EFFECTS OF SURFACE ON OXYGEN UPTAKE, POWER OUTPUT, AND HEART RATE DURING UPHILL CYCLING

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An alternative to stationary cycling is to use an actual bicycle on a treadmill. While eliminating differences between bicycles, this method may limit inferential conclusions to overground cycling. The current study examined physiological and biomechanical responses while cycling uphill overground versus over treadmill. Thirteen subjects rode uphill at 6.4 km · hr^{-1} on a 2.5 X 3.0 m treadmill and an asphalt paved road nine min at 8-12% grade. Power output (PO), cadence (CAD), VO2, and HR, were obtained via telemetry. Mean data from minutes 3 to 6 were analyzed via Two-way (surface by time) Repeated Measures ANOVA. Mean VO2, HR, and PO were higher for treadmill riding than overground ($p<0.05$). However, no significant difference in CAD was found between the surfaces ($p>0.05$). No interactions were found. Results of the current study indicate that cycling on a treadmill impose different demands than overground cycling even when the equipment is the same.

KEY WORDS: treadmill cycling, telemetry, bicycling.

INTRODUCTION: Many exercise programs and protocols base levels of work intensity on values acquired during laboratory testing. The assumption that the actual energy cost during training activities outside of the labratory setting is the same may or may not be true. Wilmore et al. (1984) suggested that good imitation of a task in the laboratory together with a minimum variation in the workload would provide a good basis for extrapolating laboratory measurements to field applications. Therefore, lab tests are used to represent the response of field work when the task utilizes the same large muscle groups and performance mechanics. In cycling, physiological responses have been assessed using ergometric devices in the laboratory which imitate the performance mode in the field. However, there is still much debate regarding the value and use of this information (Kenny et al. 1995).

Cycling has commonly been studied via stationary cycle ergometery. Frictional forces applied to the ergometer's fly wheel alter power output and allow measurement of energy cost and cycling efficiency. Limitations to this method are the inherent differences (mechanical and structural dimensions) between the stationary bicycle and an actual bicycle. Indeed, it has been shown that specific mechanical factors such as pedaling frequency (Gaesser and Brooks 1975; Hagberg et al. 1981; Faria et al. 1982; Coast et al. 1986), seat height (Laurence Shernum and deVries 1976; Nordee-Synder 1977), crank length (Carmicheal et al. 1982, Condrad and Thomas 1983), posture (Faria et al. 1982), tire pressure (Ryschon and Stray-Gundersen, 1993), and external pacing (Mastroianni et al. 2000) must be equated if laboratory measurements are to be representative of field performances.

Physiological efficiency is also affected by many factors including various physiological responses, equipment variables, and biomechanical variations in technique. An alternative to stationary cycling on an ergometer is to use an actual bicycle on a treadmill. While eliminating the differences between bicycles, this methodology also results in situations that limit inferential conclusions to overground cycling. Hamill et al., (1984) have noted that overground vs. treadmill walking have differences in the measured work being done. Furthermore, Kenny, et al. (1995) found that equating workload by heart rate would result in different oxygen uptake (VO2) values during level grade treadmill and over-ground cycling. What has not been addressed is whether the energy cost of uphill bicycling on a treadmill differs from that of overground uphill cycling. Jensen et al. (1998) found differences in VO2 and heart rate (HR) between treadmill and overground riding. However, Bowen and Jensen (2004) found no differences in HR between treadmill and overground riding but significant differences in power output. To better understand the physiological responses to treadmill

and overground uphill cycling, biomechanical variables power output (PO) and cadence (CAD) were also included in the study.
Therefore, the purpose of the current investigation was to determine how the energy cost, heart rate, power output, and cadence during uphill cycling on a treadmill compare to cycling overground at similar velocities. Information gained from this study will help determine whether using a treadmill for actual cycling is an appropriate lab measure for energy determination. The study will specifically analyze experienced cyclists and attempt to answer the following questions:

1. Does the surface type alter oxygen consumption, heart rate, power output, and cadence?
2. Is treadmill cycling an appropriate lab measure for energy demands?

METHOD:

Data Collection: The current study analyzed 13 subjects (n=13). Prior to any testing, each subject was required to read and sign an informed consent and PAR-Q forms before participation in the study. The subject's demographics (age, height, mass, and riding experience) were measured and/or recorded prior to any testing. Subject limitations included the following: subjects were between the ages of 18-35 yrs, subjects must have a height $\geq$ 165 and $\leq$ 200 cm, and subjects must have $\geq$ 1 yr of cycling experience. The mean (Mean ± SD) age, body mass, height, and riding experience in years of the subjects were 25 ± 3 yrs, 76.49 ± 9.33 kg, 181.16 ± 8.81 cm, and 10 ± 6 yrs respectively.
An Access XCL 2005 size 20 bicycle frame with platform pedals was used for all testing trials. A self selected seat height was chosen by the subject and measured prior to cycling. The measurement started at the base of the seat post collar and ended at the base of the right saddle rail clamp. The seat height was also adjusted horizontally in order to reproduce the same relative body posture the rider would use on their own bicycle. The horizontal measurement was set on the right saddle rail. The seat height was kept constant between treadmill and over ground cycling trials.
Testing took place on a local road (Old Mill Road, Houghton, MI) that had been recently paved with asphalt. Subjects cycled at a velocity of 6.4 km $\cdot$ hr^{-1} for a total of nine minutes. Treadmill cycling took place on a 2.5 X 3.0m motorized research treadmill (FitNex, Dallas, TX) at the Northern Michigan University Exercise Science Laboratory. Temperature was accounted for between cycling overground and laboratory by opening the doors and windows in the laboratory during the treadmill ride. Tire pressure was measured and set at 50 psi prior to testing in both conditions.
The road grade was determined using topographical maps acquired from the Houghton county road commission and grade was averaged over 100 ft intervals. The grade of the road ranged from 8% to 12% and the treadmill protocol mimicked the changes in the grade of the road. Subjects were instructed to ride at a constant pace of 6.4 km $\cdot$ hr^{-1}. During overground cycling a researcher rode behind each subject to ensure that the pace requirement was met. Both treadmill and overground rides were preceded by a 10 minute warm-up at a power output of 75 Watts. Each exercise trial commenced within two minutes of completion of the warm-up. Each subject was given at least 30 minutes to acclimate to treadmill cycling. Subjects were allowed to know their speed while riding, but not their heart rate, power output, torque, or cadence.
The subjects donned a mass flow sensor connected to a SensorMedics® Vmax Spectra portable metabolic analyzer. The SensorMedics® Vmax ST (Yorba Linda, CA) measured oxygen uptake and was carried on the subject's back. Oxygen uptake was sampled breath by breath, and then averaged over 60 seconds. Power output, heart rate, and cadence were all measured via the Power-Tap Link™ (Graber Products, Madison, WI) cycling computer. The cycling computer was connected to a magnetic bicycle hub laced into the rear wheel of the bicycle and also to a heart rate monitor. These devices fed data into the cycle computer and were stored as ASCII text data files. The cycle computer and storage unit were mounted on the handle bars of the bicycle. As the subject rode a trial, the power output and cadence

was calculated from the rotation of the magnetic hub and the subject's heart rate was transmitted telemetrically and stored in an open data file on the storage unit's memory chip. Upon completion of each event, the storage unit was placed in the transfer cradle and then linked to a laptop computer via a serial to USB conversion cable where it was downloaded. Data collection commenced from a stationary start and both the Vmax ST and Power-Tap Link™ were synchronized by pressing the initiation buttons at the same time.
The testing protocol for all conditions involved cycling for a total of nine minutes. The data for this study were analyzed between minutes three and six.
A two-way (surface by time) repeated measures analysis of variance (ANOVA) was used to assess the dependent variables (VO2, HR, PO, CAD). Statistical significance in all tests was set at a significance level of $p<.05$ and all analyses were performed using SPSS 12.0 for Windows (SPSS Inc, Chicago, IL, USA). Two factors were defined for this study surface (2 levels), and time (4 levels). Sixty second VO2, HR, PO, and CAD averages for Vmax and PT during overground and treadmill riding for four minutes were entered as within-subjects variables.

RESULTS: A two-way repeated measures ANOVA was calculated comparing Mean VO2, HR, PO, and CAD for surface and time. Table 1 displays the Means and SD for VO2, HR, PO, and CAD for both surface conditions (overground and treadmill). Results indicated that the subjects' (n = 13) mean VO2, HR, and PO rates were different for treadmill cycling than overground cycling ($p < 0.05$)., however, CAD means were not significantly different between overground and treadmill surface ($p > 0.05$). There were no interactions ($p > 0.05$) between surface and time for any of the dependent variables. None of the athletes reported the use of caffeine or nicotine before completing the cycling trials.

TABLE 1. Physiological and biomechanical variables (mean ± SD) recorded between surface overground (OG) vs. treadmill (TM)

	Overground	**Treadmill**
VO2 (L·min^{-1})	2.421 ± 0.3	2.743 ± 0.3 [a]
HR (beats·min^{-1})	147 ± 20	154 ± 19 [a]
PO (W)	149 ± 16	160 ± 17 [a]
CAD (r·min^{-1})	70 ± 3	70 ± 2

[a] Treadmill higher than over-ground ($p<0.05$)

DISCUSSION: The findings of the current study agree with previous studies that have shown differences in VO2, HR, and PO between overground and treadmill cycling (Kenny et al. 1995; Jensen et al., 1998; Bowen and Jensen, 2004), however, the differences found in this study contradict the previous studies results. Jensen et al (1998) found that oxygen uptake and heart rate were higher for overground cycling than treadmill cycling which was in opposition to this study. The study by Bowen and Jensen (2004) had similar findings with heart rate being higher for treadmill cycling, but contrary to the current study, power outputs were higher for overground cycling.
No significant difference in cadences suggests that the differences in power output were not likely to be from changes in rider's cadence or riding speed. It should be noted that the changes in oxygen consumption, heart rate, and power output mimicked the changes in the grade of the road over the measured time. This suggests that the treadmill protocol imitated that of the overground cycling and the criteria of maintaining task specificity described by Wilmore (1984) appeared to be met. However, as the VO2, HR, and PO were different, the two conditions should not be directly interchanged.

CONCLUSION: Although the protocol specificity would imply similarity in physiological and biomechanical responses to cycling uphill, the results suggest that cycling overground impose different demands than treadmill cycling even when the equipment is the same. It is possible that the differences in stability and maintenance of inertial characteristics in the laboratory had a significant effect on the cycling mechanics, perhaps altering the energy costs between overground and treadmill cycling. This study further demonstrates the difficulties associated with extrapolating energy costs based on laboratory testing using similar work mechanics and equipment.

REFERENCES:

Berry, M., Storsteen, J., Woodard, C. (1993) Effects of body mass on exercise efficiency and VO_2 during steady-state cycling. *Med Sci Sports Exerc.* **25**: 1031-1037.

Bowen, R. S., Jensen, B.T. (2004) Effects of added weight on power output and heart rate: Treadmill versus on road cycling. ASB Midwest Student Regional Meeting.

Carmicheal, J., Loomis, J., Hodgson, J. (1982) The effect of crank length on oxygen consumption and heart rate when cycling at a constant power output. *Med Sci Sports Exerc.* **14**: 162.

Coast, J., Cox, R., Welch, H. (1986) Optimal pedaling rate in prolonged bouts of cycle ergometry. *Med Sci Sports Exerc*. **18**: 225-230.

Condrad, D., Thomas, T. (1983) Bicycle crank arm length and oxygen consumption in trained cylists. *Med Sci Sports Exerc*. **15**: 111.

Faria, I., Sjojaard, G., Bonde-Petersen, F. (1982) Oxygen cost during different pedaling speeds for constant power output. *J Sports Med* **22**: 295-299.

Gaesser, G., Brooks, G. (1975) Muscular efficiency during steady state rate: effect of speed and work rate. *J Appl Physiol* **38**: 1132-1139.

Hagberg, J., Mullin, J., Giese, M., Spitznagel, E. (1981) Effect of pedaling rate on submaximal exercise responses of competitive cyclists. *J Appl Physiol* **51**: 447-451.

Hamill, J., Bates, B., Knutzen, K. (1984) Ground reaction force symmetry during overground and treadmill walking. *Res Quart Exerc Sport*, **55**(3): 289-293.

Jensen, R. L., Ebben, W., Gannon, E., Harney, R., Kobeinia, R., Maynard, J., Watts, P. B. (1998) Effect of added weight on heart rate and VO2 during uphill bicycling overground verses on a readmill. *Med Sci Sports Exerc*. **30**(5) Supplement: S58

Kenny, G.P., F.D. Reardon, A. Marion, and J.S. Thoren. (1995) A comparative analysis of physiological responses at submaximal workloads during different laboratory simulations of field cycling. *Eur J Appl Physiol* **71**: 409-415.

Laurence Shernum, P., deVries, H. (1976) The effect of saddle height on oxygen consumption during bicycle ergometer work. *Med Sci Sports* **8**: 121.

Mastroianni, G., Zupan, M., Chuba, D., Berger, R., Wile, A. (2000) Voluntary pacing and energy cost of off-road cycling and running. *Appl Ergonomics* **31**: 479-485.

Nordee-Synder, K. (1977) The effect of bicycle seat height variation upon oxygen consumption and lower limb kinematics. *Med Sci Sports* **9**: 113-117.

Ryschon, T.W. and J. Stray-Gundersen. (1993) The effect of tyre pressure on the economy of cycling. *Ergonomics* **36**: 661-666

Wilmore, J. (1984) The assessment of and variation in aerobic power in world class athletes as related to specific sports. *Am J Sports Med* **12**: 120-127

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