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Electric Motor Assisted Bicycle as an Aerobic Exercise Machine

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Abstract— **The goal of this study is to maintain a continuous level of exercise intensity around the aerobic threshold (AT) during riding on an electric motor assisted bicycle using a new control system of electrical motor assistance which uses the efficient pedaling rate of popular bicycles. Five male subjects participated in the experiment, and the oxygen uptake was measured during cycling exercise using this new pedaling rate control system of electrical motor assistance, which could maintain the pedaling rate within a specific range, similar to that in previous type of electrically assisted bicycles. Results showed that this new pedaling rate control system at 65 rpm ensured continuous aerobic exercise intensity around the AT in two subjects, and this intensity level was higher than that observed in previous type. However, certain subjects were unable to maintain the expected exercise intensity because of their particular cycling preferences such as the pedaling rate. It is necessary to adjust the specific pedaling rate range of the electrical motor assist control according to the preferred pedaling rate, so that this system becomes applicable to anyone who want continuous aerobic exercise.**

I. Introduction

Nowadays, people rarely find time to exercise, and lack of exercise is known to have a negative effect on human health. Regular exercise, especially aerobic exercise, is known to be effective in maintaining health and cycling is an effective way to perform exercise in daily life. To maximize the impact that exercise has on health, it is essential to maintain continuous level of exercise intensity at around the estimated anaerobic threshold (AT) [1, 2]. However, in the case of a popular bicycle, when a user cycles up a slope, the exercise intensity increases and the oxygen uptake (VO_2) exceeds the AT, i.e. an aerobic exercise switches to an anaerobic exercise. This problem can be solved with an electrically assisted bicycle, which decreases the exercise intensity while cycling up a slope. However, such an electrically assisted bicycle would also provide undesirable assistance on a flat road, thus reducing the opportunity to perform aerobic exercise. Therefore, a new type of electrically assisted bicycle was developed. This bicycle was expected to be used as a fitness machine. This bicycle provides pedaling assistance while cycling up a slope, depending on the pedaling torque, and it exerts a constant load while cycling on a flat road to ensure that a certain level of aerobic exercise intensity is maintained; this level of intensity should not exceed the AT. Evaluation of this bicycle system was carried out in a previous study [3]. The results showed that the system was effective for maintaining continuous aerobic exercise intensity in some subjects. However, at the same time, it was ineffective for some subjects because the electrical motor load had no effect on them as they had high leg muscle power. Moreover, because of weak leg muscles, the electrical motor assistance was rendered ineffective while cycling up a slope causing the VO_2 to exceed the AT.

To ensure continuous aerobic exercise by controlling the electric motor assistance and load, a subject strength independent index is necessary. To achieve this, we focused on the pedaling rate. The most efficient pedaling rate of popular bicycles was reported to be 60-70 revolutions per minute (rpm). The normal pedaling rates which most people should be cycle is within this range [4]. We used this range as an independent index of the subject's physical strength for controlling the electrically assisted bicycles. The goal of this study is to maintain a continuous level of exercise intensity around the AT at a higher exercise level than that achieved by previous types of electrical motor assistance. In this study, we evaluate the effect of new pedaling rate control system with the use of an efficient pedaling rate for popular bicycle on aerobic exercise while cycling.

II. Experimental Methodology

A. New Control System of Electrically Assisted Bicycle

The new control system maintains the pedaling rate within a specific range by controlling the electrical motor assist and load levels, regardless whether the surface is a slope or flat road, to maintain continuous level of aerobic exercise intensity. The specific pedaling rate range was decided as follows; the range is around 65 rpm (between 62 and 68 rpm, NEW65 mode) or 70 rpm (between 67 and 73 rpm, NEW70 mode) which are considered to be efficient pedaling rates. If the pedaling rate exceeds this specific range, especially while cycling down a slope or on a flat road, a constant load is exerted to make increase the level of exercise intensity. On the other hand, if the pedaling rate goes below the specific range, especially while cycling up a slope or on a flat road, an electrical motor assist is provided to decrease the level of exercise intensity. If the pedaling rate becomes 0, a constant load is exerted on a downward slope.

A universal microcomputer (ATmega328, Arduino Software) is used for controlling the electrical motor assist and load. The pedaling rate is calculated using the pedal rotation signals in the microcomputer. The microcomputer sends a signal to the electrical motor control module depending on the deviation of the pedaling rate from the predefined specific range.

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Moreover, this new control system facilitates the control of electrical motor assistance and load in a manner similar to that of previous types of electrically assisted bicycles. This is used in the experiment comparing with new control system.

B. Subjects

Five male subjects participated in this study. The mean (±SD) age, weight and height were 22.8 ± 0.7 years, 57 ± 3.7 kg and 170.9 ± 2.4 cm, respectively. All subjects ride a bicycle routinely, and one of them has exercise habit using the hybrid bicycle. All subjects were fully informed the aims and the protocol of this experiment, and accepted them.

C. Determination of VO_2 Max

Incremental exercise tests were performed to determine the estimated AT of each subject. The subjects were asked to perform a ramp exercise (about 15 W / 30 s ramp at a cycling speed of 60 rpm) using a bicycle ergometer (95Ci, Life Fitness) until they were exhausted. An initial ramp was assigned to each subject to facilitate easy pedaling. The VO_2 data were recorded using a gas-exchange and heart rate measurement device (VO2000, S&ME). Data were collected throughout the exercise, and the VO2max was calculated for each subject.

D. Bicycle Exercise Experiment

Two new control modes (NEW65 and NEW70) and one previous type of assisting mode (PREVIOUS TYPE) are used in the experiment. Fig. 1 shows scenes of the experiment. Each subject was asked to ride the electrically assisted bicycle on a field test course, using a new control system, and subjects' VO_2 were measured using the gas-exchange and heart rate measurement device during the bicycle exercise. At the same time, the pedal rotation signals are recorded using a mobile data recorder (NR-2000, KEYENCE). The field test course is about 4.6 km including up and down slopes as well as a flat road. Each exercise trial of the three control modes were examined separately after the subjects were given sufficient rest. In each trial, the subjects were asked to ride at their voluntary speed. A bicycle transmission was fixed. The order of the trial was randomly selected by the experimenter without telling subjects which mode was selected.

Figure 1. A picture of the bicycle exercise experiment.

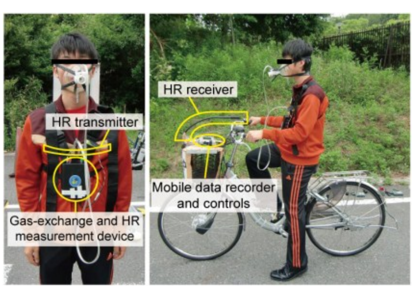

Figure 2. Representative result of VO_2 during bicycle exercise using each assist mode. *(Subject ID 003, VO_2 maintained a continuous level of exercise around the AT in the NEW65, which is higher than the PREVIOUS TYPE. The order of the control modes are NEW70, PREVIOUS TYPE and NEW65.)*

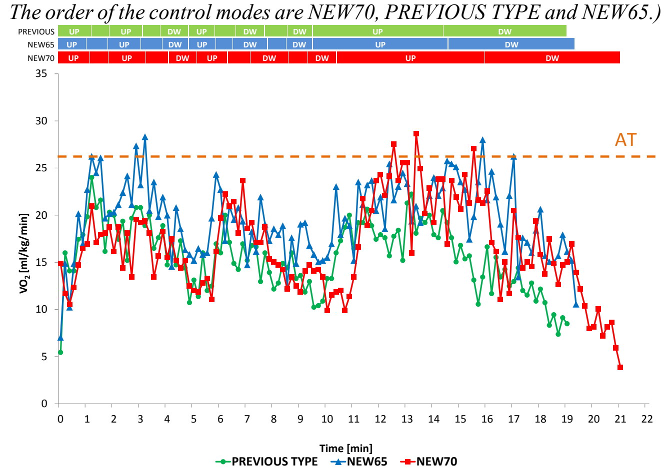

Figure 3. Representative result of VO_2 during bicycle exercise using each assist mode. *(Subject ID 004, VO_2 exceeded the AT in all assist modes,because of his cycling habit. The order of the control modes are NEW70, NEW65 and PREVIOUS TYPE.)*

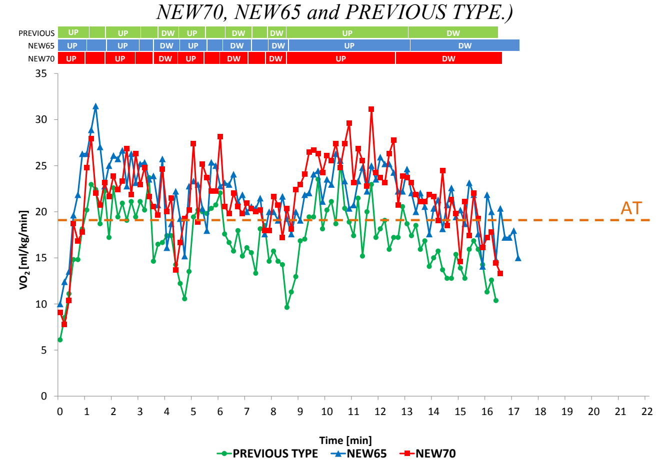

Figure 4. Representative result of VO_2 during bicycle exercise using each assist mode. *(Subject ID 005, VO_2 exceeded the AT in PREVIOUS TYPE. The order of the control modes are PREVIOUS TYPE, NEW70 and NEW65.)*

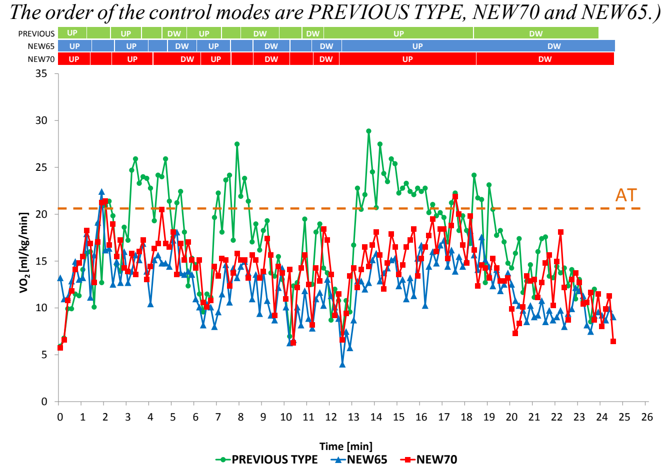

Table 1. Average VO_2 per Second and Exercise Levels of Each Subject

Subject ID	Oxygen Uptake Average per Second through Each Exercise [ml/kg/min]			Exercise Levels
	PREVIOUS TYPE	*NEW65*	*NEW70*	
001	1.57	1.72	1.59	Around the AT
002	2.82	2.32	2.56	Over the AT
003	1.58	1.98	1.67	Around the AT
004	1.71	2.19	2.18	Over the AT
005	1.75	1.25	1.41	Below the AT

III. Results

Results showed that the subjects could be classified into three groups according to their physiological responses. Fig. 2 to 4 show the representative results of three groups and each graph shows the VO_2 change during the cycling trial of each assist mode. The green plots represent the VO_2 in the previous type of assisting mode (PREVIOUS TYPE). The blue plots represent the VO_2 in the new type of electrically assisted mode around 65 rpm (NEW65). The red plots represent the VO_2 in the new type of electrically assisted mode around 70 rpm (NEW70). The brown dashed lines represent the AT of the each subject.

Fig. 2 shows that the VO_2 change during the cycling exercise in the PREVIOUS TYPE was the lowest among the three assist modes. The VO_2 changed during the cycling exercise in the NEW65 mode was higher than that in the NEW70 mode. The average VO_2 per second in the NEW65 mode was the highest among the three assist modes, and was about 25% higher than that in the PREVIOUS TYPE, without exceeding the AT (Table 1). This trend was observed in two subjects (Subject ID 001 and 003) and shows that they could maintain continuous level of exercise intensity around the AT in the NEW65 mode, which is higher than that in the PREVIOUS TYPE.

Fig. 3 shows that the VO_2 change for all assist modes exceeded the AT. Two subjects (Subject ID 002 and 004) exhibited this trend. This is thought to be because of their cycling habit. One subject (Subject ID 002) usually rides a cross bicycle, which has higher efficient pedaling rate and saddle higher than popular bicycles, this may affect his oxygen uptake. In addition, a pedaling rate preferred by the other subject (Subject ID 004) was quite higher than 70 rpm (between 70 and 85 rpm). The higher the pedaling rate, the more load is exerted; this may be a hard cycling exercise.

Fig. 4 shows that the VO_2 change in the PREVIOUS TYPE exceeded the AT, and the VO_2 change in the NEW65, and the NEW70 were below the AT. The pedaling rate preferred by this subject (Subject ID 005) was less than 65 rpm (between 45 and 55 rpm). He could perform a continuous aerobic exercise at a lower exercise intensity level. By exerting much load while cycling on a flat road and a down a slope, matching his preferred pedaling rate, even if it is not the efficient pedaling rate for a popular bicycle, it would be a continuous level of aerobic exercise around the AT.

IV. Conclusion

In this study, we evaluate the effect of new pedaling rate control system with the use of an efficient pedaling rate for popular bicycle on aerobic exercise while cycling. The result showed that the new pedaling rate control system was effective in maintaining continuous aerobic exercise intensity for two popular bicycle users whose preferred pedaling rates were around 65 rpm, and the average oxygen uptake per second significantly improved when using the new pedaling rate control system, as compared to the previous type of assist mode. In the case of the subject using a cross bicycle, the system is unsuitable for performing aerobic exercise as its efficient pedaling rate and the required cycling posture are different from those of popular bicycles. For other subjects whose preferred pedaling rates are not around 65 rpm, it is necessary to adjust the specific range of the pedaling rate for electrical motor assist control according to their preferred pedaling rate, so that this system becomes applicable to anyone who performs continuous aerobic exercise.

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