

The effects of vibration on efficiency in off-road cyclists

Tolga Aksit¹, Arzu On², Gorkem Aybars Balci¹, Ozgur Ozkaya¹

¹Department of Coaching Education, Ege University, Faculty of Sport Sciences, Izmir, Turkey

²Department of Physical Medicine and Rehabilitation, Ege University Faculty of Medicine, Izmir, Turkey

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ABSTRACT

Objectives: The aim of this study was to investigate whether vibration significantly affected the efficiency of off-road cyclists.

Patients and methods: Eight male mountain cyclists (mean age 21.1±1 years; range, 19 to 22 years) between August 2017 and November 2017 were included. The experimental protocol included four testing sessions with a one-day interval between testing sessions: a familiarization session; performance of submaximal tests; performance of maximal graded exercise test; and a 30-min mountain bike trial performed with vibration or without vibration. Physiological measures including volume of oxygen uptake (VO₂), volume of carbon dioxide output (VCO₂), heart rate, respiratory exchange ratio, rating of perceived exertion, and gross efficiency (GE) were compared between the trials performed with vibration or without vibration.

Results: There was a significant increase in the GE with the addition of intermittent vibration, particularly over the last 15 min of the cycling trial (p<0.05). There were no significant effects of vibration on other parameters.

Conclusion: This study demonstrates that addition of intermittent vibration may provide positive benefits in improving GE during a 30-min submaximal cycling trial.

Keywords: Gross efficiency, mountain biking, oxygen uptake, performance, vibration.

Off-road cycling, also known as mountain biking (MTB), has become a popular recreational and professional biking activity worldwide. Performance in MTB is influenced by multiple factors including general anthropometric characteristics of cyclists, sport-specific skills, hand grip endurance, aerobic capacity, and anaerobic capacity to perform intermittent high-intensity bouts of cycling and overall self-confidence.^[1] The physiological demands of MTB differ from those of road biking in terms of riding techniques and the roughness of the terrain to be traversed. The demands of MTB performance, both across and within MTB categories (i.e., cross-country or hill climb/uphill), can substantially vary.^[2] These physiological demands must be exerted on the varying terrains on which

MTB races are held, which require skilled techniques (technical single-track and straight tracks), roads with rough surfaces including rocky areas, and natural barriers, which require fast descent and jumps. Impellizzeri and Marcora^[3] reported that, across these various conditions, cyclists were continuously exposed to vibration.

Vibration affects neural factors of neuromuscular control, such as increased synchronization of motor units, potentiation of the stretch reflex, leading to an involuntary tonic vibration reflex, increased activity of synergistic muscles, and increased inhibition of antagonist muscles.^[4] Together, these vibration-induced effects on neuromuscular control produce acute beneficial effects on performance.^[5]

Corresponding author: Arzu On, MD, Ege Üniversitesi Tıp Fakültesi Fiziksel Tıp ve Rehabilitasyon Anabilim Dalı, 35100 Bornova, İzmir, Türkiye.

e-mail: arzu.on@ege.edu.tr

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The mechanical stimulus of vibration is transmitted along the linked segments of the body, stimulating sensory receptors including muscle spindles. It has been also argued that this sensory stimulation is responsible for increasing the number of alpha motor neurons recruited for a movement and the strength of a muscle contraction by recruiting muscle fibrils, which were previously inactive, as well as improving the change in muscle length, particularly lengthening, through the effect of vibration on muscle spindles.^[6] Therefore, in response to vibration, the number of motor units participating in a movement increases and the muscle contraction becomes stronger, while muscles stretch more quickly. Thus, acute vibration leads to an increase in the strength and a better neuromuscular adaptation.^[7,8] In contrast to the positive benefits of acute exposure to vibration, the limited research evaluating long-term exposure to vibration has reported detrimental effects, including increased muscle fatigue and decreased muscle contraction strength.^[9]

Although the vibration is inherent to MTB, due to the roughness of the off-road trails, very few studies on cycling have examined vibration exposure as an experimental variable. Review of the literature reveals only three studies including vibration in their experimental protocol, each reporting a significant increase in the volume of oxygen uptake (VO_2) during graded exercise testing performed with vibration, compared to a no-vibration condition.^[10,11] The economy of performance in off-road cyclists is defined as obtaining a high portion of energy by aerobic sources, when increased speed on rough-challenging tracks. This criterion of economy is important to include in physiological evaluation and performance determination of cyclists.^[12] The rate between the work generated and total metabolic energy cost is defined as gross efficiency (GE), where the GE is directly proportional to performance during long-term endurance exercise. However, to the best of our knowledge, the effect of whole-body vibration (WBV) on the GE in off-road cyclists has yet to be evaluated. In the present study, therefore, we hypothesized that exposure to intermittent WBV would increase GE and aimed to evaluate the effects WBV during cycling training of GE.

PATIENTS AND METHODS

This prospective study was conducted at Ege University, Faculty of Sport Sciences, Climatic Chamber Laboratory between August 2017

and November 2017. A total of eight healthy male mountain cyclists (mean age 21.1 ± 1 years; range, 19 to 22 years), three of whom were competitive cyclists in the national team, were included. All participants were trained a minimum of 8 h per week. Exclusion criteria were orthopedic problems, metabolic disorders, cardiovascular disease and age < 18 years. A written informed consent was obtained from each participant. The study protocol was approved by the Ege University Medical Research Ethics Committee (15-9/13). The study was conducted in accordance with the principles of the Declaration of Helsinki. A repeated-measures design was used for the laboratory experiment. The participants were asked to refrain from strenuous exercise for at least one day prior to each testing session. The experimental protocol included four testing sessions, each performed in the laboratory setting with a one-day interval. Sessions were consisted of four steps: (i) familiarization session; (ii) submaximal performance tests; (iii) maximal graded exercise test; and (iv) two 30-min mountain bike trial performed with vibration (VbX+) and without vibration (VbX-). The study design is shown in Figure 1.

Procedures

Familiarization sessions and submaximal incremental step test

Familiarization sessions were performed to adapt participants to the equipment such as mask of gas analyzer, Peak Bike cycle ergometer, WBV platform, or test settings (VbX- and VbX+). Following the familiarization procedures, the submaximal test was initiated consisting of five 4-min bouts performed on a frictional braked Peak Bike cycle ergometer. The workload increases were set to 24 to 32 Watts for each athlete to ensure that each athlete could reach the cyclist's ventilatory threshold (VT) determined using a regression slope of the min ventilation (VE) versus VO_2 production (VE- VO_2) and using the slope of volume of carbon dioxide (VCO₂) production and O₂ utilization (VCO₂- VO_2).

Maximal graded exercise test

Incremental tests were performed by 24 to 40 Watts increments every two min, from VT to volitional exhaustion. For the maximal incremental test, strong verbal encouragement was provided to participants throughout the tests to ensure maximal effort. The rating of perceived exertion (RPE) was recorded during the last 30 sec of each two-min

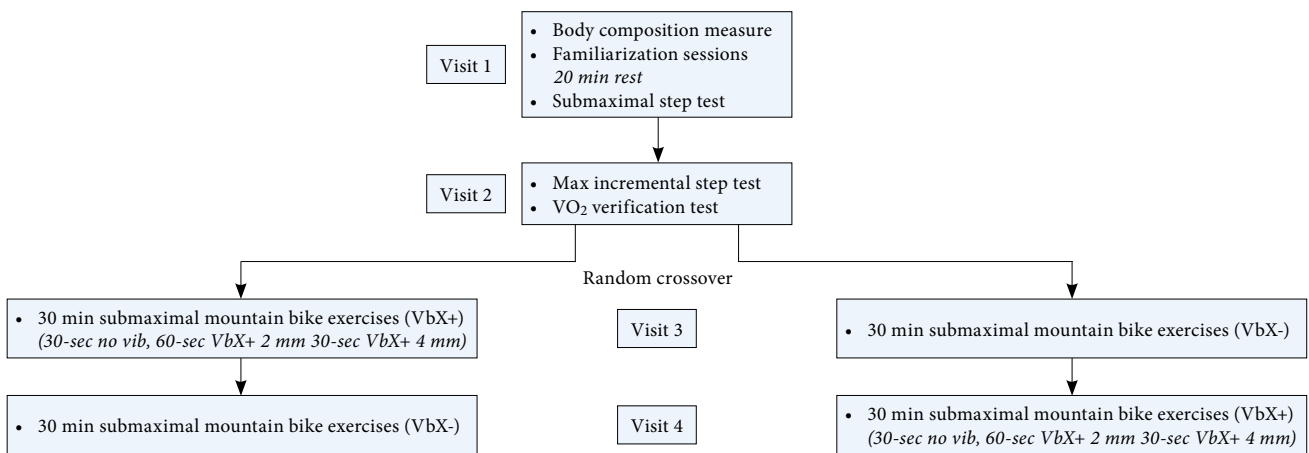


Figure 1. Schematic illustration of the experimental protocol.

VO₂: Oxygen uptake; VbX+: With vibration; VbX-: Without vibration.

stage, using 6 to 20 range of the Borg Scale. The highest average VO₂ calculated over the last 30 sec of each stage was considered as the peak oxygen consumption (VO_{2peak}). Test termination criteria were as follows: (i) plateau (<150 mL·min⁻¹ increase) in VO₂; (ii) maximal heart rate (HR_{max}) ≥ 90% of the HR_{max} predicted for age (220-age); (iii) RER ≥ 1.05, and (iv) inability to maintain an rpm of 80 over a three-sec duration.

Submaximal mountain bike trials

The VbX- and VbX+ bouts were performed on a 26-inch aluminum front suspension mountain bike (585 Eagle, Italy) with an additional frictional resistance system (Beta Elastomer, Germany). The system was placed on a platform fixed onto the WBV equipment (Power Plate my3; Performance Health Systems, Northbrook, USA; Figure 2). Specific Power Plate intensities enabled vibration stimuli of 2 mm to 4 mm in amplitude, delivered at 35 Hz. The 30-min VbX+ cycling bout was performed at the wattage corresponding to the VT. Exposure to VbX+ was provided over the last 15 min of the 30-min cycling bout, and consisted of three sessions as follows: 30 sec VbX-, 60 sec VbX+ at 2 mm, and 30 sec VbX+ at 4 mm. In addition, a 30-min VbX- bout was completed on the same platform. The cyclists were instructed to maintain a constant load with the wattage corresponding to VO₂ of 60% VO_{2peak} at an rpm of 80 throughout the test. The seat height was adjusted to accommodate the rider's personal preferences. The wheel pressure was standardized at 70 PSI for all test sessions.

Physiological measurements

The VO₂, VCO₂, VE, and RER were monitored, breath-by-breath during all tests, using a standard gas analyzer (Quark b2; Cosmed Srl., Rome, Italy). Data were smoothed over every five-point interval and interpolated every 30 sec to eliminate outlying data. The VO₂ (mL·min⁻¹·kg⁻¹) gas analyzer was calibrated according to the manufacturer's instruction. The HR was continuously recorded using a HR monitor system (Garmin EDGE 1000, Garmin International Inc., KS, USA). The GE (%) was calculated as the ratio of mechanical power-to-metabolic power. Mechanical power (P_{mec}) was evaluated from the wattage and the rpm (Eq.1), while metabolic power (P_{met}) was



Figure 2. Placement of the system on a platform fixed to whole body vibration equipment.

determined using average RER and VO_2 values of the submaximal mountain bike trial (Eq.2). The GE% was, then, calculated as the ratio of P_{met} and P_{mec} with one-min intervals (Eq.3). To obtain a valid determination of muscular efficiency, oxygen consumption was measured at steady state.

Eq.1

$$P_{mec} = \text{Load (kg)} \times \text{cadence (rpm)}$$

Eq.2

$$P_{met} = 4.94 \times \text{RER} + 16.04/60 \times VO_2$$

Eq.3

$$GE (\%) = P_{mec}/P_{met} \times 100$$

The above mentioned physiological measures were collected and calculated as VO_2 and VCO_2 ($\text{mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$), VO_2 and VCO_2 ($\text{L}\cdot\text{min}^{-1}$), VE ($\text{L}\cdot\text{min}^{-1}$), RER, HR, total energy expenditure (kcal), rpm, power output (watt), GE (%), and RPE.

Statistical analysis

Sample size was calculated based on previous studies evaluating efficiency in cyclists.^[13,14] By taking eight individuals with an effect size and type 1 error rate of 0.90 and 0.05 respectively the study power was achieved as 0.72. Statistical analysis was performed using the PASW version 18.0 software (SPSS Inc., Chicago, IL, USA). Descriptive data were expressed in mean \pm standard deviation, median (min-max), or number and frequency. Since the sample size was lower than 30, the Wilcoxon test was used to analyze VO_2 , VCO_2 , VE , RER, RPE, HR, and GE% differences

between the VbX+ and VbX- conditions. Relative reliability was analyzed by the intra-class correlation coefficient (ICC) and 95% confidence interval (CI) was estimated with two-factor mixed-effect model with an absolute agreement. A p value of <0.05 was considered statistically significant.

RESULTS

Of a total of eight male mountain cyclists, the mean height was 1.8 ± 0.1 m, the mean weight was 71.1 ± 3.7 kg, and the mean estimated body fat percentage was $10.4\pm 1.9\%$. Descriptive physiological characteristics and performance parameters are presented in Table 1. Differences in VO_2 and GE%, calculated during the 30-min submaximal mountain bike trials under VbX+ and VbX- conditions, are shown in Figure 3.

The comparisons of the physiological and performance parameters during 30-min VbX+ and VbX- are summarized in Table 2. There were no significant differences between the mean values of the physiological and performance variables at VbX+ and VbX-. However, a significant difference in GE% was observed between VbX+ and VbX- conditions ($p<0.05$).

There was also a significant GE% difference between the first 15-min and the last 15-min of the submaximal trials between the VbX+ and VbX- exercises ($p<0.05$) (Table 3). The mean VO_2 value corresponding to 60% of VO_{2peak} was 37.2 ± 6.0 $\text{mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$. The mean VO_2 value over

TABLE 1
Peak physiological and performance responses during graded exercise test (n=8)

	Mean \pm SD	Min-Max	95% CI
			Lower-Upper
VO_2 ($\text{mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$)	61.2 \pm 3.5	49.0-78.21	52.91-64.40
VO_2 ($\text{L}\cdot\text{min}^{-1}$)	4.3 \pm 0.2	3.51-4.97	3.89-4.66
P_{peak} (W)	348.1 \pm 18.5	277.0-426	304.29-391.95
Respiratory exchange ratio	1.1 \pm 0.0	1.0-1.20	1.01-1.13
Heart rate (bpm)	191.8 \pm 3.2	178.0-202	184.22-199.27
Minute ventilation ($\text{L}\cdot\text{min}^{-1}$)	165.9 \pm 6.8	134.42-199	149.77-182
VCO_2 ($\text{L}\cdot\text{min}^{-1}$)	4.6 \pm 0.2	3.65-5.27	3.98-5.11
Rating of perceived exertion (Borg scale)	19 \pm 0.4	17.0-20.0	18.10-19.89
Time to exhaustion (s)	478.9 \pm 31.6	390.0-641.0	404.19-553.55

SD: Standard deviation; VO_2 : Oxygen uptake; P_{peak} : Power output at point of exhaustion; VCO_2 : Carbon dioxide production; CI: Confidence interval.

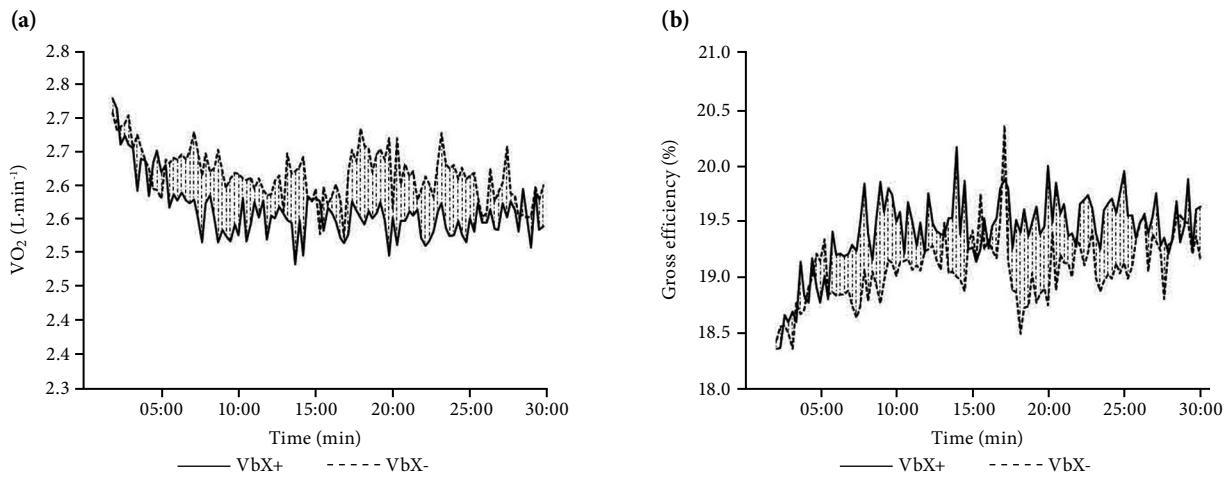


Figure 3. (a) Oxygen uptake and **(b)** gross efficiency differences of 30 min submaximal mountain bike trials. VbX+: With vibration; VbX-: Without vibration.

TABLE 2 Comparison of physiological and performance responses during submaximal mountain bike trials with (VbX+) and without (VbX-) vibration (n=8)						
	VbX+		VbX-		<i>p</i>	ICC 95% CI
	Median	Q1-Q3	Median	Q1-Q3		
VO ₂ (mL·min ⁻¹ ·kg ⁻¹)	35.44	31.2-42.4	36.68	31.53-42.53	0.106	0.92 to 0.99
VO ₂ (L·min ⁻¹)	2.59	2.2-2.9	2.63	2.2-3	0.127	0.91 to 0.99
VCO ₂ (L·min ⁻¹)	2.4	1.9-2.6	2.39	1.97-2.58	0.578	0.71 to 0.98
Minute ventilation (L·min ⁻¹)	65.73	57.54-78.66	67.55	57.54-78.66	0.241	0.86 to 0.99
Respiratory exchange ratio	0.87	0.85-0.89	0.89	0.88-0.9	0.578	0.71 to 0.98
Rating of perceived exertion (Borg scale)	10	8-12	10	8-11.5	0.598	0.83 to 0.99
Heart rate (bpm)	142	135-156	140	136-146	0.944	0.25 to 0.94
Gross efficiency (%)*	19.59	18.36-20.42	19.02	18.02-20.09	0.046	0.75 to 0.98

VbX+: With vibration; VbX-: Without vibration; IQR: Interquartile range; ICC: Intra-class correlation coefficients; VO₂: Oxygen uptake; VCO₂: Carbon dioxide production; IQR: Interquartile range; * p<0.05.

TABLE 3 Comparison of gross efficiency differences over the 15-min intervals of 30-min submaximal mountain bike trials with (VbX+) and without (VbX-) vibration (n=8)								
	Bouts	VbX+		VbX-		<i>p</i>	ICC	ICC 95% CI
		Median	Q1-Q3	Median	Q1-Q3			
Gross efficiency (%)	First 15 min	19.52	18.2-20.17	19.67	18.5-20.69	0.184	0.90	0.64 to 0.98
	Last 15 min*	18.85	17.93-19.92	19.08	18.1-20.46	0.023	0.95	0.80 to 0.99

VbX+: With vibration; VbX-: Without vibration; IQR: Interquartile range; ICC: Intra-class correlation coefficients; * p<0.05.

the 15-min phase was 36.5±6.2 mL·min⁻¹·kg⁻¹ under VbX+ (0.7 mL·min⁻¹·kg⁻¹ difference from the mean), compared to 37.15 ±6.52 mL·min⁻¹·kg⁻¹ under VbX- (0.01 mL·min⁻¹·kg⁻¹ difference from

the mean). Moreover, the mean HR values were 144.9±14.2 bpm and 144.5±15.5 bpm under VbX+ and VbX- conditions, respectively with the mean HR corresponding to 60% of VO_{2peak} of 144.1±6.1 bpm.

DISCUSSION

In this study, we evaluated the effects of GE% and different physiological parameters of WBV training among off-road cyclists during submaximal mountain bike trials. Previous studies examined the effects of acute and long-term vibration applications on anaerobic and aerobic capacity.^[15-17] To date, a few studies have evaluated the effects of providing vibration during cycling performance on the cardiovascular performance and regulation of angiogenesis in mountain bike cyclists.^[10,11] Although the GE% is a determinant performance factor in long-term aerobic endurance competitions, such as the ultra-marathon, the effects of vibration on GE% have not been previously investigated in MTB. The main outcome of our study was to identify a significant increase in GE% with the addition of intermittent vibration, compared to a normal cycling trial ($p < 0.05$). However, the WBV training also caused a 1.5% lowering of the VO_2 at a similar RPE value and same RER.

According to previous assumptions, increasing the cadence of cycling to an rpm of 80 to 120 was less economical than lower rpm cycling values.^[18] However, Lucia et al.^[19] further reported that a high cadence of 80 to 90 rpm reduced activation of the knee extensor muscles (i.e., vastus lateralis and vastus medialis). However, it was shown with the activity of the knee flexors increasing at these relatively high pedal rates.^[20,21] Abbiss et al.^[22] also suggested that the downregulation of knee extensor muscles at higher pedal rates might be beneficial, as the negative force component of the knee extensors would be counterproductive to the force needed during the upstroke of the pedal. This negative force would result from an insufficient speed of the rear leg. Comparably, studies have reported mechanical efficiency to be increased by using a pulling pedaling pattern, although this pattern decreases the muscle efficiency. This decrease in muscle efficiency might be related to neuromuscular fatigue induced by the change in coordination during practice of this technical skill.^[14,23,24] Due to well-trained cyclists' overall pedaling technique and optimization of inertial effects, recovery of negative forces can be positively affected by vibration. Therefore, efficiency of knee flexor muscles may be increased by the VbX+ condition.

The effect of the induced tonic vibration reflex may be closely related to the improvements in GE%. This reflex potentiation is caused by the mechanical effects of vibration on the muscle spindles and is evident during both eccentric and concentric muscle contractions. The positive effects of vibration in

improving neuromuscular performance are likely to be mediated via the effects of the tonic vibration reflex on postural control mechanisms.^[4,8,25] A recent study of 18 adult participants performing static squats during WBV indicated a nearly 50% increase in the muscle activity, per body mass, contributed by the enhanced reflex muscle activity.^[26] The effects of vibration on muscle reflexes are likely to be different for slow and fast-twitch muscles. Muscles which have a dominance of slow-twitch fibers are more efficient at lower speeds of contraction, whereas fast-twitch muscles are more efficient at higher speeds of contraction. In cycling, this speed differentiation is lost, with both slow and fast-twitch muscles contracting together.^[27,28] As cycling time at a high cadence increases, muscle recruitment decreases and fatigue increases, resulting in an overall decrease in the recorded electromyography signal.^[21,29] As vibration enhances neuromuscular coordination, it is likely that fast-twitch muscles are selectively influenced by the positive effects of vibration.^[30] Thus, the enhanced neuromuscular synchronization induced by VbX+ might have increased GE% in our cycling protocol through its effect on fast-twitch muscles. Based on this finding, we can speculate that the effect of GE% can be increased by VbX+ in combination with an optimal cadence.

The effects of vibration on performance may vary as a function of the exposure time. There is evidence that application of vibration for >7 min may decrease fitness parameters and activation of motor units.^[31] On the other hand, significant positive effects have been shown with a one-min exposure to vibration with benefits lasting up to 10 min after the application.^[32] Our findings obtained from an intermittent vibration application are consistent with the findings of Bosco et al.^[32]

The effects of vibration on movement may be also due to, in part, the vibration-induced improvements in peripheral blood flow and a consequent increase in muscle viscosity with muscle resistance to change in length. A previous study examined the effects of WBV on peripheral blood vessel resistance, reporting an increased dilation of capillary vessels with vibration, contributing to an overall lowering of the peripheral resistance of the vasculature.^[33] Suhr et al.^[11] reported an increase in levels of some regulators that trigger angiogenesis, such as vascular endothelial growth factor with a short-duration bout of cycling. A significant increase in the blood flow speed has also been reported

following an exercise performed on a vibrating plate (26 Hz, 3 mm amplitude).^[34] Therefore, vibration-induced dilation of small diameter vessels would decrease peripheral resistance to blood flow, which may likely be mediated through an increase in endothelium-derived vasodilators, such as nitric oxide.^[34,35] Therefore, the effects of vibration of blood circulation has been supported by various studies,^[36] and our study confirmed these effects, indicating that vibration may have improved performance by increasing the blood flow in active muscles, eventually leading to increased GE values.

Surprisingly, the measured VO_2 was lower under the condition of VbX+, compared to VbX- and, therefore, the calculated GE% was significantly higher in VbX+. It is possible that the lowering of the VO_2 could reflect the effects of vibration of blood circulation and, in particular, in the increase in nitric oxide. Indeed, it is known that L-arginine infusion, which is the active substance for nitric oxide formation, increases the glycolysis use, independent from insulin, as well as limits fat oxidation during aerobic exercises. Thus, increasing levels of nitric oxide could suppress cytochrome c oxidase and mitochondrial respiration.^[37,38] Therefore, the increase in GE values may be related to a rise in the anaerobic metabolism synchronized to fast-twitch muscle fibers and suppressed aerobic metabolism. This pathway would lead to a greater oxygen deficit and, therefore, to the decrease of approximately 1.5% in VO_2 which we identified under the condition of VbX+, compared to VbX-.

We conducted our study using a bike and trainer system that is commonly used by well-trained off-road cyclists in their training. These trainer systems do not provide a measure of external force in watts, but rather workloads are defined to correspond to specific ratios of physiological values, such as VO_2 and HR obtained directly from the maximal incremental test. In our protocol, cyclists were asked to continue for 30 min at 60% of $\text{VO}_{2\text{peak}}$. Indeed, VbX+ and VbX- exercises were conducted at the work rates corresponded to 36.5 and 37.2 $\text{mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$; ($p>0.05$).

The major limitation of our study was the small sample size that may have led to lower statistical power. Application of rigid inclusion criteria and difficulty in finding mountain cyclists who are riding at such advanced and professional level. Thus, caution should be taken in generalizing our results to other populations. Further studies are needed to explore efficacy of vibration in other sport activities.

In conclusion, best of our knowledge, this is the first study to provide evidence of a positive benefit of intermittent acute vibration, using a 30-min submaximal cycling trial, in improving GE%. The effects of vibration exercises on efficiency should be evaluated for other vibration characteristics and protocols, as well over the recovery period following various exercises to help define optimal strategies for recovery in cyclists. In practical applications, this study may encourage trainers to provide intermittent vibration during cycling due to their possible positive effects and the natural role of vibration in off-road cycling.

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