Efficiency Variation in Cycling Exercise Related to Cadence and Work Rate Standardized by Ventilatory Threshold

Yukio Fujita¹, Keisuke Koizumi¹, Motomu Manabe² and Jun Nomura³

¹Department of Sports sciences, Faculty of Education, Chiba University, 1-33 Yayoicho, Inage-ward, Chiba-city, 263-8522 Japan
E-mail: fuzzyta@faculty.chiba-u.jp
²Tokyo University of Foreign Studies, 3-11-1 Asahicho, Fuchu-city, 183-8534 Japan
³Department of School Health Nursing, Faculty of Education, Chiba University, 1-33 Yayoicho, Inage-ward, Chiba-city, 263-8522 Japan

[Received January 23, 2014; Accepted June 4, 2014; Published online June 25, 2014]

We investigated the influence of cycling cadence (60, 80 and 100 rpm) on the gross efficiency (GE), net efficiency (NE), work efficiency (WE) and apparent efficiency (AE) with different cycle exercise work rates standardized by ventilatory threshold (VT). Firstly, the participants (6 male young adults) performed 3 ramp exercise tests to determine ventilatory threshold (\(\text{VO}_2\text{@VT}\)) and AE at each cycling cadence. They then carried out 9 steady state tests (the combination of each work rate (50\%\(\text{VO}_2\text{@VT}, 75\%\(\text{VO}_2\text{@VT} and 100\%\(\text{VO}_2\text{@VT}\) and cycling cadence). There were no significant differences among the cycling speeds in AE during the ramp exercise. The oxygen uptake values during unloaded cycling exercise significantly increased related to the increments of cycling cadence (p < 0.01). In all steady work rates, GE, NE and WE were decreased associated with the increase of cycling cadence (p < 0.05). In all cycling cadence, each efficiency was heightened related to the magnitude of work rate below VT (p < 0.05). These results rearranged in terms of relative value to VT would provide significant basis for light exercise treatment like in active recovery.

Keywords: cycle exercise, efficiency, cadence, Ventilatory Threshold

1. Introduction

A number of previous studies have attempted to evaluate energy efficiency in cycle exercise. The factors which have been pointed out as to affect the efficiency are working parts of body (Bunc and Heller, 1991; Kang et al., 1997), muscle fiber type (Coyle et al., 1992; Barstow et al., 1996), type of training (Marsh et al., 2000; Boone et al., 2010), altitude acclimatization (Green et al., 2000), body mass (Berry et al., 1993), physical maturity (Rowland et al., 1990), type of exercise (Bahr et al., 1991; Passfield and Doust, 2000) and so on. Quite a few investigators also have studied interactions between the cycling frequency and the output power on mechanical efficiency during sub-maximum cycling exercise (Foss and Hallén, 2004; Lucia et al., 2004; Foss and Hallén, 2005; Pierre et al., 2006). The mechanical efficiency is basically estimated in terms of the magnitude of oxygen uptake (\(\text{VO}_2\)). Foss and Hallén (2004) measured \(\text{VO}_2\) at 60, 80, 100 and 120 rpm for different work rates ranging from 0 to 350 W, and showed the lowest \(\text{VO}_2\) was observed at 80 rpm for 350 W. This result seems comparable to a former study by Hagberg et al. (1981), which showed the most economical pedaling rate for competitive cyclists evaluated by “net \(\text{VO}_2\)” was 91 rpm (range 72-102 rpm) at 80% of maximum \(\text{O}_2\) consumption (\(\text{VO}_2\text{max}\)). These results can be interpreted that the rather low to middle level of cadence suit with the higher submaximum power output level. On the contrary, Pierre et al. (2006) showed the gross efficiency (GE) increased according with the increase in power output (range 40-160 W), whereas GE decreased with the increments of cycling cadence (range 40-120 rpm). Lucia et al. (2004) indicated significantly higher GE at 100 rpm than 60 rpm for 366 W.
The term efficiency is defined as the ratio of work accomplished to energy expended in the performing work, and GE is simply indicated with whole energy consumption. However, some of subtypes of the efficiency require to make so called “base-line” corrections. The net efficiency (NE) is defined as the ratio of the accomplished work to energy expended above rest (resting metabolism as base-line correction), while the work efficiency (WE) is defined as the ratio of the work to energy expended above unloaded (“0 W”) cycle exercise. The effectiveness of each definition has been discussed by several investigators (Francescato et al., 1995; Chavarren and Calbet, 1999; Moseley and Jeukendrup, 2001; Scheuermann et al., 2002; Ettema and Lorás, 2009), but have provided inconsistent conclusions. Hagberg et al. (1981), Francescato et al. (1995) and Foss and Hallén (2004) showed the influences of “0 W” cycle exercise, that the more the cycling frequency increased, the more energy expenditure was observed. The agreement strongly suggests that the estimate of “0 W” cycle exercise energy consumption is indispensable when the effect of cycling cadence on the efficiency is evaluated. Nevertheless, only a few literatures (Gaesser and Brooks, 1975; Berry et al., 1993, Hintzy-Cloutier et al., 2003) performed the comparison taking the issue into consideration. In addition, almost all previous studies were carried out at uniform work rates (such as 160 W, 350 W) without measuring the ability of endurance exercise for each participants, or at relatively high intensities (e.g. 85%, 93% VO₂max). It is well known that the constant work rates above ventilatory threshold (VT) do not provide steady-state physical condition. To study the efficiency during the steady-state exercise, the work rates have to be set below the VT level of each participant. It seems only by making use of the qualified criteria which should set off the multiplicity of the individual ability, the efficiency in the long-term exercise can be actually evaluated. Additionally, the long-term moderate exercise standardized by VT or lactate threshold (LT) has been used as a positive treatment after an intensive exercise bout (Active recovery; Fujita et al. (2009), Mukaimoto et al. (2014)). Koizumi et al. (2011) indicated the improved performance after the recovery exercise at 40%VT, concomitant with the decrease in blood lactate concentration and increased muscle oxygenation level. It is of particular interest how the efficiency changes from the light to moderate cycle exercise within VT level, in relation to the active recovery effect. From this point of view, the precise rearrangement in terms of the relative intensity value to VT against the efficiencies could provide significant basis, claiming physiological accuracy.

Therefore, the purpose of the present study was to determine the effect of cycling cadence on the efficiencies (especially WE) at the steady-state physical intensities below each participant’s VT, and to compare the effect of work rates.

2. Methods

2.1. Participants

Six well-conditioned males between 21 and 23 years of age participated in these experiments. The participants’ age, height and body mass were 22.4 ± 0.83 yrs, 172 ± 5.9 cm and 64.6 ± 7.2 kg (mean ± SD), respectively. All participants were physically active and trained at least 4 days per week in the 6 years prior to the study. They were all minor level players who had been associated with minor prefutural collegiate league (2 baseball players, 2 soccer players and 2 track and field players). None of the participants was a smoker, habitual drinker, or took any medications or nutritional supplements known to affect energy metabolism. After the participants were explained possible risks involved and discomforts related to the experiments, voluntary written consent was obtained from each participant. This study was approved by the local University Institutional Review Board and undertaken in accordance with the Declaration of Helsinki.

2.2. Ramp exercise tests

The participants reported to the laboratory on 12 separate occasions intervened by 2-3 days over a 6-week time frame. They were requested not to participate in any vigorous activities on the day before each trial. The experiments were conducted in a laboratory with air-conditioning, and room temperature and relative humidity were maintained at 19-22°C and 50-60% throughout the experiments. During the first 3 visits, incremental ramp exercise tests (Figure 1) were performed by using an electromagnetically controlled cycle ergometer equipped with 170 mm crank arms (High power ergometer, Takei Co. LTD,
Tokyo, Japan). After a 5 min resting period sitting on the cycle ergometer, followed by a warm-up exercise at a work rate of 0.8 W/kg Body Mass (W/kgBM) for 3 min, the participants performed ramp exercises with an incremental loading rate of 0.36 W/kgBM every min, at 60, 80 and 100 rpm respectively. All tests were performed until the participants reached volitional exhaustion.

The participants breathed room air through a face mask, which was connected to a hot-wire flowmeter and to rapidly responding O₂ (Zirconia) and CO₂ (infra-red) analysers by fine suction tubing at a sampling rate of 250 ml·min⁻¹. The mechanical dead space of the system including the face mask and flowmeter was 0.2 l. All gas exchange variables were continuously measured throughout the testing period (at rest, warm-up and ramp exercise) by using a data acquisition and processing system on a breath-by-breath basis (AE-280, Minato Medical Science, Osaka, Japan). Before each test, the volume detection transducer was calibrated by strokes with a 2-1 syringe; the gas analyzers, with two mixtures of gases of known oxygen and carbon dioxide concentrations. The electrocardiogram was monitored on an oscilloscope and heart rates were also continuously recorded. From plots of the gas exchange criterion variables against time, oxygen consumption levels at each VT were determined (VO₂@VT) through the tests by both the V-slope and VE/VO₂ methods, as well as detecting abrupt increasing points in the respiratory exchange ratio and FETO₂ (Wasserman et al., 1973; Okano et al., 2006). From the values of VT and the resting level, the net VO₂ (resting metabolism was subtracted as base-line correction) levels of 50%, 75% and 100% (equal to VO₂@VT) of each VO₂@VT determined at each cycling cadence were calculated respectively as “Target” steady-state physical intensities. The delta efficiency (DE) is originally defined as:

$$\varepsilon_d = \Delta \text{power} / \Delta \text{metabolic rate},$$

where $\Delta$power and $\Delta$metabolic rate stand for increment of power and metabolic rate with increasing work rate (Ettema and Lorås, 2009). This efficiency can be measured during both the step up tests and ramp incremental tests, and the latter has been called the apparent efficiency (AE). We calculated the value as the inverse of the slope of the regression line obtained in each ramp exercise test.

### 2.3. Steady-rate exercise tests

The steady-rate exercise tests were performed during the remaining 9 laboratory visits. Figure 2 shows the experimental protocol of the steady-rate test at the “Target” steady-state physical intensity. After the participants rested on the cycle ergometer for 5 min, they exercised at a work rate of “0 W” prior to each steady-rate test for 5 min. The steady-rate exercise tests were then performed at the designated physical intensities, where the “Target” 50%, 75% and 100% of each VO₂@VT physiological steady-state were obtained at 60, 80 and 100 rpm for 10 min in total. The work rates were gradually increased so that the VO₂ values reached and did not exceed the “Target” levels within the initial 5 min.
Once the “target” levels confirmed, the work rate kept a constant value within the remaining 5 min. The prescribed cycling cadence was unchanged throughout the testing period. The mean \( \text{VO}_2 \), \( \text{VO}_2 \) and RER were calculated from the data during the last 2 min of the tests, and the efficiencies were calculated by means of each definition (GE, NE and WE). The rate of energy expenditure was calculated from the thermal equivalent values of oxygen for non-protein respiratory quotient. The cycling cadence order of the testing was randomly assigned in each category (ramp and steady-rate).

2.4. Statistical analysis

Results are shown as means \( \pm \) SD. The difference in the efficiency value among the work rates and cycling frequencies was analyzed by a two-way analysis of variance. A level of \( p < 0.05 \) was accepted as statistical significance. All statistical analysis were performed by using Microsoft Excel 2007 for Windows (R) (Microsoft Co., Ltd., Seattle, USA) with a statistical add-in package software (Ekuseru-Toukei Ltd., Tokyo, Japan)). To examine where significant differences existed, all pairwise comparisons by means of the Tukey’s method of multiple comparisons were applied.

3. Results

All exercise tests were performed without any complications. The only symptoms the participants experienced were leg fatigue or shortness of breath. The influences of cycling cadence on the data of peak\( \text{VO}_2/kgBM \), \( \text{VO}_2/VT/kgBM \) and the net percentage (resting metabolism was subtracted) of \( \text{VO}_2/VT \) to peak\( \text{VO}_2 \) (%peak\( \text{VO}_2 @ VT \)) are given in Table 1. Despite \( \text{VO}_2/VT/kgBM \) demonstrated slightly increasing values according with the increments of cycling cadence, there were no significant differences among \( \text{VO}_2/VT/kgBM \) values obtained at each cycling cadence. There were no significant differences among the values of peak\( \text{VO}_2/kgBM \) and %peak\( \text{VO}_2 @ VT \).

Table 2 presents the relationships among the cycling frequencies, work rates and efficiencies in each definition (AE during the ramp tests, GE and NE during the steady-rate tests). There were no significant differences in AE. At 60 rpm, the value of 100%\( \text{VO}_2/VT \) was significantly greater than that of 50%\( \text{VO}_2/VT \) (\( p < 0.01 \)) and 75%\( \text{VO}_2/VT \) (\( p < 0.05 \)) in GE, and 100%\( \text{VO}_2/VT \) was significantly greater than 50%\( \text{VO}_2/VT \) (\( p < 0.01 \)) in NE. At 80 rpm, 100%\( \text{VO}_2/VT \) was significantly greater than 50%\( \text{VO}_2/VT \) (\( p < 0.01 \)), while 75%\( \text{VO}_2/VT \)

Table 1  Peak\( \text{VO}_2/kgBM \), \( \text{VO}_2/VT/kgBM \) and %peak\( \text{VO}_2 @ VT \) at each cycling cadence

<table>
<thead>
<tr>
<th>Cadence</th>
<th>Peak( \text{VO}_2/kgBM ) (ml kg(^{-1}))</th>
<th>( \text{VO}_2/VT/kgBM ) (ml kg(^{-1}))</th>
<th>%peak( \text{VO}_2 @ VT )</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>60 rpm</td>
<td>50.4 ± 6.62</td>
<td>37.3 ± 7.44</td>
<td>73.7 ± 6.12</td>
<td></td>
</tr>
<tr>
<td>80 rpm</td>
<td>50.9 ± 7.95</td>
<td>38.0 ± 7.05</td>
<td>74.5 ± 4.04</td>
<td></td>
</tr>
<tr>
<td>100 rpm</td>
<td>50.5 ± 7.33</td>
<td>39.6 ± 7.06</td>
<td>78.4 ± 5.49</td>
<td></td>
</tr>
</tbody>
</table>

Data are means \( \pm \) SD.

Table 2  Apparent efficiency in ramp procedure, Gross and Net efficiency in steady-rate exercise at each condition

<table>
<thead>
<tr>
<th>Pedaling rate</th>
<th>Apparent efficiency (%</th>
<th>%( \text{VO}_2 @ VT )</th>
<th>Gross efficiency (%)</th>
<th>Net efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 rpm</td>
<td>29.1 ± 2.39</td>
<td>50%</td>
<td>11.5 ± 2.67</td>
<td>14.4 ± 2.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75%</td>
<td>14.5 ± 1.70</td>
<td>17.1 ± 2.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>18.2 ± 1.20**</td>
<td>20.8 ± 1.49**</td>
</tr>
<tr>
<td>80 rpm</td>
<td>31.5 ± 3.63</td>
<td>50%</td>
<td>7.10 ± 2.10&quot;</td>
<td>8.82 ± 2.21&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75%</td>
<td>13.0 ± 2.55**</td>
<td>15.2 ± 2.72&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>15.5 ± 1.08**</td>
<td>17.6 ± 0.956&quot;</td>
</tr>
<tr>
<td>100 rpm</td>
<td>32.7 ± 2.89</td>
<td>50%</td>
<td>5.39 ± 1.09&quot;</td>
<td>6.69 ± 1.33&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75%</td>
<td>7.87 ± 2.04&quot;</td>
<td>9.03 ± 2.31&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>12.6 ± 2.42&quot;**</td>
<td>14.2 ± 2.44&quot;**</td>
</tr>
</tbody>
</table>

Data are means \( \pm \) SD. * and § in the table show significant difference in each frequency (*: vs 50%\( \text{VO}_2/VT \) and §: vs 75%\( \text{VO}_2/VT \)). Similarly, † and ‡ show significant difference in each work rate (†: vs 60 rpm and ‡: vs 80 rpm). Two symbols show \( p < 0.01 \), and a symbol shows \( p < 0.05 \).
being greater than 50% VO₂@VT (p<0.01) in both GE and NE. At 100 rpm, 100% VO₂@VT was significantly greater than 50% VO₂@VT (p<0.01) and 75% VO₂@VT (p<0.01) in both GE and NE. When compared the cycling frequencies at 100% VO₂@VT, the value of 100 rpm was significantly larger than 60 rpm in GE, and 100 rpm was significantly larger than 60 rpm (p<0.01) and 80 rpm (p<0.05) in NE. At 75% VO₂@VT, the value of 100 rpm was significantly greater than that of 60 rpm (p<0.01) and 80 rpm (p<0.05) in both GE and NE. At 50% VO₂@VT, 100 rpm was significantly greater than 60 rpm (p<0.01), while 80 rpm being significantly greater than 60 rpm (p<0.01) in both GE and NE.

Figure 3 shows the relationship between the cycling cadence and VO₂/kgBM at the work rate of “0 W”. The data showed significantly increasing values according as the increments of cycling cadence (p<0.01). The values of WE in each work rate as a function of cycling cadence are presented in Figures 4A, 4B, and 4C. At 50% VO₂@VT, the value in 60 rpm was significantly higher than that in 80 rpm and 100 rpm (p<0.05) in WE. At 75% VO₂@VT and 100% VO₂@VT, 60 rpm was significantly higher than 100 rpm (p<0.05). Figures 5A, 5B, and 5C display the relationships between the work rates and WE in each cycling cadence. When compared the work rates at 60 rpm, the value in 100% VO₂@VT was significantly greater than that in 50% VO₂@VT.

**Figure 3** Comparisons of VO₂/kgBM at a work rate of “0 W” in each cycling cadence. Data are means (± SD). The data showed significantly increasing values as cycling cadence increased (**: p<0.01).

**Figure 4** The relationships between cycling cadence and Work efficiency (WE) in each work rate (A: 50% VO₂@VT, B: 75% VO₂@VT, and C: 100% VO₂@VT, respectively). Data are means (± SD). At 50% VO₂@VT, 60 rpm was significantly higher than 80 rpm and 100 rpm (**: p<0.05). At 75% VO₂@VT, 60 rpm was significantly higher than 100 rpm (: p<0.05). At 100% VO₂@VT, 60 rpm was also significantly higher than 100 rpm (: p<0.05).

**Figure 5** The relationships between work rate (% VO₂@VT) and Work efficiency in each cycling cadence (A: 60 rpm, B: 80 rpm, and C: 100 rpm, respectively). Data are means (± SD). At 60 rpm, 50% VO₂@VT was significantly lower than 100% VO₂@VT (: p<0.05). At 80 rpm, 50% VO₂@VT was significantly lower than 75% VO₂@VT and 100% VO₂@VT (**: p<0.01). At 100 rpm, 50% VO₂@VT and 75% VO₂@VT were significantly lower than 100% VO₂@VT (**: p<0.01).
(p < 0.05). At 80 rpm, 100% \( \bar{V}O_2 \)@VT was greater than 50% \( \bar{V}O_2 \)@VT (p < 0.01), while 75% \( \bar{V}O_2 \)@VT being greater than 50% \( \bar{V}O_2 \)@VT (p < 0.01). At 100 rpm, 100% \( \bar{V}O_2 \)@VT was greater than 50% \( \bar{V}O_2 \)@VT and 75% \( \bar{V}O_2 \)@VT (p < 0.01) in WE.

4. Discussion

4.1. The influences on the efficiencies at different cycling cadence

The effects of 3 different cycling cadence on the efficiencies at 3 individual steady-state physical intensities below VT were examined in the present study. The results demonstrated that both GE and NE, together with WE tended to decrease associated with the increments in cycling frequency within 60 to 100 rpm, however, no significant differences were shown in AE among the frequencies.

Regarding GE, Berry et al. (1993), and Chavarren and Calbet (1999), Foss and Hallén (2005) and Pierre et al. (2006), each showed decreasing values according with increasing cycling cadence. In contrast, Coast et al. (1986) demonstrated minimum GE at 60 or 80 rpm (range 40-120 rpm) for 100, 150, 200, 250 and 300 W. Lucia et al. (2004) also showed significantly smaller GE at 60 rpm for the continuous work at 350 W. As for NE, Gaesser and Brooks (1975), and Berry et al. (1993) demonstrated decreasing values concomitant with the increments of cycling cadence in NE, which coincided with the results of Zoladz et al. (1998) in “net \( \bar{V}O_2 \)” where the resting oxygen consumption was subtracted. Some investigations showed increasing energy expenditure at “0 W” related to the increasing cycling cadence (Sidossis et al., 1992; Francescato et al., 1995; Foss and Hallén, 2004). The energy for internal work can not be ignored especially at the higher movement speed. The increased “0 W” energy in the higher frequency may relate to the underestimation of the values of both GE and NE, and the results in the present study supported the tendency in GE and NE which have been shown in almost all previous studies.

With regard to the delta efficiency (DE) and AE, there are some varieties in the methodology of the computation which may affect the calculated values. Sidossis et al. (1992), andNickleberry and Brooks (1996) calculated DE by means of the slope of regression lines which describe the change in energy expended (\( \Delta E \)) relative to the change in work accomplished (\( \Delta W \)). Similarly, multiple steady-state exercise test has been conducted where the work rates progressively increased step by step. Gaesser and Brooks (1975) computed DE as the values between the each pair of adjacent cycling frequencies from the data obtained at each work rate. In addition, Boone et al. (2010) calculated the value of \( \Delta \bar{V}O_2/ \Delta W \) during a ramp protocol (ramp25), which would be regarded as the inverse number corresponding to AE. Another considerable factor that may influence the results of DE is the magnitude of performed work rate. Nickleberry and Brooks (1996) found smaller values with the increments of cycling cadence in the work rates ranging from 50 W to 75% \( \bar{V}O_2 \)peak, which were consistent with the results of Gaesser and Brooks (1975) at 400 kgm·min\(^{-1}\) (65.4 W). On the contrary, Sidossis et al. (1992) reported that the DE values were especially changed at the higher cadence with the exercise intensities compared with the DEs that Sidossis et al. (1992), and Nickleberry and Brooks (1996) had measured.

Our findings on WE were consistent with the results of Gaesser and Brooks (1975) who found reduced WE at the higher cycling frequencies. Berry et al. (1993), however, showed different results between two cycling frequencies. At 25 W, they found greater values of WE at 90 rpm than those at 60 rpm, whereas at 100 W, the results were reversed. Gaesser and Brooks compared WE at four different work rates from 200 kgm·min\(^{-1}\) (32.7 W) to 800 kgm·min\(^{-1}\) (131 W) and showed similar results. It seems there is not much difference in the range of work rate between these studies. Nevertheless, their conclusions contradicted each other. One can be speculated for the disagreement that the sexual difference between the subject groups considerably affected the results. Betty et al. (1993) measured WE in 50 females ranged from 41.5 kg to 98.9 kg of body mass, whereas Gaesser and Brooks (1975) performed the experiments on twelve “well-conditioned” males. It is also possible to point out that wide-ranging body weight may have varied the relative intensities, when the same absolute work
rates are given to all subjects. The participants in the present study carried out the steady-rate exercises standardized by their physical capacities, which may appreciably reduce the deviation of relative intensities.

4.2. The efficiencies at different work rates below VT

Chavarren and Calbet (1999) found that GE improved with increasing exercise intensity from 54% to 93%\(\text{VO}_2\)max, regardless of the pedaling frequency. The results are consistent with the findings of Moseley and Jeukendrup (2001) who showed lower GE at lower work rates ranging from 95 to 305 W at 80 rpm. In contrast, Sidossis et al. (1992) concluded that GE did not differ with the increments of work rate (from 50% to 90%\(\text{VO}_2\)max) at 60 and 80 rpm, while at 100 rpm, GE increased progressively as work rate increased. Several groups (Seabury et al., 1977; Hagberg et al., 1981; Coast and Welch, 1985) investigated optimum pedaling frequency by regressing the relation between the frequency and energy expenditure to either the parabolic or quadratic function. Some of them referred to the relation between optimum frequency and work rate, and indicated that the optimum frequency increased with the increments of work rate, however, these studies were conducted by means of \(\text{VO}_2\) or energy expenditure (i.e., the output values only). Our results of GE, NE and WE are consistent with the results of Chavarren and Calbet (1999), and Moseley and Jeukendrup (2001), showing the greater values of these efficiencies at the greater work rates. Even so, it seems the previous authors have used relatively high work rates, so that they aimed at evaluating the costs with the notion of competitions. It might be speculated that the work rates at 90% and 93%\(\text{VO}_2\) max, and 305 W were higher than the VT levels of the subjects in those studies. It is generally accepted that the steady-state physical condition is not maintained at the higher work rates above VT, resulted in an upward drift in \(\text{VO}_2\), \(\text{VCO}_2\), VE and blood lactate concentration. Obviously, there must be undesirable influences on the values of efficiencies when experiments are performed for prolonged periods at higher intensities than VT. For this reason, it should be inappropriate to compare the efficiencies between the values below VT and those above VT.

Among the previous studies, Pierre et al. (2006) evaluated GE at relatively lower work rates (range 40-160 W). They concluded as work rate increased, GE increased, while GE decreased related to the increase of cycling cadence. Likewise Hintzy-Cloutier et al. (2003) showed significantly higher WE at 120 W than 80 W. These work rates could be speculated as intermediate levels which would not widely exceed VT, and their results are in accordance with the present study. McDaniel et al. (2002) determined the metabolic cost at 4 pedaling frequencies (40, 60, 80 and 100 rpm) at 3 different work rates below lactate threshold (LT) level. Prior to the main testing, the participants performed a stepwise incremental procedure for evaluating individual power outputs commensurate to 30, 60 and 90% of LT. However the estimation was carried out only at 100 rpm. It would be uncertain whether the magnitudes of the power at 100 rpm is applicable to those at every single pedaling frequency. We estimated, therefore, the VT levels during incremental ramp exercise tests at each pedaling frequency. The “steady-rate” exercise tests were also performed individually at the “Target steady state” physical intensity on nine occasions.

With regard to the effects of fiber type patterns on the efficiencies, Suzuki (1979) indicated that the subjects with a higher percentage of slow-twitch fibers recorded lower DE at a higher pedaling frequency of 100 rpm. On the contrary, Coyle et al. (1992) found the values of the Type I fibers were positively correlated with those of DE and GE, showing conflicting results. However it seems the muscular type characteristics were not biased in the participants as a whole in the present study. Moreover, since the work rates used in the present study were all below VT, the recruitment of Type II fibers would not practically occur during the experimental trials. Therefore the results could be applicable to the individuals who are diverse in fiber types, and would suggest that the higher efficiency at the higher work rate is derived with the magnitude of rate coding in Type I fibers. The effect of active recovery has been evaluated with light to moderate exercise intensity standardized by VT (Koizumi, K., et al. (2011)) or LT (Mukaimoto, T., et al. (2014)), and showed lower blood lactate concentration with the active condition. Mukaimoto, T., et al. (2014) also compared 50%, 70% and 100%LT and showed the lower the intensity, the lower the lactate concentration. In the present study, WE showed sig-
significantly lower value in 50% VT compared to the higher intensities of 75% and 100% VT. The lactic acid generated in the Type II fibers transfers to the Type I fibers within the proper muscle and out to the other muscles where it is oxidized. It can be speculated that the lower efficiency is more efficient in consuming lactic acid as an energy resource during the resting period. In any case, it is of particular interest whether the faster speed of movements (with lower force) requires the more fast-twitch fiber contribution. Ahlquist et al. (1992) compared the degree of contribution of each fiber type making use of glycogen depression levels, and indicated an increased recruitment of Type II fibers in lower (50 rpm) pedaling frequency than higher (100 rpm). Nevertheless, the comparison between the combination of high frequency and low force, and that of low frequency and high force, in the recruitment levels of both type I and type II has not been precisely elucidated yet. Hence future studies need to examine a wider range of pedaling frequencies to determine the optimum speed for WE at each work rate, and to inspect the relationships between those and fiber type contributions.

In conclusion, the present study showed that the efficiencies of cycle exercise at steady-state physical intensities below VT were affected by both cycling cadence and work rate. The GE, NE and WE were decreased associated with the increments of cycling cadence ranging from 60 to 100 rpm. These efficiencies showed increasing values with the increase in work rates which were standardized by each subject’s VT.

References

Name:
Yukio Fujita

Affiliation:
Department of Sports sciences, Faculty of Education, Chiba University

Address:
1-33 Yayoicho, Inage-ward, Chiba-city, 263-8522 Japan