INVESTIGATION OF POWER OUTPUT ON A NOVEL BICYCLE DRIVE IN COMPARISON WITH THE COMMON BICYCLE DRIVE

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The aim of this study is to check whether a novel bicycle drive allows a higher power output. In order to be able to judge the efficiency of this drive the power output during use of this specific drive was matched with the one of a traditional bicycle drive. Both maximal power output tests and endurance tests with lactate determination where carried out. During the maximal power output tests a power output increase of 5.2% could be measured. During the endurance tests the anaerobe threshold (4 mmol lactate / l blood) at 80 rpm could be raised by 4.17 W, this is equivalent to 2.4%. At four time trials of an amateur cycling club the test riders were 5.3% faster with the new drive over the distance of 14.62 km (with a hairpin bend). This corresponds to a power output increase of 15.9%.

KEY WORDS: bicycle, power output, bicycle drive, test bed, time trials, lactate

INTRODUCTION: In order to achieve an increase of power output a lot of money and work is still invested to build lighter, more rigid and aerodynamically more favourable bikes (Oehme & Lychatz, 1996). Research is also being done on optimising the position of the athlete on measuring bikes for best possible drive with minimum air resistance (Schaale & Nitsch, 1995). Yoshihuku and Herzog (1990) examined some parameters which are responsible for maximum power output. Particularly Hull (Hull & Davis, 1981; Hull & Jorge, 1985) and in recent years also Neptune (Neptune & Hull, 1999) carried out innumerable investigations on cycling. These investigations however have one thing in common: the circular pedal path. In this investigation a driving mechanism that makes a novel pedal path is used (four-bar linkage, figure 1). This mechanism is the result of a computer simulation, that calculates the optimum of muscular power output of the lower extremity (Angeli, 1996; Pawlik, 1995). A comparable drive was patented already in 1898 (!) (Goldman, 1898), however its pedal path does not represent a biomechanical optimum of power output. For professional cycling, the drive we developed is not according to regulations and has not yet been approved.

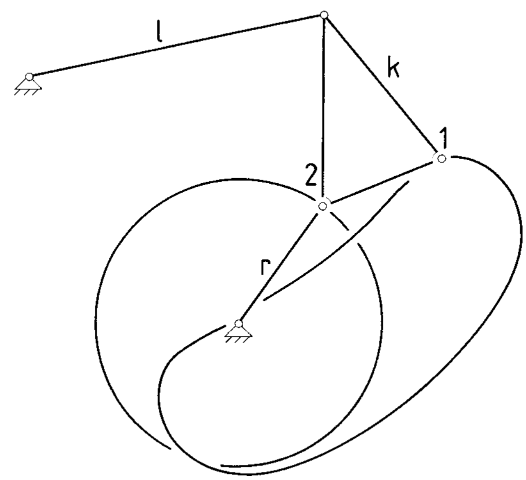


Figure 1 - Scheme of a four-bar linkage.

1 pedal position for the novel pedal path
2 pedal position for the circular pedal path
r crank
l lever
k coupler

METHODS: Measurements of the maximal power output, endurance tests and street tests (time trials) were done. The novel drive was compared to the traditional drive on a bike test bed. The pedal rate was determined by a servo motor and the transferred torque was measured with a torque measuring shaft.
Maximal power output tests: Pre-tests have shown, that the maximal power output

for hobby cyclists is achieved at a pedal rate between 100 and 130 rpm. 16 test persons (age 28.6 ± 3.6 years; size 184.7 ± 5.8 cm; body weight 73.5 ± 6.7 kg) had the task to deliver their maximal power output on the novel pedal path and on the circular path on two series each. Pedal rates of 100, 110, 120 and 130 rpm were tested in a random order. The first two series were done in the same pedal rate sequence. In the following series, the opposite pedal rate sequence was chosen. To avoid accumulation of lactate, the test persons were strained for short time periods only. Maximal power output was averaged over three seconds. The experiment was stopped, when the peak value was reached. Between the experiments of one series (one drive type) the test persons had a break of five minutes. In the first and fourth series, the power output was measured on one of the two pedal paths and in the second and third series, the other pedal path was measured on (compare figure 3 a, b). This sequence was varied to obtain objective results. Between the series, the test persons had a break of 15 minutes, in which the drives were exchanged. When measuring on the circular pedal path the entire linkage was taken away, so that the additional friction losses of the novel drive would not falsify the measured values.

Endurance tests: To check the suitability of this drive for long-term loads as well, ergometer tests in the form of endurance tests with lactate determination were performed (50 W power at the beginning, 50 W power steps every 3 min). Coast, Cox & Welch (1986) showed that both the heart frequency and the lactate level of cycle racers have a clear minimum at 80 rpm. This pedal rate was chosen for our tests.

Time trials: Motivated by the positive results, a prototype was built. The carbon frame was constructed in a way that it can be adjusted for both short and tall test persons. It weighs 2.7 kg and the additional gear 1.6 kg. An amateur cycling club that organises time trial competitions in Vienna every month from May to September was contacted. The prototype was tested there and compared to the traditional racing cycles. Each amateur participant of our test group raced several time trials in that season on traditional racing cycles and on our prototype and were motivated to give their best on both bicycles (club championship).

RESULTS AND DISCUSSION: Maximum power output tests: Compared to the traditional circular path the increase of performance achieved on the novel pedal path (table 1 and figure 2, 3) was 5.2% (averaged).

Table 1 Maximal Power Output (m.p.o.; averaged) on the Circular Pedal Path and the Novel Pedal Path and Power Output Increase

pedal rate	m.p.o. on circular path	m.p.o. on novel pedal path	m.p.o. increase
100 rpm	949.8 W	998.4 W	5.1%
110 rpm	980.5 W	1032.4 W	5.3%
120 rpm	986.5 W	1037.5 W	5.2%
130 rpm	956.9 W	1006.3 W	5.2%

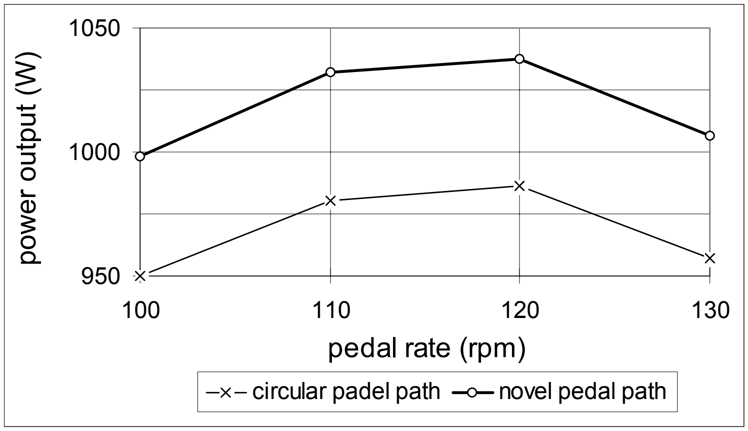
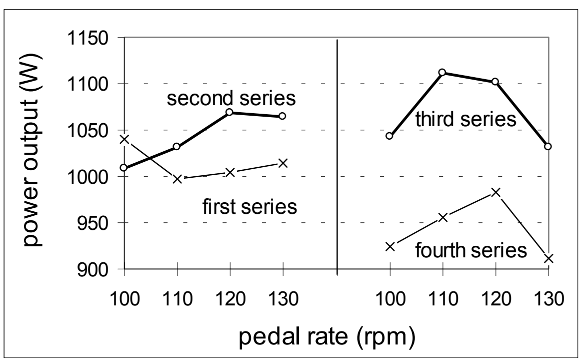
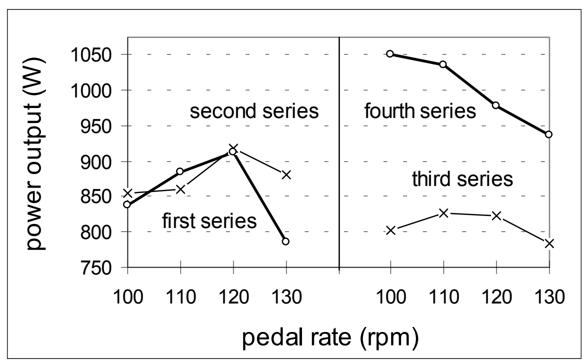


Figure 2 - Maximal power output (averaged) on the circular pedal path and the novel pedal path. Two test persons that were especially accustomed to the novel pedal path, could achieve a averaged power output increase of 6.7%. We assume that an additional increase of performance can be expected by training for an extended time on the novel pedal path. The power output on the novel pedal path was higher, independently of the series' sequence (see figure 3 a, b). This rules out the possibility of muscle fatigue falsifying results.



a) Test person with the novel pedal path in the 2nd and 3rd series



b) Test person with the novel pedal path in the 1st and 4th series

Figure 3 - Test procedures for maximum power output with two test persons (novel pedal path: thick line; circular pedal path: thin line).

Endurance tests: The anaerobe threshold was 4.17 W higher on the novel pedal path which corresponds to 15012 J for a one-hour race. Immediately after the last load of the endurance tests, maximal power output measurements were done. The results showed an averaged increase of maximal power output of more than 18% (table 2). **Time trials:** During the four time trial races of that season, the test riders were one minute and 15 seconds (averaged) faster on the prototype compared to their results on their own traditional racing cycles over the distance of 14.62 km (with a hairpin bend). This time difference is equivalent to 5.3%. This corresponds to a 15.9% higher power output. The increase of power output during the time trials is not proportional to the increase of velocity. The degradation of power output must be considered. This loss mainly consists of the rolling reistance and aerodynamic resistance (Gressmann, 1995; Kyle, 1986; Kyle, 1996; table 3, 4).

Table 2 Maximal Power Output Measurements Immediately After Endurance Tests

	series	pedal path	power output
first test day	first	novel	675 W
	second	circular	535 W
second test day	first	circular	583 W
	second	novel	648 W
average values		circular	559 W
		novel	661.5 W

Table 3 Power Dissipation and its Difference in Percent (abbr. are explained in table 4)

	v	P_{Roll}	P_S	$P_{Roll} + P_S$
Circular pedal path	10.12 m/s	20.0 W	213,8 W	233.8 W
Novel pedal path	10.66 m/s	21.1 W	249,8 W	270.9 W
difference	5.3 %	5.3 %	16.8 %	15,9 %

Table 4 Explanations and Equations for Rolling Resistance and Drag

rolling resistance - P_{Roll}	drag - P_S
$F_{Roll} = F_W + F_R = 1{,}2 \times F_R = 1{,}98$ N $F_R = F_G \times$ □$_R = 1{,}65$ N $P_{Roll} = F_{Roll} \times v = 1{,}98\ N \times v$	$F_S = ½ \times c_W \times$ □ $\times v^2 \times A = 0{,}206 \times v^2$ $P_S = F_S \times v = 0{,}206\ kg/m \times v^3$
F_{Roll} F_W F_R F_G □$_R$	F_S drag c_W (Gressmann, 1995) □ air density; 1,205 kg/m^3 at 20°C v riding velocity; in m/s A

CONCLUSION: Among other things the increase of power output in the fourth series on the novel pedal path causes following (compare figure 3 a, b). In the state of fatigue the coordination decreases because of the hyper-acidification of the muscle tissue and the tiredness of the central nervous system (Zintl, 1994). The clear increase of the maximal power output under these conditions can be explained, because the simpler movement on the novel pedal path needs less coordination. Considering this considerable increase of power output we do hope, that the international cycling federation will change equipment regulations so that this novel pedal path can be used at international competitions in the near future.

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