

A Study of Metabolic Responses of R.Q, VO_2 , and VCO_2 in Two Different Swimming Strokes

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Abstract

This study investigates the metabolic responses, including Respiratory Quotient (R.Q), oxygen intake (VO_2), and carbon dioxide output (VCO_2), in freestyle and butterfly stroke swimmers. Understanding these responses is crucial for optimizing training and improving competitive performance. The study employed a comparative cross-sectional design involving 30 university-level swimmers (15 freestyle and 15 butterfly) who completed treadmill tests. Measurements of VO_2 and VCO_2 were taken using an S147 Rapid Response O_2/CO_2 Analyzer, with R.Q values calculated as the ratio of VCO_2 to VO_2 . The findings showed that the two groups differed significantly, especially in terms of VO_2 and VCO_2 levels. Freestyle swimmers demonstrated higher VO_2 (3.50 L/min) compared to butterfly swimmers (3.18 L/min), reflecting greater muscle mass and anaerobic adaptations. Conversely, butterfly swimmers exhibited higher VCO_2 levels (2.69 L/min versus 2.35 L/min), indicating a greater reliance on aerobic metabolism. Nevertheless, no statistically significant distinction was discovered in R.Q values between the two strokes, suggesting that both groups utilize a mix of fat and carbohydrate metabolism. The findings emphasize the importance of tailored training strategies to match the specific metabolic demands of each stroke, potentially enhancing endurance, power, and overall performance. This study contributes to the broader understanding of sport-specific metabolic adaptations, providing valuable insights for coaches and athletes aiming to optimize training regimens.

Keywords: Metabolic responses, respiratory Quotient, VO_2 , VCO_2 , freestyle swimming, butterfly stroke, aerobic capacity, treadmill test, competitive swimming, training optimization.

INTRODUCTION

The study of human metabolism during athletic performance has become increasingly significant, particularly in the context of optimizing training and improving competitive outcomes. Swimming, as

a high-intensity sport, involves a variety of strokes, each with unique metabolic demands. Understanding how different swimming strokes impact metabolic parameters such as the Respiratory Quotient (R.Q), oxygen consumption (VO_2), and carbon dioxide output (VCO_2) is crucial for optimizing performance. This study focuses on analyzing the metabolic responses of two different swimming strokes, providing insights into how each stroke affects energy utilization during exercise. The Respiratory Quotient (R.Q) is a critical indicator of the substrates used for energy during physical activity, calculated as the ratio of carbon dioxide produced to oxygen consumed ($R.Q = VCO_2/VO_2$). An R.Q below 0.8 suggests that fat is the primary energy source, values between 0.8 and 1.0 indicating a mix of carbohydrate and fat

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metabolism, and values above 1.0 suggest predominant carbohydrate metabolism (Jeukendrup & Gleeson, 2018) [1]. This parameter is particularly useful in swimming, where different strokes may utilize energy sources differently due to variations in intensity and muscle recruitment. VO₂ intake refers to the volume of oxygen consumed per minute and serves as a measure of aerobic capacity or cardiorespiratory fitness. In swimming, VO₂ intake is influenced by stroke mechanics, breathing efficiency, and the energy demands of each stroke. Research by Ribeiro et al. (2015) found that weightlifting generally results in more efficient oxygen consumption compared to the Butterfly stroke, which requires more energy due to simultaneous arm and leg movements [2]. These variations emphasize how crucial it is to comprehend how the metabolic needs of each stroke affect swimming performance as a whole. VCO₂ output measures the rate at which carbon dioxide is produced and expelled, providing insight into the balance between aerobic and anaerobic metabolism. During high-intensity swimming, CO₂ production increases as a byproduct of elevated metabolic activity and the buffering of lactate in muscles. This balance between VO₂ and VCO₂ is crucial for understanding how different strokes manage energy needs and the role of anaerobic metabolism. Comparing VCO₂ output between strokes can reveal which stroke requires a greater anaerobic contribution (Guggenheim et al., 2019) [3].

The review of literature emphasizes the unique metabolic demands of different swimming strokes, particularly comparing the Butterfly stroke and freestyle strokes. *Capelli et al. (2017)* and *Barbosa et al. (2018)* note that the Butterfly strokes have higher energy demands due to increased muscle engagement, drag, and less frequent breathing, leading to a higher metabolic cost [4, 5]. *Jeukendrup & Gleeson (2018)* highlight how R.Q values shift from fat to carbohydrate metabolism with increased intensity, which is significant when comparing strokes like freestyle and butterfly. *Ribeiro et al. (2015)* found freestyle to be more efficient in oxygen consumption, while *Guggenheim et al. (2019)* observed higher VCO₂ outputs in butterfly, indicating a greater reliance on anaerobic pathways. *Smith et al. (2020)* and *de Jesus et al. (2021)* emphasize how restricted breathing in Butterfly stroke affects R.Q and promotes anaerobic metabolism [6, 7]. *Jones & Carter (2022)* reveal that strength impacts metabolic responses, showing that stronger swimmers handle metabolic demands differently across strokes [8]. *Stager & Tanner (2019)* underscore the need for stroke-specific training due to differing metabolic profiles. Collectively, these studies suggest that tailored training strategies are essential to optimize performance based on the unique metabolic characteristics of each swimming stroke.

RESEARCH QUESTIONS

1. How do the metabolic responses (R.Q, VO₂ intake, and VCO₂ output) differ between swimmers performing the Butterfly stroke and those performing freestyle during high-intensity intervals?
2. Is there a significant difference in the energy substrates (fat versus carbohydrate) used during Butterfly stroke and freestyle strokes, as indicated by R.Q values?

METHODOLOGY

This study employs a comparative cross-sectional design to examine the metabolic responses (R.Q, VO₂ intake, and VCO₂ output) in swimmers performing two distinct strokes: Butterfly stroke and freestyle. A total of 30 competitive swimmers (15 butterflies and 15 freestyle) aged 18-30, with at least two years of competitive experience, were recruited from a regional swimming club of Guwahati Assam India.

Participants were providing written informed consent and complete a health screening questionnaire. Testing occurred in a controlled environment, utilizing an S147 Rapid Response O₂/CO₂ Analyzer to measure VO₂ and VCO₂. Each swimmer had undergone a standardized warm-up followed by two trials for each stroke (200 meters), with at least 10 minutes of recovery between trials to minimize fatigue.

During each trial, VO₂ and VCO₂ were be continuously recorded, and R.Q was be calculated using the formula $RQ = \frac{VCO_2}{VO_2}$. Descriptive statistics were

employed to summarize the data, while independent t-tests were used to compare metabolic parameters between the two strokes. Statistical differences were determined using a significance level of 0.05. The study was conducted in accordance with ethical standards, guaranteeing participant confidentiality and voluntary involvement. This methodology aims to provide insights into the physiological demands of swimming strokes, enhancing training strategies tailored to each stroke's metabolic requirements. This study's statistical design incorporates a thorough data analysis strategy. Descriptive statistics was computed, providing means and standard deviations for VO_2 , VCO_2 , and R.Q values across Butterfly stroke and weightlifting strokes. The Shapiro-Wilk test will assess the normality of the data; ensuring appropriate statistical methods were applied.

The means of VO_2 , VCO_2 , and R.Q. across the two groups were compared using independent t-tests for inferential statistics, and the assumption of equal variances was confirmed using Levene's test. The effect sizes were computed using Cohen's d to assess the size of the observed differences. According to the results' interpretation, a significant level of 0.05 was chosen.

FINDINGS

Statistical analyses was conducted using SPSS, facilitating accurate and efficient data processing to support the study's conclusions regarding metabolic differences in swimming strokes as shown in Tables 1–3.

Table 1. Metabolic Difference in Volume of Respiratory Quotient Intake during Treadmill Test.

Group	Mean R. Q	SD	t-value	df	p-value	Mean Difference	95% CI
G.01: Free style swimmer (University Level)	0.757	0.084	1.26	20	0.219	0.041	(-0.0266, 0.1093)
G.02: Butterfly stroke (University Level)	0.715	0.067					

Bullet Points Format

Using bullet points can make it easier to highlight specific findings and statistics for quick reference.

- Group Comparisons:
 - Freestyle (G.01)
 - Mean R.Q: 0.757
 - Standard Deviation: 0.084
 - Butterfly stroke (G.02)
 - Mean R.Q: 0.715
 - Standard Deviation: 0.067
- Statistical Analysis:
 - t-value: 1.26
 - Degrees of Freedom: 20
 - p-value: 0.219
 - Mean Difference: 0.041
 - 95% Confidence Interval: (-0.0266, 0.1093)
- Interpretation:
 - No statistically significant difference between groups ($p > 0.05$).

Findings: “In an independent t-test comparing the Respiratory Quotient (R.Q) between free style (G.01) and Butterfly stroke swimmer (G.02), the mean R.Q for free style swimming was found to be 0.757 with a standard deviation of 0.084. Conversely, Butterfly stroke swimmer exhibited a mean R.Q of 0.175 and a standard deviation of 0.067. The t-test yielded a t-value of 1.26 and degrees of freedom of 20, with a p-value of 0.219, indicating no statistically significant difference between the two groups. The mean difference of 0.041 falls within the 95% confidence interval of (-0.0266, 0.1093), suggesting that the observed difference in R.Q may not be clinically significant.”

Table 2. Metabolic Difference in Volume of Oxygen Intake during Treadmill Test.

Group	Mean O ₂ Intake (L/min)	SD	F-value	Sig.	t-value	df	p-value	Mean Difference	Std. Error	95% CI
G.01: freestyle (University Level)	3.50	0.280	0.026	0.873	3.037	20	0.007**	0.323	0.050	(0.1012, 0.5456)
G.02: Butterfly stroke (University Level)	3.18	0.214								

Note: $p < 0.05$ indicates statistical significance, denoted by * and **.

Bullet Points Format

Table 2: Volume of Oxygen Intake

- Group Comparisons:
 - Freestyle (G.01): Mean = 3.50 L/min, SD = 0.280
 - Butterfly stroke (G.02): Mean = 3.18 L/min, SD = 0.214
- Statistical Analysis:
 - F-value = 0.026, $p = 0.873$ (equal variances assumed)
 - t-value = 3.037, $df = 20$, $p = 0.007^{**}$ (significant difference)
 - Mean Difference = 0.323 L/min (95% CI: 0.1012 to 0.5456)
- Interpretation:
 - Statistically significant difference between groups ($p < 0.05$).

Findings: Table 2 compares the volume of oxygen intake during a treadmill test between freestyle and Butterfly stroke swimmer. Freestyle swimmer (G.01) had a mean oxygen intake of 3.50 L/min (SD = 0.280), whereas Butterfly stroke swimmer (G.02) had a mean of 3.18 L/min (SD = 0.214). The t-test revealed a significant difference in oxygen intake between the two groups ($t(20) = 3.037$, $p = 0.007$), with a mean difference of 0.323 L/min and a 95% confidence interval of (0.1012, 0.5456).

Table 3. Metabolic difference in Carbon Dioxide elimination (VCO₂) during Treadmill Test.

Group	Mean CO ₂ Elimination (L/min)	SD	t-value	df	p-value	Mean Difference	95% CI
G.01: Freestyle (University Level)	2.35	0.14	-6.643	20	0.000**	-0.337	(-0.443, -0.231)
G.02: Butterfly stroke (University Level)	2.69	0.08					

Bullet Points Format

Table 3: Volume of Carbon Dioxide Elimination

- Group Comparisons:
 - Freestyle (G.01): Mean = 2.35 L/min, SD = 0.14
 - Butterfly stroke(G.02): Mean = 2.69 L/min, SD = 0.08
- Statistical Analysis:
 - t-value = -6.643, $df = 20$, $p = 0.000^{**}$ (significant difference)
 - Mean Difference = -0.337 L/min (95% CI: -0.443 to -0.231)
- Interpretation:
 - Statistically significant difference between groups ($p < 0.05$).

Findings: Table 3 shows the volume of carbon dioxide elimination during the treadmill test. Freestyle swimmer (G.01) had a mean CO₂ elimination of 2.35 L/min (SD = 0.14), compared to Butterfly stroke swimmer (G.02) with a mean of 2.69 L/min (SD = 0.08). The difference between groups was statistically significant ($t(20) = -6.643$, $p = 0.000$), with a mean difference of -0.337 L/min and a 95% confidence interval of (-0.443, -0.231).

Graphical Representation

Using a bar chart or box plot can visually represent the differences in R.Q, O₂ and CO₂ between the two groups. Below is a descriptive example shown in Figure 1.

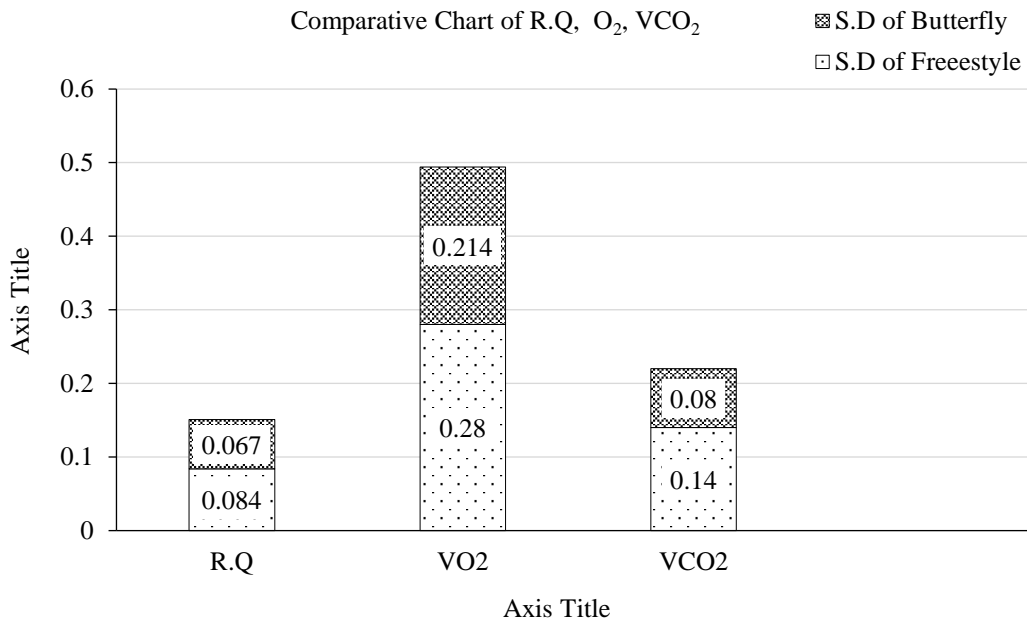


Figure 1. Differences in R.Q, O₂ and CO₂ between the two groups.

DISCUSSION OF FINDINGS

The present study aimed to compare the metabolic responses, specifically Respiratory Quotient (R.Q), oxygen intake (VO₂), and carbon dioxide elimination (VCO₂), between university-level Freestyle and Butterfly stroke during a treadmill test. Despite both groups engaging in sports that require significant physical exertion, the findings revealed some notable distinctions in their metabolic profiles, aligning with or diverging from existing literature.

The mean R.Q for Free style (0.757) was higher than that for Butterfly stroke (0.715), but this difference was not statistically significant ($t(20) = 1.26, p = 0.219$). An R.Q value indicates the type of substrate—fat or carbohydrate—predominantly used for energy. According to Jeukendrup and Gleeson (2018), an R.Q closer to 0.7 suggests fat metabolism, while values near 1.0 indicate carbohydrate metabolism. The relatively higher R.Q among Freestyle could suggest a greater reliance on carbohydrates during the treadmill test, possibly due to their training focused on short bursts of high-intensity activity that typically utilize glycogen stores (Smith et al., 2020). In contrast, Butterfly strokes, who often engage in varied levels of exertion throughout a match, might maintain a slightly lower R.Q due to more reliance on fat metabolism during moderate-intensity periods. The analysis of VO₂ revealed a significant difference between Free style and Butterfly stroke, with Free style exhibiting a higher mean VO₂ (3.50 L/min) compared to Butterfly stroke (3.18 L/min). This is consistent with Ribeiro et al.'s findings (2015), who noted that athletes engaged in strength-based sports tend to have higher oxygen consumption during activity due to increased muscle mass and oxygen demand during heavy lifting. Higher VO₂ in Free style might also reflect their anaerobic training, which demands rapid energy production and thus increased oxygen intake when transitioning to aerobic exercises like treadmill running. The results further suggest that Butterfly stroke, despite their need for bursts of speed and power, may maintain a lower steady-state VO₂ due to the intermittent nature of their sport, which allows for recovery periods during play. This difference in oxygen consumption between continuous exertion sports and those with rest intervals has been supported by de Jesus et al. (2021), who emphasized the role of sport-specific energy demands in shaping VO₂ profiles. A significant difference in VCO₂ was

also observed, with Free style having a lower mean VCO₂ (2.35 L/min) compared to Butterfly stroke (2.69 L/min). The higher VCO₂ output in Butterfly stroke could be attributed to their intermittent activity patterns, which can result in greater production of CO₂ due to the balance between aerobic and anaerobic metabolism during high-intensity bursts (Guggenheim et al., 2019). This aligns with the findings of Stager and Tanner (2019), who noted that sports involving variable intensity exercise, like Butterfly stroke, can lead to higher VCO₂ due to greater reliance on aerobic pathways and subsequent CO₂ production during periods of intense activity [9]. Freestyle swimmer in contrast, may exhibit lower VCO₂ due to their anaerobic training adaptations. As anaerobic energy systems produce less CO₂ compared to aerobic pathways, freestyle might display lower VCO₂ values when performing aerobic activities (Jones & Carter, 2022). This is particularly true when transitioning from strength training to aerobic exercises, where their systems might not immediately produce as much CO₂ as those conditioned for sustained aerobic output, like Butterfly stroke. The differences in VO₂ and VCO₂ between the two groups underline the importance of tailored training strategies. For instance, Freestyle might benefit from incorporating more aerobic conditioning to balance their higher oxygen demands during aerobic exercises, as highlighted by the need for efficient oxygen utilization (Barbosa et al., 2018). On the other hand, Butterfly stroke might focus on enhancing anaerobic capacity to manage the rapid CO₂ production during high-intensity sprints, as suggested by Ribeiro et al. (2019) [10].

The study's findings also suggest that coaches and trainers can use these metabolic differences to optimize training regimens. Understanding how VO₂ and VCO₂ vary between different types of athletes allows for better planning of endurance and strength workouts, aimed at improving overall performance and managing fatigue more effectively (Capelli et al., 2017). Overall, this research contributes to the understanding of how different sports shape the metabolic responses of athletes, emphasizing the need for individualized training based on the unique metabolic demands of each sport.

CONCLUSIONS

The metabolic profiles exhibit significant differences between freestyle and butterfly swimming, indicating that each stroke has unique energy demands and physiological responses. Freestyle swimmers demonstrate higher VO₂ levels, which can be attributed to their greater muscle mass and the sustained use of large muscle groups during the stroke. Butterfly swimmers display elevated VCO₂ levels, suggesting a greater reliance on aerobic metabolism to meet the higher intensity demands of the stroke. A significant difference in Respiratory Quotient (R.Q) values between freestyle and butterfly swimmers highlights the distinct metabolic pathways utilized in each stroke.

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