Kawasaki Journal of Medical Welfare Vol. 29, No. 1, 2023 1－6

Original Paper

Differences between Riding Positions on Oxygen Uptake during Tandem Bicycle Pedaling

Sho ONODERA[*1], Takuma WADA[*2], Yasuo ISHIDA[*3], Akira YOSHIOKA[*4], Kiho SO[*5], Sotaro HAYASHI[*6], Yurie ARATANI[*7], Kaori MATSUO[*1], Yasuko ISHIMOTO[*1], Terumasa TAKAHARA[*8], Hidetaka YAMAGUCHI[*8] and Keisho KATAYAMA[*9]

(Accepted May 23, 2023)

Key words: tandem bicycle, oxygen uptake, heart rate, blood pressure, RPE

Abstract

The aim of this study was to prove the new Douglas bag use method and the hypothesis that oxygen uptake of front riders was higher than rear riders during tandem bicycle riding in a field study. Fourteen male subjects volunteered to participate in this study. The heart rate, oxygen uptake, blood pressure and rating of perceived exertion (RPE) were measured. The rear-riding participant operated the cock of the Douglas bag. A significant difference was observed between the front rider (22.8 ± 6.3 ml/kg/min) and rear rider (20.2 ± 6.4 ml/kg/min) where oxygen uptake was lower for the rear rider than the front rider ($p<0.05$). RPE tended to be higher for front riders than for rear riders. The originality of this study is in the development of the idea of a method of exhaled gas sampling using the new Douglas bag method. A new finding is that we clarified the physical stress of tandem bicycle riders in terms of both energy expenditure and perceived exertion. This study successfully measured the absolute value of oxygen uptake in a field experiment. Our results suggest that front riders are more stressed than rear riders. This study confirmed the physiological stress of the front rider based on the new Douglas bag use method in a field study.

1. Introduction

A tandem bicycle is a two-seater bicycle in which the front and rear rider cooperate in pedaling. Due to factors such as wind pressure, handling and braking, the physical responses of front riders are higher than

[*1] Department of Health and Sports Science, Faculty of Health Science and Technology
Kawasaki University of Medical Welfare, 288 Matsushima, Kurashiki, 701-0193, Japan
E-Mail: shote@mw.kawasaki-m.ac.jp
[*2] Department of Living Science, Tottri College
[*3] Faculty of Management, Okayama University of Science
[*4] Faculty of Education, Kansai University of Social Welfare
[*5] JOY LIFE Co., Ltd
[*6] Faculty of Education, Fukuyama City University
[*7] Department of Nursing, Shikoku Medical College
[*8] Department of Sports Social Management, Kibi International University
[*9] Research Center of Health, Physical Fitness and Sports, Nagoya University

that of rear riders[1]. Previous field studies[2,3] reported that the degree of physical responses during tandem cycling was determined from relative oxygen uptake (%VO_2) calculated from heart rate (HR). It is well known that there is a linear relationship between HR and VO_2 during leg cycling and a lot of studies have utilized the individual HR-VO_2 equation to estimate VO_2 and energy expenditure during exercise in the field[4-6]. We calculated %VO_2 from HR for the 2-hour, 3-hour, and 5-hour tandem bicycle races[2,3,7]. From these field experiments, we obtained data that front riders have a higher physical response than rear riders[2,3,7,8].

Previous studies have already performed breath gas analysis during single seat-bicycle pedaling in the field[9,10]. However, no previous field studies have directly analyzed the exhaled gas of subjects during tandem cycling. Breath gas analysis is used to quantify the concentration of oxygen and carbon dioxide in exhaled breath. For the first time, we developed a method to measure oxygen uptake of subjects during tandem bicycle riding using the Douglas bag method.

Therefore, the aim of this study was to prove the new Douglas bag method and the hypothesis that the oxygen uptake of front riders is higher than that of rear riders during tandem bicycle riding in field studies using the Douglas bag method.

2. Methods

Fourteen male subjects volunteered to participate in this study. Average (SD) age, body weight and body height were 33 (8.4) years, 73 (7.8) kg and 171 (6.1) cm, respectively.

The heart rate (HR; RS800CX; POLAR, Sweden), oxygen uptake, blood pressure (501; KENZMEDICO, Japan), and rating of perceived exertion (RPE)[11] were measured. Heart rate was measured at rest, during exercise, and at the end of exercise. Blood pressure was measured before and after exercise. RPE was scored using the Borg scale[11] and was measured during the riding at each rep. Participants were seated for 30min at rest. Oxygen uptake (ml/kg/min) of participants during rest was measured using the Douglas bag method. Expired gases were collected in the Douglas bag during the 60s. Gas fractions were analyzed by mass spectrometer (ARCO-2000; AROCO SYSTEM, Japan) that was calibrated before each test. The expired gas volume was measured using a certified dry gas meter (DC-5; SHINAGAWA, Japan). As for the VO_2 measurement, Taylor et al. reported the error associated with Douglas bag testing of VO_2 during exercise to be 2.4%[14]. Since then, the Douglas bag method has been considered to be the gold-standard method in the exercise and sports sciences field, and it has recently been utilized to verify the accuracy of VO_2 measurement with online breath-by-breath gas analysis systems[13-16].

Fourteen subjects were divided in tandem into seven pairs. Pairs matched subjects with the same oxygen uptake. Subjects cycled for six laps on an outdoor 400m track one day and again on a 2nd day in reversed positions on the tandem bike. The pedaling rate was maintained at 90 rpm using a metronome. The speed of the tandem-bicycle was about 33km/h. The same gear ratio was used for pedaling.

The rear-riding participant operated the cock of the Douglas bag. The rear-riding subject opened the cock of the front rider's Douglas bag at 270 seconds after the start of the exercise and closed the cock at 330 seconds. Moreover, the rear-riding participant opened the cock of his Douglas bag at 300 seconds after the start of the exercise and closed the cock by himself at 360 seconds. Experiments were performed at the same time on different days. The temperature and humidity on the day of the experiments were 26℃ and the humidity was 50%.

All data are expressed as mean and standard deviation. RPE is the median and nonparametric analysis. Changes in all measurements during rides were compared by one-way analysis of variance (ANOVA). When differences were found to be significant, comparisons were made using Bonferroni's post hoc test. Values of $P<0.05$ were considered statistically significant.

3. Results

A significant difference was observed between the front rider (22.8 ± 6.3 ml/kg/min) and rear rider (20.2 ± 6.4 ml/kg/min) where oxygen uptake was found to be lower for the front rider (Table 1, $p<0.05$). No

Table 1 Changes in the minute ventilation ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER) and oxygen uptake per body weight ($\dot{V}O_2$ / kg) of each cyclist

	$\dot{V}E$ (ml/min)		$\dot{V}O_2$ (ml/min)		$\dot{V}CO_2$ (ml/min)		RER (%)		$\dot{V}O_2$ / kg (ml/min/kg)	
	pre	post	pre	post	pre	post	pre	post	pre	post
Front cyclist	8.6 ± 1.3	47.2 ± 11.6	270.5 ± 45.9	1645.3 ± 412.8	253.5 ± 28.2	1675.3 ± 417.4	0.89 ± 0.04	1.02 ± 0.04	3.7 ± 0.5	22.8 ± 6.2
Rear cyclist	8.6 ± 1.3	39.9 ± 13.3	270.5 ± 45.9	1452.9 ± 411.3	253.5 ± 28.2	1475.5 ± 505.6	0.89 ± 0.04	1.00 ± 0.07	3.7 ± 0.5	20.1 ± 6.4 †

(mean±SD)

† : $p<0.05$ (vs. Front cyclist)

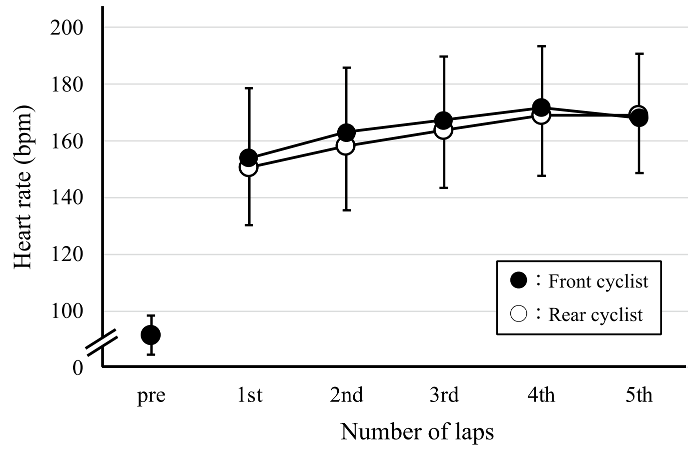

Figure 1 Changes in heart rate of each cyclist

Table 2 Changes in the blood pressure of each cyclist

	Systolic blood pressure		Diastolic blood pressure	
	pre	post	pre	post
Front cyclist	114.7 ± 6.8	136.3 ± 12.3	64.7 ± 11.8	60.7 ± 9.1
Rear cyclist	114.7 ± 6.8	134.3 ± 7.2	64.7 ± 11.8	56.7 ± 7.8

(mmHg) (mean±SD)

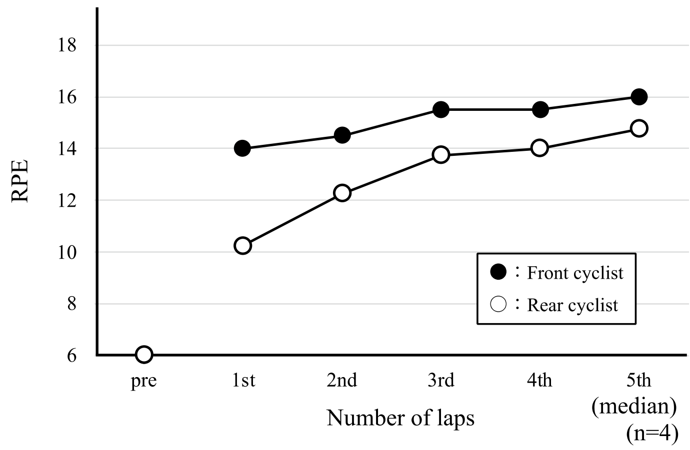

Figure 2 Changes in RPE of each cyclist

difference in HR (Figure 1) and blood pressure (Table 2) was observed between front rider and rear rider during the exercise ride or immediately after. RPE tended to be higher for front riders than for rear riders (Figure 2). These data suggest that the physical stress of the front rider could be higher than that of the rear rider.

4. Discussion

The originality of our paper is the development of the idea of a method of exhaled gas sampling using the Douglas bag method during tandem bicycle riding. A new finding in our paper is that we clarified the physical stress of tandem bicycle riders in terms of both energy expenditure and perceived exertion. This study successfully measured the absolute value of oxygen uptake in a field experiment. Our results revealed that front riders showed more stress than rear riders.

Yamaji[17)] showed that the accuracy of breath gas analysis using the Douglas bag method had a maximum error of 2%. Wasserman et al.[18)] and Weber and Janicki[19)] showed that the accuracy of breath gas analysis using an automated metabolic unit had 4% error. These are two of the reasons why breath gas analysis using the Douglas bag method is called the gold standard of breath gas analysis. This study is the first to evaluate the oxygen uptake of subjects riding a tandem bicycle in a field study using the Douglas bag method, and is highly original in this respect. We adopted a cross-analyses design as a way of checking the reliability of the data. We found that the oxygen uptake of front riders was greater than that of rear riders. From these statistical results, the hypothesis was verified. These data agreed with the findings of previous research. Previous studies reported no significant differences between front and rear riders in comparing absolute values of heart rate. However, there is a significant difference when comparing the relative heart rate and relative oxygen uptake. The obtained data supported the previous findings that the front rider was more burdened than rear rider.

Seifert et al. reported that no differences were observed between the captain and stoker (front and rear position)[20)]. They analyzed the heart rate (HR), rating of perceived exertion (RPE) and lactic acid (LA). In this study, our analysis and theirs were concordant for HR and RPE. As far as tandem bicycle riding is concerned, it was reported that the exercise intensity of a person on the front saddle during tandem-bicycle exercise was larger than that of the person on the rear saddle[2,3)]. As background, air, rolling, and frictional resistances are forces that must be overcome when riding a bicycle[1)]. Onodera et al. reported that the physical stress of the front rider was higher than that of the rear rider during a 2-hour tandem bicycle ride[7)]. Another study reported that during a 5-hour tandem bicycle ride[9)], the same tendency was observed up to the 3-hour mark[8)], however, no difference was reported after that. It has been reported that the physical stress of the front rider was greater than that of the rear rider during uphill riding when comparing the uphill and downhill[9)]. The relative values of oxygen uptake calculated based on these inference methods are not of an absolute value. Therefore, there have been discrepancies in the results of previous studies. We considered that relative value comparisons have limitations.

We performed additional experiments with two more pairs of riders to improve the reliability of breath gas analysis. During tandem riding, the rear rider opened the cock of the rear rider's Douglas bag and took air, and 30 seconds later, opened the cock of the front rider's and took air. The result was the same (front rider: 23.2 ± 4.18ml/kg/min, rear rider : 16.18 ± 2.15ml/kg/min) even if the order of air sampling was reversed.

This study has supported the previously proposed reasons for stress such as distance, uphill or downhill, handling, braking, wind pressure and weather on the front rider. At the same time, it is considered that trust in front riders reduces stress for rear riders. It is desirable that the front rider has better physical ability than the rear rider.

5. Conclusion

This study confirmed that the physiological effects of the front rider were greater than that of the rear rider based on oxygen uptake measured by the new Douglas bag usage method in this field study.

Ethical review

All procedures were approved by the Ethics Committee of Kawasaki University of Medical Welfare (21-091) and all subjects provided informed consent before data collection began.

Conflicts of interest

The authors declare no conflicts of interest associated with this manuscript.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number JP18K10950.

References

1. Japan Cycling Association : Investigative research project on the spread of tandem bicycles: Research Committee Report. https://dl.ndl.go.jp/pid/11338746/1/1, [2011]. (January 22, 2023)
2. Onodera S, Yoshioka A, Yamaguchi H, Matsumoto N, Nishimura K, Kawano H, Saito T, Arakane K, Hayashi S, ...Ogita F : Suitability of modified tandem-bicycle ergometer for the improvement of physical fitness and athletic performance. *Journal of Physical Fitness and Sports Medicine*, 4(2), 249-251, 2015.
3. Onodera S, Saito T, Wada T, Tamari Y, Murata M, Yoshida N, Yoshioka A, Katayama K and Ogita F : Suitability of modified tandem-bicycle ergometer during submaximal and maximal exercise. *European Journal of Sports & Exercise Science*, 5(2), 23-30, 2017.
4. Astrand PO and Rodahl K. *Textbook of work physiology*. McGraw Hill, New York, 1986.
5. Achten J and Jeukendrup AE : Heart rate monitoring. *Sports Medicine*, 33, 517-538, 2003.
6. Shephard RJ and Aoyagi Y : Measurement of human energy expenditure, with particular reference to field studies: An historical perspective. *European Journal of Applied Physiology*, 112, 2785-2815, 2012.
7. Onodera S, Saito T, Wada T, Murata M, Hayashi S, Watanabe Y, Fujiwara Y and Wakimoto T : Changes of heart rate during tandem bicycle cycling in a 2-hour endurance race. *Kawasaki Medical Welfare Journal*, 24(1), 89-94, 2014. (In Japanese with English abstract)
8. Onodera S, Tamari Y, Yoshida N, Hamada H, Tamari Y, Hayashi S, Wada T, Yoshioka A, Tuchida Y, ... Yamaguchi H : Changes in physiological responses to tandem-bicycle cyclists and a single-bicycle cyclist during a three hours endurance race. *Kawasaki Journal of Medical Welfare*, 24(2), 85-89, 2019.
9. Onodera S, Wada T, Tamari Y, Yoshida N, Hayashi S, Yamaguchi H, Wakimoto T, Hamada H and Yoshioka A : Changes in physiological responses to tandem bicycle exercise during the 5 hours endurance race in Okayama International Circuit. *Kawasaki Journal of Medical Welfare*, 23(2), 65-70, 2018.
10. Ricci J and Léger LA : VO_2max of cyclists from treadmill, bicycle ergometer and velodrome tests. *European Journal of Applied Physiology*, 50, 283-289, 1983.
11. Borg GA : Perceived exertion: A note on "history" and methods. *Medicine and Science in Sports*, 5(2), 90-93,1973.
12. Taylor HL, Buskirk E and Henschel A : Maximal oxygen intake as an objective measure of cardio-respiratory performance. *Journal of Applied Physiology*, 8, 73-80, 1955.
13. Winkert K, Kirsten J, Dryhaupt J, Steinacker JM and Treff G : The COSMED K5 in breath-by-breath and mixing chamber mode at low and high intensities. *Medicine Science Sports Exercise*, 52, 1153-1162, 2020.
14. Crouter SE, LaMunion SR, Hibbing PR, Kaplan AS, Bassett Jr DR : Accuracy of the Cosmed K5 portable calorimeter. *Plos ONE*, 14, e0226290, 2019.
15. Keely AS, Gordon AZ, Scotty JB, Jong BK, Leandy B and Phillip DC : The impact of face masks on performance and physiological outcomes during exercise: A systematic review and meta-analysis. *Applied Physiology Nutrition Metabolism*, 46(7), 693-703, 2021.
16. Reybouck T, Deroost F and Van der Hauwaert LG : Evaluation of breath-by-breath measurement of respiratory gas exchange in pediatric exercise testing. *Chest*, 102, 147-152, 1992.
17. Yamaji K : *The science of maximal oxygen uptake*. Kyorin Shoin, Tokyo, 1994. (In Japanese)
18. Wasserman K, Hansen JE, Sue DY and Whipp B : *Principles of exercise testing and interpretation*. Lea & Febiger, Philadelphia, 1987.
19. Weber KT and Janicki JS : *Cardiopulmonary exercise testing: Physiological principles and clinical applications*. WB Saunders company, Philadelphia, 1986.
20. Seifert JS, Bacharach DW and Burku ER : The physiological effects of cycling on tandem and single bicycles. *Biomechanics Journal of Sports Medicine*, 37(1), 50-53, 2003.