A 4-Beat Kick Frequency May Optimize Consistency and Efficiency in 800 Meter Freestyle Swim Performance

Original Research

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Open Access

Published: January 9, 2026

Research in Strength and Performance: *2026, Volume 6 (Issue 1): 2*

ISSN: 2768-5187

Abstract

Introduction: This exploratory study examined the effects of kick frequency (KF) on performance, biomechanical, physiological, and psychophysiological variables to determine optimal performance in an 800 m long course freestyle swim.
Methods: Six international-level swimmers completed 5 x 100 m pacing efforts at 2-, 4-, and 6-beat KF. Multiple one-way repeated measures ANOVAs compared effects of KF on target time coefficient of variation (TTCV), stroke rate (SR), stroke length (SL), heart rate (HR), caloric energy expenditure (EE), and rate of perceived exertion (RPE).
Results: A significant KF effect was found for RPE [$F(2,10) = 17.143$, $p = .009$, $\eta^2 = .774$]. RPE was greater in the 6-beat (14.43 ± 1.85) vs. 4-beat (12.03 ± 0.64; $p = .027$) and 2-beat (11.23 ± 1.78; $p = .024$) KF. The effect of KF on TTCV was significant [$F(2,10) = 4.090$, $p = 0.050$, $\eta^2_p = 0.450$], but while the 4-beat KF demonstrated the lowest mean variability, the sensitivity of pairwise comparisons failed to detect where significance lay. No significant effects were found for HR, EE, SR, or SL ($p > .05$).
Conclusions: Coaches may consider the 4-beat KF as a hybrid advantage since it requires less metabolic cost than the 6-beat KF, allows for higher velocity without a proportional increase in EE or RPE, promotes pacing consistency, and provides an efficient balance between SL and SR.

Key Words: swimming pacing, stroke length, stroke rate, WHOOP

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Introduction

Freestyle swimming performance is governed through a balance of biomechanical efficiency and physiological demands [1]. Kick frequency (KF) is the number of leg kicks performed per arm stroke cycle, and altering KF likely changes the trade-off between stroke mechanics, energetic costs, perceived effort, and performance in an 800 m effort. Because small changes in technique can produce meaningful performance differences at elite levels, systematically comparing 2-, 4- and 6-beat kick patterns provides mechanistic insight into how technique adjustments affect both efficiency and output under race-like pacing. Establishing these links helps coaches select stroke-kick strategies that optimize speed while managing energetic expenditure. Stroke rate (SR) and stroke length (SL) are key determinants of swimming efficiency. SL is defined as the distance covered from the entry of one hand to the entry of the opposite hand [1]. SR is the number of strokes taken per minute [1]. In a study of elite sprinters, the swimmer with the shortest SL also had the greatest SR and the greatest overall velocity [1], demonstrating an inverse relationship between SL and velocity for a sprinter. While having the greatest velocity is ideal, this maximal SR, minimal SL technique has been shown to yield the greatest energy cost [1]. In contrast, distance swimmers prioritize swimming efficiency with lower physiological strain to sustain their velocity over extended periods [2,3]. The 6-beat KF is widely accepted as the optimal cycle because it facilitates greater SL, increases body roll and stroke reach, and stabilizes the lower body to maintain a high body position [4]. It likely lowers the energy cost of each stroke, allowing them to maintain their velocity for the maximum amount of time, but this has yet to be investigated. Sortwell [4] claimed the 6-beat kick is the most efficient KF and that decreasing from a 6-beat to a 2-beat kick would shorten SL. However, accomplished distance swimmers, such as Janet Evans, have been documented to use a 2-beat kick [5]. Morias et al. [6] showed that elite male swimmers had an average SL during a 1500 m race of 2.62 m, ranging from 2.46 - 2.66 m during a 50 m period. Guedes et al. [7] studied a group of master's swimmers' training in a pool for open water endurance events, and reported SL ranges of 2.22 m during the last lap of a 2000 m race to 2.41 m during the first lap. SL for the French national sprint specialists in the Komar et al. study [1] ranged from 2.44 m in the slowest to 2.23 m in the fastest [1].

Pacing in an 800 m long course race depends on an athlete's ability to reproduce target split times. Changes in KF could influence stroke rhythm stability and mental or physiological strain. By quantifying how 2-, 4-, and 6-beat kicks affect both within-trial pacing variability in addition to stroke mechanics, physiological strain, and psychophysiological aspects of performance, this knowledge would directly inform coaches' pacing strategies and race-specific training prescriptions for elite swimmers. Therefore, the purpose of this study was to examine the preliminary performance (target time coefficient of variation [TTCV]), biomechanical (SR, SL), physiological (HR, caloric energy expenditure [EE]), and psychophysiological (rate of perceived exertion [RPE]) responses to 2-, 4-, and 6-beat kick frequencies during 800m freestyle pacing efforts. Given the small sample size, inherent to elite swimmer populations, the study was not designed for definitive inferential conclusions but rather to identify effect sizes, descriptive trends, and practical feasibility to inform future confirmatory research. It was hypothesized that the lower, 4-beat KF would provide a lower internal load to allow sustainable pacing.

Scientific Methods

This exploratory, within-subject study was used to compare performance across three assigned KF. KF was randomized to limit outside variables, including exertion from prior practices. Testing occurred outdoors in an Olympic style (50-meter) competition pool.

Participants

This study aimed to analyze developed distance specialists with a World Aquatics (formerly FINA) level of 1, 2, or 3, as defined by Ruiz-Navarro et al. [10]. Participants were five male and one female (age, 21.85 ± 2.51 years; height, 177.00 ± 6.60 cm; mass, 73.00 ± 8.27 kg) international-level swimmers training with a local team under World Aquatics scholarships. All swimmers were classified as World Aquatics (formerly Fédération Internationale de Natation) level 3 swimmers, with the average World Aquatics points for their 800m freestyle being 702.33 ± 56.20 points. Ethical approval was obtained from the university's Institutional Review Board. All participants provided informed consent in accordance with the Declaration of Helsinki.

Protocol

Participants were instructed to fuel and hydrate as they would before a typical practice prior to each session. Participants arrived in practice suits, wearing their caps, goggles, and any necessary equipment for the warm-up. Participants were informed of their prescribed KF prior to the warm-up of each session. Participants were then asked to complete a self-led warm-up. Each swimmer was assigned different session days to perform the 2-, 4-, and 6-beat KF. A 2-beat KF was defined as two complete emersion and/or immersion kicks within one arm cycle. A 4-beat KF was defined as four complete emersion and/or immersion kicks within one arm cycle. A 6-beat KF was defined as six complete emersion and/or immersion kicks within one arm cycle. All swimmers completed one trial of five 100 m efforts with each of the prescribed KF. Each 100 m trial was initiated on a fixed 1:45 send-off, such that rest duration varied depending on individual swim time. KF conditions were completed on separate testing days, a minimum of 48 hours apart, with condition order randomized across swimmers to minimize order and fatigue effects.

Performance Assessment

Performance was assessed as the consistency of 100-meter trial times for each KF. A FINIS 3X100M stopwatch (FINIS Inc., Livermore, CA, USA) was used to collect swimmers' times to the nearest 0.01 s. The stopwatch was started on a verbal "go" command of the "ready…go" send off. The stopwatch ended when individual swimmers touched the wall as seen from a perpendicular angle to the wall. All times were collected by one individual. Each swimmer had a target 100 m time that was calculated as 1/8 of their fastest recorded time as reported by the lead coach. For each KF, TTCV was calculated based on the times of the five trials as follows: $\left(\frac{\sigma}{\mu}\right) \cdot 100.$

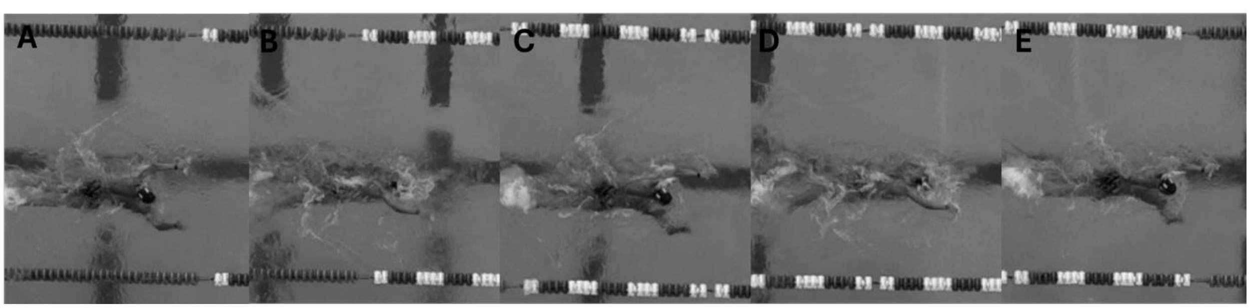
Biomechanics Assessment

The DJI Mini 3 drone (DJI Technology Co., Ltd., Shenzhen, China) was used to capture an aerial view of each swimmer. Aerial footage was used to find SL and SR. The drone was first placed at the center of the pool. The auto takeoff feature was used, and the drone was flown to 20m. From this height, the gimble was adjusted to -90° to allow the camera to capture an aerial view of the pool. Drone footage was continuously recorded at 30 frames per second through each trial. Swimmers were captured between the 15-35 m and 65-85 m segments of the pool. The DJI Mini 3 has a reported vertical hovering accuracy of +-1.5m and a horizontal hovering accuracy of +-0.5m without vision positioning [11].**Error! Reference source not found.** Drone position data were gathered from the "Flight Data Center" under the "Profile" on the DJI Mini 3 RC and uploaded as a .txt file. The .txt file was uploaded to the website, https://www.phantomhelp.com/LogViewer/Upload/, which was used to translate the data into a .csv file for data interpretation. Adherence to the prescribed KF was verified using frame-by-frame analysis of drone footage, with visual confirmation of KF counts within analyzed stroke cycles. Video files were uploaded to the biomechanics software Kinovea (ver.2024.1), which was used as the timer to measure the SR and SL from aerial footage recorded by the DJI Mini 3. Kinovea has been validated with an error of <10% compared to a 3D motion capture system [8]. The segment distances were tracked using yellow 15 m marker buoys. Buoys placed at the 15 m mark are standard in a competition pool, although they can be marked with a different color (e.g., Red). One cycle was defined as two strokes, a left and a right. Swimming velocity (SV, meters per second), SR (cycles per second), and SL (meters per cycle) were calculated as follows:

$$(1)\quad SV = 20\ \text{m} \div \Delta t$$
$$(2)\quad SR = 1 \div \Delta ave._{2\ cycle}$$
$$(3)\quad SL = SV \div SR$$

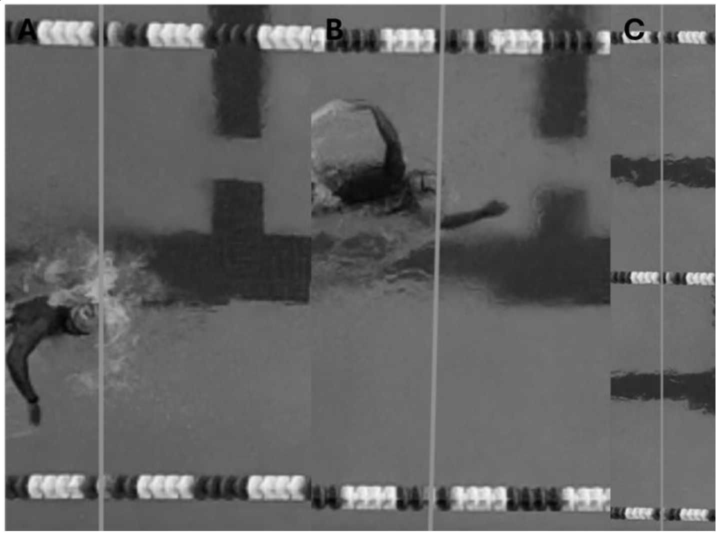
For analysis, the cycle started at the entry phase of the stroke. SR was calculated as 1/average duration of two cycles during the 15-35 m and 65-85 m segments. Each cycle was calculated at the entry of one hand to the entry time of the same hand beginning the third cycle, as displayed in Figure 1. Swimming velocity was measured from the 15-35 m and 65-85 m segments. These segments were determined to be the distance between the 15 m marker buoys. Time was gathered as the point at which the head crossed the threshold into or out of the space between the buoys, as displayed in Figure 2. The threshold of the 15 m marker was determined through the creation of a line using the first and third lane lines closest to the edge of the pool, as displayed in Figure 2.

Figure 1. Stroke Cycle Calculations Via Drone Video.



Note. Two cycle completion times were calculated from the first entry of one hand (A) to the third entry time of the same hand (E). (A) displays the first stroke at the entry of the left hand. (B) displays the second stroke at the entry of the right hand. (C) displays completion of the first cycle and third stroke at the second entry of the left hand. (D) displays the fourth stroke by the entry of the right hand. (E) displays the completion of the second cycle.

Figure 2. Swim Velocity Calculations via Drone Video.



Physiological Assessment

The WHOOP 5.0 wrist-worn straps (WHOOP Inc., Boston, MA, USA) were used to record HR and EE data. A WHOOP profile was created for each participant using self-reported height, weight, age, and sex. Participants were instructed to secure and adjust the WHOOP wrist strap to ensure a stable fit to minimize interference with stroke mechanics. The 5.0 model has not been independently validated; however, the 3.0 model has demonstrated high accuracy (>99.7%) in comparison to electrocardiography [9]. WHOOP devices were connected to Apple iOS devices (iPhone 13 Pro Max, iPad Air 5th Gen, iPad Mini 5th Gen, and iPad 7th Gen; Apple Inc., Cupertino, CA, USA) for real-time data synchronization. Average HR in beats per minute (BPM) was collected for individual 100 m efforts. Participants' self-reported height, weight, sex, and age were entered into an individual WHOOP profile. These measures allowed the WHOOP to estimate EE during the session. Participants secured the WHOOP strap on their wrist and adjusted the fit to their comfort. A comfortable, secure fit was required to limit changes it may have introduced to the participants' stroke technique. HR and EE were averaged from the start of the first 100 m trial to the last 100 m trial.

Psychophysiological Assessment

Within ten seconds of touching the wall, each swimmer was asked to verbally state their RPE during that 100-meter effort. RPE was assessed according to the Borg Rating of Perceived Exertion, 6-20 [12].

Statistical Analysis

All statistical analyses were processed using the Statistics Package for Social Sciences (ver. 29; IBM Corporation, New York, NY, USA). Descriptives [means ± standard deviations (SD); 95% confidence intervals (CI)] were calculated for all dependent variables: TTCV, SL, SR, HR, EE, and RPE. One-way repeated measures ANOVAs were used to compare the average effect of each KF for the dependent variables with an a priori alpha = .05. Greenhouse-Geisser corrections were applied where the assumption of sphericity was violated. Post hoc comparisons were performed under Bonferroni adjustment. Partial eta squared (η^2_p) was reported for effect size thresholds of .01, .06, and .14 interpreted as small, medium, and large, respectively [13]. Given the small sample size, results were interpreted with an emphasis on effect sizes and descriptive trends rather than on statistical significance alone. The study was not powered to detect small-to-moderate effects, and null findings should be interpreted cautiously.

Results

Results are presented descriptively with corresponding effect sizes to reflect the exploratory nature of the study. Performance, biomechanical, and physiological variables were analyzed using data from six participants, while physiological variables were analyzed using data from five participants due to incomplete wearable data for one swimmer. Table 1 depicts the means ± standard deviations (SD) and 95% confidence intervals (CI) across 2-, 4-, and 6-beat KF.

Table 1. Mean ± SD (95% CI), Significance and Effect Sizes across KFs.

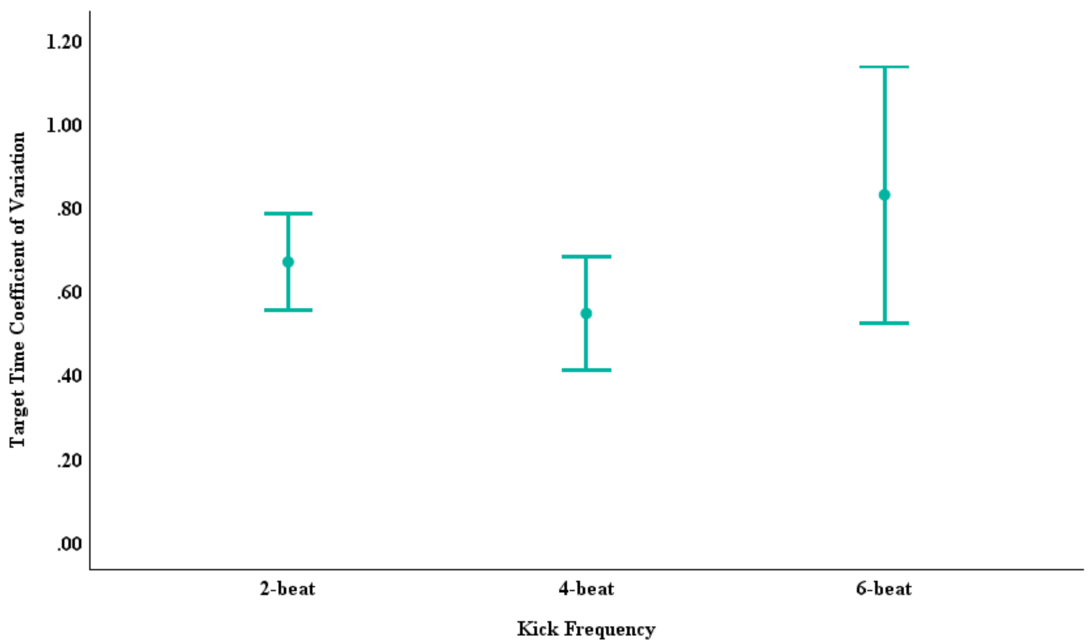
Variable	2-beat KF	4-beat KF	6-beat KF	p, η^2_p
TTCV	0.67 ± 0.11	0.55 ± 0.13	0.83 ± 0.29	0.050, 0.450
	(0.56, 0.78)	(0.42, 0.68)	(0.54, 1.12)	
SR	0.34 ± 0.03	0.33 ± 0.03	0.34 ± 0.02	0.154, 0.359
	(0.31, 0.37)	(0.30, 0.36)	(0.32, 0.36)	
SL	4.18 ± 0.36	4.40 ± 0.45	4.30 ± 0.41	0.077, 0.402
	(3.82, 4.54)	(3.95, 4.85)	(3.89, 4.71)	
HR	144 ±15.40	148 ± 9.37	153 ± 5.36	0.324, 0.246
	(128, 160)	(138, 158)	(147, 159)	
EE	98.0 ± 30.3	109. ± 10.5	116. ± 24.4	0.394, 0.208
	(66.2, 130.0)	(98.0, 120.0)	(90.4, 142.)	
RPE	11.2 ± 1.77	12.0 ± 0.64	14.4 ± 1.85	0.002, 0.774
	(9.3, 13.1)	(11.3, 12.7)	(12.5, 16.3)	

Notes. SD, standard deviation; CI, confidence interval; KF, kick frequency; TTCV, coefficient of variation from target time; SR, stroke rate; SL, stroke length; HR, heart rate; EE, caloric energy expenditure; RPE, rate of perceived exertion.

Performance

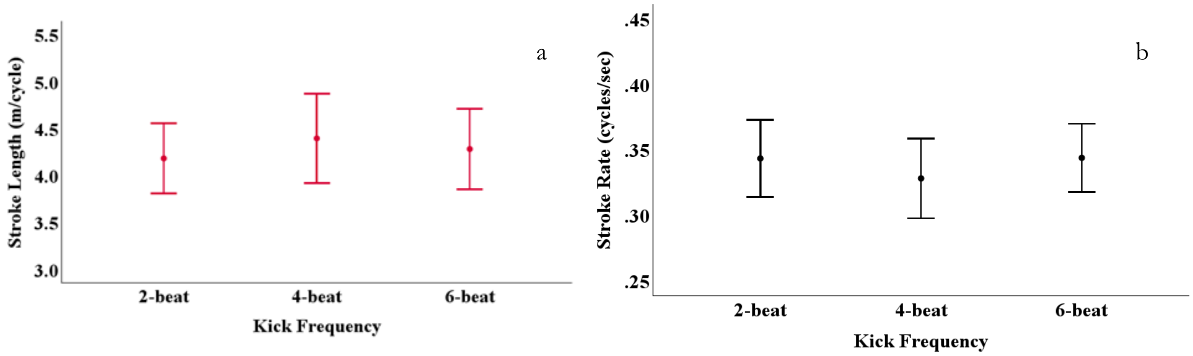
Performance variables were defined as the consistency of the athlete to perform the target swim times across five trials for each KF and measured as the target time coefficient of variation (TTCV). See Figure 3 for an illustrated display of estimated marginal mean differences across KF for performance variables. TTCV demonstrated a large effect size across KF ($\eta^2_p = 0.450$). While pairwise comparisons did not reach statistical significance, the 4-beat KF exhibited the lowest mean variability.

Figure 3. Coefficients of Variation for Target 100m Times.



Biomechanics. Biomechanical variables were SL and SR as collected through frame-by-frame Kinovea analysis of video footage collected by the DJI Mini 3. See Figure 4a and 4b for mean differences across KF for SL and SR, respectively. SR demonstrated a large effect size across KF ($\eta^2_p = 0.359$). While differences did not reach statistical significance, mean stroke rate was lowest in the 4-beat condition. SL also demonstrated a large effect size ($\eta^2_p = 0.402$). Although not statistically significant, the 4-beat KF produced the greatest mean stroke length.

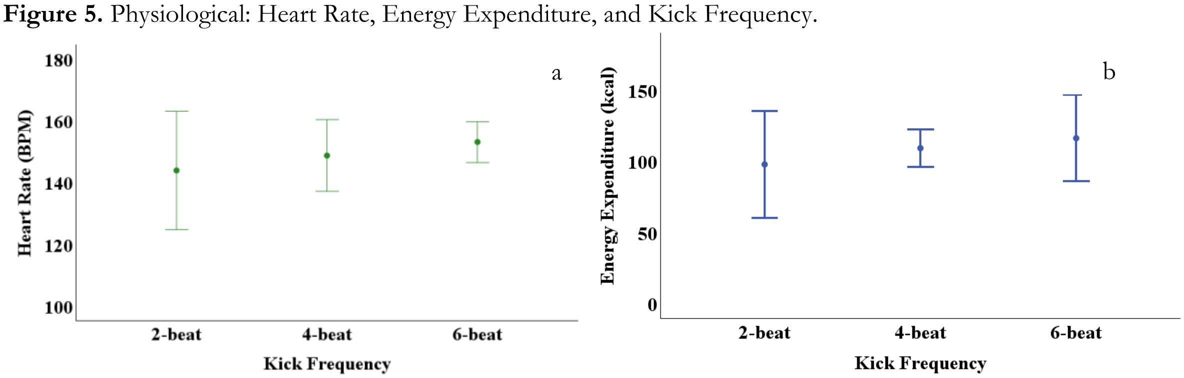
Figure 4. Biomechanics: Stroke Length, Stroke Rate, and Kick Frequency.



Physiological

Physiological variables were HR and EE collected from WHOOP 5.0. See Figures 5a and 5b for an illustrated diagram of estimated marginal mean differences across KF for physiological variables. Although not statistically significant, large effect sizes were seen for HR ($\eta^2_p = 0.246$) and EE ($\eta^2_p = 0.208$) across KF. Mean values followed a consistent direction pattern, with the 2-beat KF producing the lowest HR and EE and the 6-beat KF producing the highest.

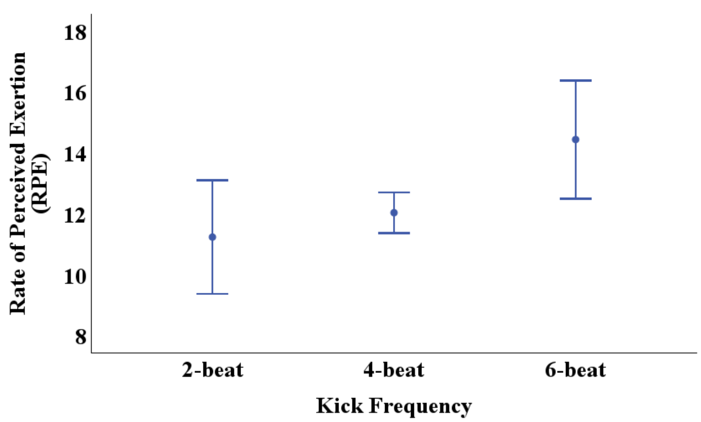
Figure 5. Physiological: Heart Rate, Energy Expenditure, and Kick Frequency.



Psychophysiological

Psychophysiological variables were defined as the subject-reported RPE. See Figure 6 for an illustrated diagram of estimated marginal mean differences across KF for psychophysiological variables. RPE demonstrated a large effect size across all KF ($\eta^2_p = 0.711$). RPE increases progressively with KF. Post hoc comparisons indicated that the 6-beat KF condition elicited higher perceived exertion than the 2-beat and 4-beat conditions, while no meaningful difference was observed between the 2- and 4-beat conditions.

Figure 6. Psychophysiological: Rate of Perceived Exertion and Kick Frequency.



Discussion

This exploratory study examined preliminary performance, biomechanical, physiological, and psychophysiological responses to the commonly executed KF in international-level 800 m freestyle swimmers. Collectively, the results suggest the 4-beat KF may offer a favorable balance across multiple domains, though findings should be interpreted as preliminary.

Optimal performance requires balancing performance, biomechanical, physiological, and psychophysiological variables. For men's and women's world record holders in the 800 m, both maintain consistent splits throughout the race [14, 15]. To achieve this performance, the KF must allow the swimmer to swim for an extended period consistently. While differences did not reach statistical significance, swimmers demonstrated the lowest mean TTCV under the 4-beat KF, accompanied by the lowest variability across trials. This trend suggests a potential ability to maintain more consistent pacing under a 4-beat KF, warranting further investigation. The first length (50 m) and the last length (800 m) were outliers in the world record performances race. Averaging the two performances, there were 3.27 s and 2.32 s differences between the middle lengths (100-750 m) and the first and last lengths, respectively [14, 15]. This suggests that for optimal performance, the swimmer must also retain sufficient energy (both physiologically and psychophysically) to increase speed during the final length. In the present study, swimmers reported no significant difference between RPE of 2- and 4-beat KF, whereas the 6-beat KF was significantly higher than both. Although physiological variables (HR and EE) did not differ significantly, mean values for the 4-beat KF tended to fall between the 2- and the 6-beat conditions, suggesting a possible balance between intensity and sustainability. Taken together, these observations suggest the 4-beat KF may allow swimmers to maintain race-appropriate intensity without disproportionately increasing perceived exertion. Elevated RPE associated with the 6-beat KF may limit a swimmer's ability to effectively execute the final length of the race, though this interpretation should remain cautious given the exploratory nature of this data.

In the present study, SR was measured in cycles/sec and SL in m/cycle, representing full arm cycles rather than individual strokes. Previous literature often report SR in Hz (strokes/sec) and SL in m/stroke, so a conversion must be used to make direct comparisons. Komar et al. [1] observed sprint specialists during 6x300m efforts and found the swimmer with the lowest energy cost possessed the lowest SR at 0.25 cycles/sec and the greatest SL at 4.88 m/cycle. Notably, while not significant, the 4-beat KF in the present study produced both the lowest mean SR (0.33 cycles/sec) and greatest mean SL (4.40 m/cycle), suggesting a potential favorable biomechanical pattern. The decreased SR and increased SL found in these sprint specialists compared to the distance specialists in the present study are likely a reflection of the pacing and event distance. This is supported by Morias et al. [6] during the analysis of 1500m performance in the LCM European Aquatic Championships, who recorded similar performance to that of the distance swimmers in this study at an SR of 0.31 cycle/sec and 4.18 m/cycle. Interestingly, average SL in the 2-beat KF of this study also produced an average SL of 4.10 m/cycle; potentially suggesting that lower KF may be preferentially adopted in the longer-distance events. The lower SR compared to that found by Morias et al. (2024) compared to the SR of 0.34 cycles/sec found in the present study was likely due to the increased distance of the 1500 m race compared to the 800 m.

Collectively, these preliminary findings suggest the 4-beat KF may support consistently fast split performance while avoiding excessive increases in perceived exertion. The moderate kicking demand of the 4-beat KF may optimize propulsion efficiency by maintaining longer SL without excessive metabolic cost, aligning with previous findings linking lower SR and higher SL to reduced energy expenditure. While this opposes previous research that found the 6-beat KF to be optimal, it is likely a reflection of the distinction of optimal performance for sprint and distance specialized techniques.

This study is not without limitations. It is preliminary with only six international, elite swimmers. The small sample size is inherent to elite swimmer research. The imbalance of male and female swimmers is also a limitation of this study, as previous research by Hawley et al. [2] has shown male SL of junior male swimmers to be greater than that of females. Analysis of this data indicates that future studies using similar protocols would be beneficial for the development of the 800 m freestyle technique. We found significant RPE differences between KF; however, there was no significance in HR or EE. Outcomes were derived from wrist-worn wearable technology, which provides practical field-based estimates but limits direct inference regarding metabolic cost. While individual variability should be considered, these preliminary data suggest that the 4-beat KF promotes pacing consistency and biomechanical efficiency in the 800m freestyle, offering a practical framework for training and race strategy. Conversely, the 6-beat KF was associated with greater RPE and a trend toward decreased pacing accuracy. This suggests that in the 800 m freestyle, the 6-beat KF may compromise efficiency relative to lower KF, though these trends require confirmation in larger samples.

Conclusions

Findings suggest that a 4-beat KF may promote pacing consistency and favorable biomechanical characteristics in 800 m freestyle swimming, without disproportionately increasing perceived exertion. Further research with larger sample sizes is required to confirm these preliminary observations.

Acknowledgements

The authors would like to thank the Kentucky Office of Vocational Rehabilitation (USA) for the use of their DJI Mini 3, the swimmers who participated in this study for their time and commitment, and the coaching staff who facilitated data collection.

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