre-test | Test | Post-test | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $\bar{X} \pm Sd$ | $\bar{X} \pm Sd$ | $\bar{X} \pm Sd$ | $F_t$ | | $F_{s*t}$ | |
| VLF/ms² | FS | 133.5±8.4#† | 109.5±18.5† | 138.7±29.1 | 13.2 | .375 | **2.590*** | 0.08 |
| | BS | 128.2±10.9#† | 112.3±17.5† | 102.5±31.2 | 8.6 | .280 | | |
| | BRS | 130.1±14.4#† | 112.3±15.6† | 120.5±34.9 | 3.1 | .124 | | |
| | BF | 135.4±49.8#† | 105.9±22.3† | 112.3±45.9 | 3.8 | .146 | | |
| LF /ms² | FS | 489.5±23.2#† | 620.0±141.7† | 500.0±80.2 | 14.0 | .358 | **4.271*** | 0.13 |
| | BS | 463.7±63.8#† | 656.3±86.6† | 369.2±95.4 | 69.0 | .758 | | |
| | BRS | 497.9±84.6#† | 659.6±78.7† | 431.6±81.8 | 48.5 | .688 | | |
| | BF | 457.8±109.3#† | 609.8±107.3† | 479.3±138.1 | 11.4 | .342 | | |
| HF /ms² | FS | 1054.0±24.3#† | 747.4±85.7† | 765.3±138.5 | 89.7 | .803 | **3.156*** | 0.10 |
| | BS | 1017.0±114.0#† | 771.6±121.6† | 634.0±137.8 | 68.9 | .757 | | |
| | BRS | 1058.2±146.9#† | 764.9±90.0† | 668.4±151.6 | 66.5 | .752 | | |
| | BF | 1040.0±139.7#† | 711.3±146.2† | 718.1±249.8 | 25.7 | .538 | | |

#: There is a statistically significant difference according to the Test and Post-test ($p<0.05$), †: There is a statistically significant difference according to Pre-test and Post-test ($p<0.05$). Pre-test: Before swimming, Test: During swimming, Post-test: After swimming, FS: freestyle; BS: backstroke; BRS: breaststroke; BF: butterfly

The interaction of time and style ($F_{s*t}$ = 2.590) of the VLF values was found to have a statistically significant difference and medium effect size ( = 0.08). The interaction of LF values with time and style ($F_{s*t}$ = 4.271) was found to have a statistically significant difference and a large effect size ( = 0.13). The interaction of RMSSD values with style and time ($F_{s*t}$ =0.746) was found to have a statistically significant difference in small effect size ( = 0.07).

## DISCUSSION AND CONCLUSION

The findings revealed that HRV showed significant changes in terms of time and style interactions. $F_{s*t}$ value determined for RR and SDNN indicates a significant effect on heart rate variability during swimming. These results are supported by Triposkiadis et al. (2002) and Nakamura et al. (2015), which showed that HRV may reflect the effects of different loads on ANS during swimming. Remarkably, the interaction between time and style $F_{s*t}$ was not found to have a significant difference in the RMSSD values ($F_{s*t}$ = 0.746, = 0.01). This finding suggests that temporal factors and style types have a more limited effect on the recovery of parasympathetic activity, especially during short-distance swimming. Morales et al. (2013) and Hellard et al. (2011) stated that parasympathetic reactivation in post-exercise recovery processes may vary according to different swimming styles; however, in this study, the effect on temporal measures of HRV was limited in styles with more intense anaerobic energy expenditure such as butterfly and backstroke. The findings obtained from the frequency domain parameters show significant changes before and during swimming. For example, VLF data were significant in time and style interactions ($F_{s*t} = 2.590$, = 0.08) and found to reflect the effects of different swimming styles on vagal activity, albeit with a small effect size. In the LF (low frequency) parameter, the interaction between time and style variables ($F_{s*t} = 4.271$, = 0.13) made a significant difference in terms of sympathovagal balance. This supports that intense anaerobic energy expenditure, especially in butterfly style, prolongs the recovery process by increasing sympathetic tone (Battaglia et al., 2014; Fortes et al., 2016). HF measurements were also found significant in time and style interactions ($F_{s*t} = 3.156$, = 0.10), which is in line with evidence of Battaglia et al. (2014) and Morales et al. (2013) that the aerobic energy system restores vagal activity faster. This study is one of the few investigations to examine in detail the relationship between HRV and time and style variables in short-distance swimming performances. The findings revealed the effects of different swimming styles on HRV and showed that sympathovagal balance varied significantly depending on swimming style and exercise intensity.

It was determined that high LF (low frequency) values in the butterfly style increased sympathetic tone and prolonged the recovery process, and the decrease in HF (high frequency) values indicated a delay in parasympathetic reactivation. These results are consistent with the findings reported by Hellard et al. (2011) and Morales et al. (2013) that high-intensity short-term exercises create sympathetic dominance and slow down parasympathetic recovery processes. The faster recovery process in freestyle swimming was attributed to the fact that this style relies more on the aerobic energy system. The previous evidence from Battaglia et al. (2014) that the aerobic system restores vagal activity faster and support these results. In addition to frequency parameters, significant findings were also obtained in time domain parameters. RR and SDNN values differed significantly depending on time and style, indicating that heart rate dynamics during swimming are specific to exercise style. On the other hand, RMSSD values were found to have low sensitivity to temporal changes. This is in line with the findings of Morales et al. (2013) and Proietti et al. (2017) that high-intensity exercise suppresses vagal tone. Heart rate variability (HRV) parameters can be used as an effective tool to monitor individual adaptation and recovery process in the optimization of training programs. Since higher HF levels indicate better parasympathetic activity and recovery capacity, more intense training can be applied during periods of high HF. Since the LF/HF ratio reflects the sympathetic-parasympathetic balance, an increased LF/HF ratio indicates a predominance of sympathetic activity and in this case the training load can be reduced or active rest can be applied. Since higher HF levels during the taper period are associated with better performance in elite swimmers, training intensity can be adjusted according to these data during the taper period (Koenig et al., 2014). An important contribution of the present study to the sports sciences is the detailed analysis of the effects of different swimming styles on post-exercise recovery processes. Previous research has generally addressed long-distance swimming performances or other sports (D'Ascenzi et al., 2014). In this context, our study provides a unique perspective to understand the dynamics of sympathovagal balance in activities dominated by intense anaerobic energy expenditure, such as short-distance swimming. It has been emphasized that the devices and methods used in different laboratory environments may affect the results, as stated in case studies (Triposkiadis et al., 2002; Lakin et al., 2013). The practical but lower sensitivity of the Polar v800 watch and h-7 chest strap devices used in this study compared to ECG is considered a limitation in terms of the generalizability of the results. Another limitation of the study was that insufficient control of environmental factors (e.g., water temperature and clothing choice) may also affect the accuracy of such measurements (Hellard et al., 2011). The strengths of our study include the detailed investigation of different time domain and frequency domain parameters. However, methodological limitations should not be overlooked. For example, the limited measurement accuracy of the devices used (Polar v800 watch and h-7 chest strap) limits the generalizability of some data compared to ECG-based measurements (Triposkiadis et al., 2002). Furthermore, the inability to control environmental factors (e.g. water temperature) made it difficult to consider potential effects on HRV measurements (Hellard et al., 2011). While this study reveals the effects of swimming styles on HRV at short distances, it sheds light on future studies at longer distances and in different age groups. For example, associating HRV variability with different energy systems at distances such as 100 m, 200 m, and 400 m may provide a better understanding of the roles of these parameters in physiological recovery processes. Furthermore, the effect of competitive stress and anxiety (e.g., somatic anxiety) on HRV may be related to psychological interventions such as biofeedback or imagery (Battaglia et al., 2014; Fortes et al., 2016).

This study makes an important contribution to the literature as it is one of the first studies to examine the effects of different swimming styles on heart rate variability (HRV) during and after short distance (50 m) performance. By comparatively analyzing the effects of different swimming styles on sympathovagal balance, it provides new information for developing style-specific recovery strategies. In addition, the findings on physiological adaptation processes in young swimmers can guide the development of personalized training programs. In conclusion, this study provides valuable knowledge of the relationship between HRV parameters in short distances for 4 different styles of swimming performances. Freestyle, backstroke, breaststroke, and butterfly short-distance (50 m) swimming can have different effects on HRV time and frequency domain parameters before, during, and after maximum swimming. The findings suggest that HRV measurements can be considered as a useful tool in the restructuring of young swimmers' training programs. Future research may confirm these findings in a broader context by examining HRV dynamics in different age groups and distances.

## Conflict of Interest Declaration

There is no personal or financial conflict of interest between the authors of the article within the scope of the study.

## Author Contribution Rates

Design of Study: Mİ(%50), RA(%50)

Data Acquisition: Mİ(%80), MS(%20)

Data Analysis: Mİ(%50), MA(%50)

Writing Up: Mİ(%30), RA(%30), MS(%20), MA(%20)

Submission and Revision: Mİ(%50), RA(%30), MA(%20)

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