Article

The Correlation Between Pedaling Rate and Gross Efficiency of Road Bike Cycling

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Abstract: To investigate the relation between the gross efficiency (GE) and the pedaling cadence (rpm) under different intensities of cycling. Methods: Ten amateur male cyclists were recruited. Each participant completed five tests, which were the maximal incremental test, functional threshold power (FTP) test and three multi-cadence ride tests. The three multi-cadence ride tests were conducted under different intensities of personal 90% FTP, 100% FTP and 105% FTP. A repeated measures 2-way ANOVA was adopted to compare the effects of intensity and gear ratio on GE. Pearson's correlation was conducted to investigate the relation between gross efficiency and cadence (rpm). Results: For the main effect of intensity, no statistically significant difference was shown. For the main effect of gear ratio, GE's values among gear 1 to gear 4 or 5 didn't show significant difference while the values in gear 6 or gear 7 mostly demonstrated significant difference to other gear ratio. By splitting the data according to cadence (e.g. 80, 85, 90 and 95 rpm), the original data of GE versus rpm would be divided into two groups. Through linear regression, the rpm data of 90 and lower showed no significant correlation with GE. Conversely, the rpm data higher than 90 were negatively correlated with GE. In the current study, we found that there is a turning point of rpm corresponding to a drop of exercise efficiency. And it seems not a certain cadence, but a range of cadence demonstrates an equivalent and personal optimal GE. Whether the cyclists should pedal at a rpm close to the turning point is valuable for further study.

Keywords: metabolic energy expenditure, cadence, work rate,

1. Introduction

1.1 Background

For most of the endurance exercise, one key factor of a high performance is to spend as little amount of metabolic energy as possible while executing a specific output (e.g. speed, power or intensity) during race. In other words, efficiency plays a key role for endurance exercise performance. During cycling, because the pattern of body movement is frequently associated with biomechanical issues as well as efficiency, one of the most common ways to minimize the energy cost is to adjust the cadence (Williams, 1985). For the past decades, numerous investigations have been done aiming to clarify the effects of pedaling cadence on cycling efficiency.

In previous studies, Seabury et al. (1977) first suggested that optimal cadence would change with power output. In their experiment, they found that the most efficient cadence increases with power output from 42 rpm at 40-48 W to 62 rpm at 326-328 W. They indicated that there is massive relevance between cadence and power output with the results from other research. Then, Foss and Hallen (2004) further supported the idea mentioned above with direct experimental data. In their study, six elite level male road cyclists were asked to conduct a submaximal and a maximal test under each four different cadences, which were 60, 80, 100 or 120 rpm in a randomized order on an ergometry. The results in the submaximal test showed that the efficiency determined byVO_2 increased with the increasing cadence from 60 rpm to 120 rpm at 0, 50, and 150 W. In addition, the optimal cadence differs under different intensities. At low workload (e.g. 0, 50, and 150 W), 60 rpm is the optimal cadence, while 80 rpm is better for high workload (e.g. 350 W). Based on this knowledge, it could partially explain why some investigations showed that the most economical cadence is around 50 rpm (Banister & Jackson, 1967; Chavarren & Calbet, 1999). In reality, there were previous studies

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Met opmerkingen [黃亮程2R1]: 原文如下：the best work economy, shifted from 60 rpm at 0 W to 80 rpm at 350 W (P<0.05)
實驗內容是用不同回轉數騎漸進式的測驗
在特定功率時會收攝氧量的資料，然後只用攝氧量來看哪個迴轉數較有效率

showed the most economical cadence can be relatively diverse, which range from 35-57 rpm, 80-90 rpm or 90-105 rpm, respectively (Coast & Welch, 1985; Hagberg et al., 1981; Widrick et al., 1992). In addition to power output, most of the research mentioned above were adopting different criteria, methods and devices (e.g. ergometer, cycling trainer etc.). In terms of difference in research devices, laboratory ergometer and commercial road bike were quite different in biomechanical demand as well as subsequently physiological load for cyclists. Namely, different devices might be associated to different optimal pedaling cadence. In reality, among those previous studies investigating the effects of pedaling cadence on efficiency, the results from using road bike as research data collecting devices seemed to be different from those of using ergometer.

1.2 Hypothesis of the study

There is an optimal cadence in road bike cycling, and it may differ due to different work rate.

1.3 Research Purposes

i. To investigate the existence of an optimal cadence for a specific work rate for road bike cycling system.

ii. To examine whether the optimal cadence varies with different work rate on a road bike cycling system.

2. Materials and Methods

2.1 Participants

Ten volunteer male amateur cyclists (age 21.1 ± 10.4 years, weight 71.4 ± 10 kg, height 178.1 ± 5.6 cm, FTP 183.6 ± 22.2 watts, peak oxygen uptake ($\dot{V}O_2peak$): 54.4 ± 6.7 mL · min^{-1} · kg^{-1}) were recruited in this study. All participants were given their written informed consent before participating in this study. All study procedure followed the Declaration of Helsinki and has been approved by the Institutional Review Board of National Cheng Kung University (Document No. A-ER-108-095).

2.2 Experimental Protocols

Each participant had their first visit to perform an incremental load test to volitional fatigue for the measurement of VO_2max, and the test is adapted from Buchfuhrer et al. (1983). After a 10- min warm-up at 100 watts (W), the test began at 150 W and had 25 W increment for every 5-min until exhaustion (level off in VO_2, RER ≥ 1.10, RPE of ≥18, and/or HR of ±10 bpm of the age-predicted maximum (220-age)). VO_2max was classified as the highest 1-min average VO_2 during the test (Figure 1).

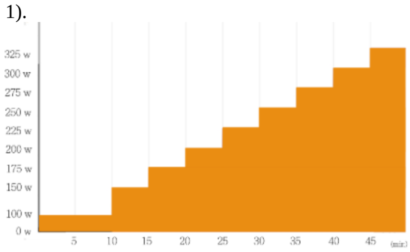

Figure 1. The protocol of the incremental cycling test for VO_2max.

During second visit, the participants conduct a functional threshold power (FTP) test to determine their exercise intensity for the following tests, and the protocol is shown in **Table 1**. Functional Threshold Power (FTP) is defined as the highest average power a person can sustain for approximately an hour, measured in watts.

Table 1. The testing protocol of functional threshold power test.

	Duration	Description
Warm up	10 min	Endurance pace
	3*1 min (1 min rest)	High cadence
	5 min	Easy pedaling
Main set	5 min	All-out effort
	10 min	Easy riding
	20 min	Test

After the VO_2max and FTP tests, each participant came to the lab for three other multi-cadence tests under different intensities (e.g. 90% FTP, 100% FTP, and 105% FTP). Before executing each intensity test, each participant was asked to make their own choice of personal favorite gear ratio and set it as gear no. 4. Then, based on gear 4, three lighter (e.g. gear no. 1, 2 & 3) and three heavier gear ratio setups (gear no. 5, 6 & 7) were selected for each individual testing protocol under a specific cycling intensity. Each test includes a 10-min warm-up and followed by seven repetitions of 3-min pedaling and 3-min recovery with randomized gear ratios order from personal seven gear ratios (**Figure 2**).

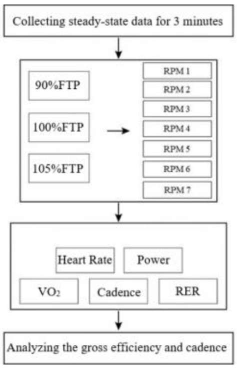

Figure 2. The protocol of pedaling cadence tests.

2.3 Data collections

Gas exchange values including RER, VO_2, and VCO_2 were measured with a gas analyzer (Metamax 3B, Cortex, Germany) during all tests and workout. Moreover, heart rate was also recorded during all tests and workout using a chest strap (Polar H10, Polar, USA). Work rate and cadence generated from the hub power meter (Powertap G3, Quarq – SRAM LLC, USA) were collected by a wearable device (Forerunner 945, Garmin, Taiwan). The GE was calculated using the data from power meter and Metamax 3B with the equation of energy transformation. All the tests were executed on the bike trainer (Kinetic Rock and Roll | Smart 2 Bike Trainer, Kinetic, USA) to simulate the real road cycling.

2.4 Statistical Analysis

Repeated-measures 2-way ANOVA analysis of variance (SPSS 17.0) with two factors [three intensities (90% FTP, 100% FTP and 105% FTP) × 7 gear ratios (no. 1 to 7)] were used to identify the effects of exercise intensities and cadence on different variables. Pearson's correlation was conducted to calculate investigate the relation between gross efficiency (GE) and cadence (rpm).

3. Results

The two factors (e.g. intensity and cadence) showed no significant interaction. For the main effect of intensity, no statistically significant difference was shown in GE (Figure 3). For the main effect of cadence, the values among gear 1 to gear 4 or 5 didn't show significant difference between each other while the values in gear 6 or gear 7 demonstrated significant difference to other gear ratio.

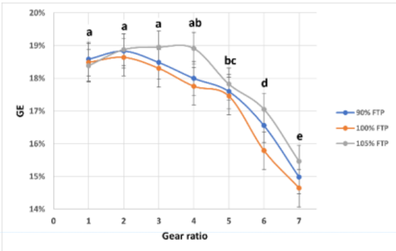

Figure 3. Gross efficiency (GE) of three different intensities and seven gear ratios. Data were shown as mean ± SD. [a-e] Data not sharing a common superscript are significant difference to each other.

Figure 4. illustrated the relation between cadence and GE. With the cadence getting higher, the GE declined progressively. Through observation, there seemed to be a turning point among the data set. Thus, we further divided the data according to a specific cadence (rpm), such as 80, 85 & 90 rpm (**Fig 5-7**). Then, the original data rpm versus GE would be divided into two groups. Through linear regression, the rpm data of 90 and lower had no significant correlation between rpm and GE. In other words, the corresponding GE of ≤ 90 rpm is basically the same. When using 95 rpm as data split point, the rpm data of 95 and lower had a negative regression with GE (R^2=0.1079, p<0.05); suggested a rpm of 95 is not the turning of rpm corresponding to a drop of GE (**Figure 8**).

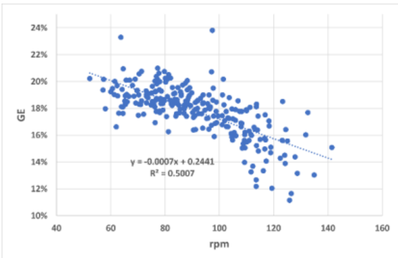

Figure 4. The relation between rpm and GE of all data.

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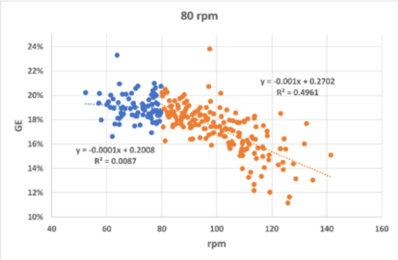

Figure 5 The relation of GE and RPM while using 80 rpm as a split point.

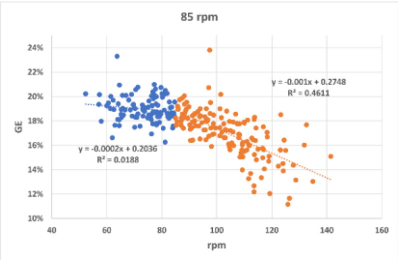

Figure 6 The relation of GE and RPM while using 85 rpm as a split point.

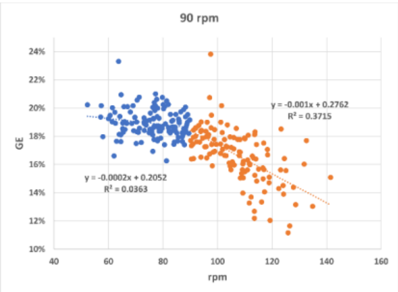

Figure 7. The relation of GE and RPM while using 90 rpm as a split point.

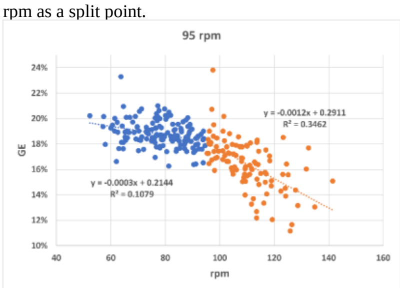

Figure 8. The relation of GE and RPM while using 95 rpm as a split point.

4. Discussion

The main finding of the present study was that the value of GE was significantly lower in gear 5 to 7 (from 94 to 120 rpm), meanwhile, the GE among gear 1 to gear 4 (from 68 to 93 rpm) didn't show statistical difference in every intensity. Suggesting that three cycling intensities did not affect GE performance, which is not match to our hypothesis. However, we verified there seemed to be a range of cadence but not a specific cadence before GE started to drop down.

Even though the GE lower than 90 is the same, choosing relatively high cadence can be beneficial for both training and competition (Paton et al., 2009). Furthermore, high-cadence riding is more preferred in the field condition (Marsh & Martin, 1993).. These results showed that there can be a threshold of cadence where the physiological status (e.g. GE) would acutely drop down. Thus, we suggested that there could be a turning point for the physiological condition when a certain cadence is reached.

In previous studies, several researchers have found other possibility of optimal cadence. Sacchetti et al. (2010) have also done research of the relation between cadence and efficiency in younger and older cyclists, indicating that while riding with 60 rpm, the GE had the peak value among young people. As for older subjects, they reached the peak value at 40 rpm, and there was no difference between two groups' peak GE value; implied that optimal cadence was not only affected by the level of the subjects, but also affected by the age. In addition, Brennan et al. (2019) also found that the metabolic cost was lowest at 60 rpm, but the cyclists preferred to ride a higher cadence at around 80 rpm under the same power output. Shastri et al. (2019) discovered that when cadence is over 70 rpm, the physiological data would have a turning point, too. Study of Formenti et al. (2019) agreed with the low cadence by determined the tissue saturation index. The results showed that at low cadence such as 40 and 50 rpm are better for skeletal muscle oxygenation comparing to high cadence (90rpm). Even though low cadence riding seemed to have a better GE, the force that needed for every pedal is relatively higher, which may have higher risk to cause cramp or muscle fatigue during long distance riding. By testifying with the linear regression, GE would dramatically drop down when reaching certain rpm, which we called the turning point in the present study. The range of the turning point may vary by several factors such as the level of the subjects or age. Before pedaling high enough to reach the cadence as well as the turning point, the GE would remain the same. Taken together, it is suggested that the cyclist maybe better to pedal as high as possible before reaching that turning point of GE.

5. Practical Applications

To sum up, a better GE did not match to a certain cadence, but a range. Once the cadence exceeded the range, the GE would start to drop dramatically. Whether the cyclists should pedal within the range of the turning point or somewhat higher than this turning point is remain unknown. To be more specifically, whether the sacrifice in GE can get other advantages on kinetics or neuro-muscular system would be worthy for further study.

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Gewijzigde veldcode

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