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Characteristics of power output during supramaximal cycle ergometer exercise in first- and third-grade male Japanese high school cyclists

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Abstract:

Purpose: The purpose of this cross-sectional study was to clarify the characteristics of power output in first- and third-grade high school cyclists.

Methods: Forty-three male high school cyclists (first grade: 15.6 ± 0.5 years, n = 20; third grade: 17.3 ± 0.5, n = 23) participated in this study. The maximal anaerobic power test was conducted at three different loads using an electrically braked cycle ergometer, and maximal anaerobic power, optimal load, and optimal cadence were determined. The subjects' isokinetic knee extensor and flexor muscle strengths were measured at 180°/sec in an isokinetic dynamometer.

Results: The maximal anaerobic power value of the third-grade cyclists was significantly higher than that of the first-grade cyclists (1116.2 ± 131.8 vs. 946.6 ± 106.5 W, Effect Size (ES) = 1.40, $p < 0.01$). There was no difference in optimal cadence between the two grades, whereas optimal load was significantly higher in third-grade cyclists than first-grade cyclists (9.4 ± 0.8 vs. 8.2 ± 0.7 kp, ES = 1.61, $p < 0.01$). Both muscle strengths were significantly higher in third-grade cyclists than first-grade cyclists. In all subjects, muscle strengths were significantly correlated with optimal load (knee extension and flexion; r = 0.670 and r = 0.466, respectively, $p < 0.01$).

Conclusion: It is suggested that the higher maximal anaerobic power resulting from greater optimal load in third-grade high school cyclists is related to greater upper leg muscle strength, compared with that of first-grade high school cyclists.

Keywords: maximal anaerobic power, force-velocity relationship, junior athletes, cyclists

1. Introduction

In sprint events in track cycling, power output greatly influences sprint performance (Dorel et al. 2005). Elite sprint cyclists have a higher level of maximal anaerobic power (MAnP) output (1533-2063 W) (Dorel et al. 2005; Gardner et al. 2007) compared with amateur sprint cyclists (1241 ± 266 W) (Davies and Sandstrom 1989). In sprint cyclists ranging from local to elite levels, higher peak power (High vs. Low; 1646 W vs. 1050 W) resulted in a faster performance in 25 m short sprinting (High vs. Low; 4.140 s vs. 4.817 s) (Stone et al. 2004). Because power comprises two factors, force and velocity, the increase in force and/or velocity results in improved power output. In cycle ergometer measurements, a parabolic shape regression between load (or cadence) and power has been obtained since there is a linear regression between load (force factor) and cadence (velocity factor). The highest value of the parabolic shape is MAnP, which is calculated using optimal load (Lopt) and optimal cadence (Copt). These are equal to the half of maximal load (Lmax, which is the maximal load at zero cadence) and that of maximal cadence (Cmax, which is the maximal cadence at zero load), respectively (Driss and Vandewalle 2013).

Copt was 110 revolutions per minute (rpm) in untrained healthy adults (27.4 ± 4.4 years) (Sargeant et al. 1981). Meanwhile, the average Copt value was obtained at 132 ± 3 rpm in young male amateur sprint cyclists (Davies and Standstrom 1989) and at 129 ± 6 rpm in elite sprint male cyclists (Dorel et al. 2005; Gardner et al. 2007). There was no reported difference in Copt between elite and amateur sprint cyclists, although Copt in these cyclists is higher compared with that of untrained healthy adult. Thus, the magnitude of MAnP would be determined by that of Lopt in cyclists. Indeed, MAnP was strongly correlated with Lopt (r = 0.91), but not with Copt, even in elite sprint cyclists (Dorel et al. 2005). Meanwhile, as a result of conducting a 13-week aerobic training program for 10-11 year-old non-cyclist boys and girls, MAnP was significantly higher in trained group compared with control group at the end of the training period (Obert et al. 2001). In addition, although there was no change in Copt, Lopt in trained group was significantly improved at the end of training period (Obert et al. 2001). From the above, similar trends with elite cyclists were obtained for non-cyclist children.

MAnP increases with growth. A previous study demonstrated that Lopt was explained linearly by lean leg volume ($R2 = 83\%$, $p < 0.05$), whereas Copt was explained linearly by leg length ($R2 = 55\ \%$, $p < 0.05$) in 7.5- to 17.5-year-old non-cyclist boys (Martin et al. 2004). As there was no major change in height during 15-17 year-old boys (15 vs. 17 years old; 171 ± 7 vs. 173 ± 5 cm) (Saavedra et al. 1991) or the growth of height during 14-20 year-old boys slowed down (8-10, 10-12, 12-14, 14-16, 16-18 and 18-20 years old; 135 ± 8, 144 ± 6, 155 ± 8, 169 ± 9, 175 ± 7 and 173 ± 7 cm) (Dore et al. 2005), there would be no big difference in Copt between freshman and senior high school boys. Meanwhile, in addition to the increase in lean leg volume with growth (Martin et al. 2004), proper training could increase muscle volume and strength even in adolescent age (14-18 years) (Harries et al. 2016). Therefore, we hypothesized that, in male high school cyclists, the increase in Lopt results in the improvement of MAnP, with the force factor mainly influencing MAnP. Although a longitudinal study is eventually needed to prove this, initially, the purpose of this cross-sectional study was to clarify the characteristics of power output in first- and third-grade high school cyclists.

2. Methods

Subjects

Forty-three well-trained male high school cyclists (first grade, 15.6 ± 0.5 years: n = 20; third grade, 17.3 ± 0.5 years: n = 23) participated in this study. All subjects started competition cycling from entering high school, and they trained for 2-3 hours per day, six to seven times a week. Thus, since the competition history of all subjects was controlled in this study, we carried out this research for a homogeneous population. The mean age, height, and weight and the 1-km time trial (1-km TT) records of the two groups are shown in Table 1. All subjects and their parents gave written consent to participate after being fully informed of the study protocol, procedures, and risks. All procedures performed in studies involving human participants were in accordance with the ethical standards of the Ethics Committee of Juntendo University (Japan) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Table 1 Physical characteristics of first and third grades

	Age (years old)	Height (cm)	Weight (kg)	1-km TT (sec)
First grade (n=20)	15.6 ± 0.5	170.1 ± 4.4	57.2 ± 4.6	82.7 ± 3.2
Third grade (n=23)	17.3 ± 0.5**	169.7 ± 5.5	64.3 ± 5.2**	73.5 ± 4.2**

Values are mean ± standard deviation.
**P<0.01 vs. first-grade cyclists

Experimental design

Physical fitness (MAnP and muscle strength) measurements were conducted from September to December, half a year after the enrollment in high school, for the first-grade cyclists and from May to July for third-grade cyclists from 2015 to 2017. Additionally, the subjects' MAnP and muscle strength were measured in random order on the same day with an interval of more than 30 minutes.

The 1-km TT records of all subjects were adopted as the season's best records at the same year of physical fitness measurements in officially accredited competitions held outdoors. The gear ratio at the 1-km TT was determined by individuals.

MAnP test

The MAnP test was conducted using an electrically braked cycle ergometer (Powermax V3; Combi, Tokyo, Japan). For the MAnP test, the subjects warmed-up on the cycle ergometer at 1.5 kp for 5 minutes at 60-70 rpm and then sprinted at 3 kp for 5 seconds. Then, the MAnP test was conducted at three different loads ranging from 3 to 10 kp. Based on the three different loads and cadences, the relationship between load and cadence was represented by a linear regression equation for each subject ($Y = -aX + b$, $a > 0$, $b > 0$, a: slope, b: intercept). The power output in each load was calculated using the following formula:

Power output (W) = Work (J) / Time (sec)

Work (J) = Force × Distance

Force = Load (kp) × Gravity acceleration (m/s2)

Distance = Cadence (rpm) × 6 (m/one crank revolution)

= Load (kp) × 9.8 (m/s2) × Cadence (rpm) × 6 (m)

Power output (W) = Load (kp) × 9.8 (m/s2) × Cadence (rpm) × 6 (m) / 60(sec)

= Load (kp) × Cadence (rpm) × 0.98

After calculating the power output in each load, MAnP was determined for each subject based on the linear regression equation for the three pairs of loads and cadences using the least-squares method described by Nakamura et al. (1985). Lopt and Copt were calculated using the following formulae:

$$Lopt = b/2a$$

$$Copt = b/2.$$

The relative MAnP and Lopt were calculated by dividing body weight by the absolute MAnP and Lopt values.

Knee extensor and flexor muscle strength

For the isokinetic knee extensor and flexor muscle strength measurement, subjects were seated (hip joint angle: 85°) in an isokinetic dynamometer (BIODEX System 3; Biodex Medical System, Shirley, NY, USA), with the axis of the knee joint aligned with the center of the rotation of the dynamometer and the lower leg secured to the lever arm just proximal to the ankle. Muscle strength measurements were conducted with the upper and lower body fixed by strapped.

To measure muscle strength, subjects performed bilateral isokinetic knee extension and flexion in each of the five trials at 180°/sec, from full flexion (90°) to full extension (0°). The highest values of the right and left legs were recorded separately, and knee extensor and flexor muscle strengths were adopted by averaging the values of the right and left legs. Relative muscle strength was calculated by dividing body weight by the absolute muscle strength. The gravity effect torque was measured at an angle of 20° below the full extension for each leg.

Statistical analyses

All data are presented as mean ± standard deviation (SD). The parameters (age, height, weight, 1-km TT, MAnP, Lopt, Copt, and muscle strength) of the first- and third-grade cyclists were analyzed by Student's t-test. Correlation analysis was conducted between Lopt and knee extensor and flexor strengths. Statistical analysis was performed using SPSS version 24.0 statistical software (IBM Corp., Armonk, NY, USA). Statistical significance was set at $P < 0.05$. We also calculated the effect size (ES) (Cohen et al. 1988) for each group and parameter. According to Cohen, ES of 0.20–0.49 was considered as small, 0.50–0.79 as moderate, and more than 0.80 as large.

3. Results

Physical characteristics and 1-km TT performance

The values of the physical characteristics of the groups are presented in Table 1. There was no difference in height between the two grades ($p = 0.782$). In contrast, the age and weight of the third-grade cyclists were significantly higher than those of the first-year cyclists ($p < 0.01$), and the 1-km TT of third-grade cyclist was significantly faster compared with that of first-grade cyclists ($p < 0.01$).

Power output characteristics and muscle strength

Table 2 shows the power output characteristics and muscle strength, and Figure 1 demonstrates the relationships of load-cadence and load-power obtained in all first- and third-grade cyclists.

Table 2 Power output characteristics and muscle strength of first and third grades

			First grade (n=20)	Third grade (n=23)
Power output				
	Maximal anaerobic power	(W)	946.6 ± 106.5	1116.2 ± 131.8**
		(W/kg)	16.6 ± 1.5	17.4 ± 1.6
	Optimal load	(kp)	8.2 ± 0.7	9.4 ± 0.8**
		(kp/kg)	0.14 ± 0.01	0.15 ± 0.01
	Optimal cadence	(rpm)	119.9 ± 18.3	122.0 ± 12.8
Muscle strength				
	Knee extensor (180 deg/sec)	(N·m)	108.8 ± 16.2	128.1 ± 18.5**
	Knee flexor (180 deg/sec)	(N·m)	65.0 ± 12.0	78.5 ± 14.1**
	Knee extensor (180 deg/sec)	(N·m /kg)	1.91 ± 0.29	1.99 ± 0.19
	Knee flexor (180 deg/sec)	(N·m /kg)	1.14 ± 0.19	1.22 ± 0.22

Values are mean ± standard deviation.
**P<0.01 vs. first-grade cyclists

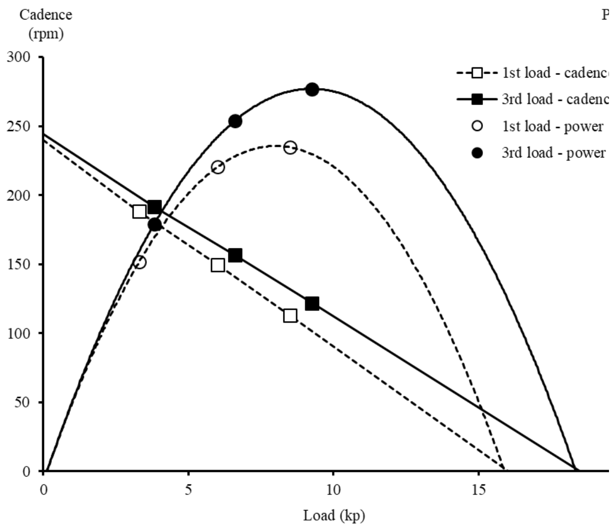

Figure 1: The relationships of load-cadence and load-power obtained in all first- and third-grade cyclists.

The MAnP value of third-grade cyclists was significantly higher compared with that of first-grade cyclists (ES = 1.40, $p < 0.01$). The relative values of MAnP to body weight of third-grade cyclists tended to be higher compared with that of first-grade cyclists (P = 0.094).

There was no difference in Copt between the two grades (ES = 0.13, p = 0.662), whereas Lopt was significantly higher in third-grade cyclists than first-grade cyclists (ES = 1.61, $p < 0.01$). However, there was no difference in the Lopt to body weight between the two grades (ES = 0.26, p = 0.405).

The absolute muscle strengths of knee extensor and flexor were significantly higher in third-grade cyclists than that of first-grade cyclists (extensor; ES = 1.10, $p < 0.01$, flexor; ES = 1.03, $p < 0.01$). However, there were no differences in the relative values of muscle strengths to body weight between the two grades (extensor; ES = 0.32, p = 0.307, flexor; ES = 0.43, p = 0.163).

Figure 2 shows the significant correlation between knee extensor and flexor muscle strengths and Lopt in all subjects (extensor; r = 0.670, $p < 0.01$, flexor; r = 0.466, $p < 0.01$).

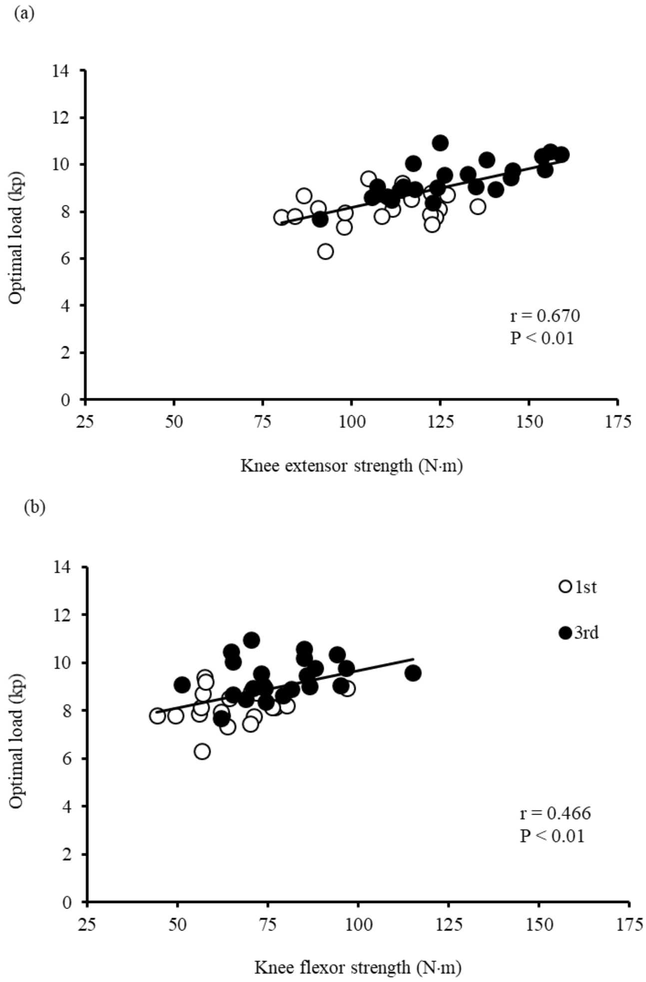

Figure 2: Relationship between knee extensor and flexor muscle strengths and optimal load in the first and third grades

(a) Significant correlation between knee extensor muscle strength and Lopt in all subjects. (b) Significant correlation between knee flexor muscle strength and Lopt in all subjects.

4. Discussion

The major findings of this study were that third-grade male Japanese high school cyclists had significantly greater MAnP compared with that of first-grade male Japanese high school cyclists, and Lopt was significantly higher in third- than in first-grade male Japanese high school cyclists, although there was no difference in Copt between both grades. Furthermore, knee extensor and flexor muscle strengths were significantly greater in third- than in first-grade cyclists and these muscle strengths were significantly correlated with Lopt. Thus, it is plausible that higher Lopt due to higher lower-body strength resulted in greater MAnP in third-grade male high school cyclists.

This study showed that the MAnP value of third-grade cyclists was significantly higher compared with that of first-grade cyclists. Based on previous research, amateur sprint male cyclists (age: 18.7 ± 2.7 years; MAnP: 1241 ± 266 W) had higher MAnP compared with that of the subjects in the present study (Davies and Sandstrom 1989), and the MAnP of elite sprint male cyclists (age: 24.3 ± 3.9 years; range: 19-31 years; 1533-2063 W) was higher compared with amateur sprint male cyclists and the subjects of the present study (Dorel et al. 2005; Gardner et al. 2007). MAnP appears to be affected by the performance level and/or age. Meanwhile, Martin et al. (2004) showed that the maximal peak power of untrained first- and third-grade boys were 644 ± 145 and 842 ± 128 W, respectively, and the subjects in the present study had approximately 300 W higher MAnP for each grade compared with untrained boys of the same grade. Based on these studies, the absolute increment amount, a little less than 200 W, from the first to the third grade was similar between untrained and trained high school boys. Given that the present measurements were conducted half a year after enrollment in high school for first-grade cyclists, all of whom started cycle training after enrollment, MAnP may increase after half a year of training.

Given that the MAnP was 17.9 % improvement from first to third grade, it is expected that force (Lopt) and/or velocity (Copt) factors changed. However, there was no difference in Copt between the two grades. Although Copt was significantly correlated with leg length in elementary school to high school boys (Martin et al. 2004), there was no difference in height between the two grades in the present study, which suggests that there might be no difference in leg length between the two grades. In contrast to Copt, the Lopt values of the third-grade cyclists were significantly higher compared with that of the first-grade cyclists. For athletes (gymnastics, weight-lifters, and endurance subjects), the previous study showed that Lmax, which is the double value of Lopt, depends heavily on muscle strength: the subject with higher strength has greater Lmax (Driss et al. 2002); however, to our knowledge, there was no research investigating this relationship in cyclists. In the present study, knee extensor and flexor muscle strengths were significantly greater in third-grade high school cyclists compared with first-grade high school cyclists and there was a significant positive correlation between knee extensor and flexor muscle strength and Lopt. In contrast, there were no differences in Lopt relative to body mass between first- and third-grade high school cyclists, suggesting that higher Lopt in third-grade cyclists is related to greater muscle volume. In addition to Lopt, there was also no difference in muscle strength relative to body mass between two grades. From the above, muscle volume influences Lopt and muscle strength mainly, resulting in MAnP increase. Thus, performing exercise training for muscle volume and strength gain such as resistance exercises may be important for improving cycling performance. Additionally, since there was no change in relative muscle strength and Lopt from first to third grade, this result demonstrated that no change was found in muscle quality. To further improve cycling performance, exercise training for improvement of muscle quality also may need to be carried out.

Three limitations exist in this study, including the period of measurement and the absence of untrained subjects. First, since we measured MAnP and muscle strengths for first-grade cyclists half a year after enrollment in high school, the changes during the first half of the year could not be observed. Second, since the present study did not have untrained subjects, we could not compare the MAnP, upper leg strength, and magnitude of increase during high school between cyclists and untrained subjects. Last, we did not measure leg length correlated Copt. Although leg length can be estimated by measuring height, further research is needed to clarify.

In conclusion, it is suggested that the higher MAnP value resulting from greater Lopt in third-grade high school cyclists is related to greater upper leg muscle strength, compared with that of first-grade high school cyclists. This suggests that the increment in force factor, but not velocity factor, influences MAnP output improvement in male high school cyclists. In cycling, the force factor equals gear ratio. Given that gear ratio is the absolute load regardless of both junior and senior categories (U23 and Elite category), we suggest that both junior and senior category cyclists perform resistance exercise for muscle mass and strength gain. In the future, a longitudinal intervention research including both untrained control and cycle training groups is needed to draw a robust conclusion.

5. Practical applications

In sprint events in track cycling, MAnP influences cycling performance strongly. With performing higher power, cyclists are able to pedal higher gear ratio. From the results of this study, it is necessary to improve force factor, i.e. muscle strength, in order to improve MAnP. Thus, increment of maximal strength results in MAnP improvement, which may improve cycling performance in junior-level cyclists. In addition to junior-level, it can be expected to be effective for senior-level cyclists as well. From the above, we suggest performing resistance exercise to improve muscle strength from junior-level cyclists. In addition, to obtain higher muscle strength and power contributes to pedal higher gear ratio.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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