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PHYSIOLOGICAL AND PERCEPTUAL RESPONSES OF ADDING VIBRATION TO CYCLING

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ABSTRACT

Sperlich B, Kleinoeder H, DE Marees M, Quarz D, Linville J, Haegele M, Mester J. Physiological and perceptual responses of adding vibration to cycling. ***JEP**online* 2009; 12(2):40-46. The goal of the study was to evaluate the effects of local vibration-induced cycling (at a frequency of 20Hz and amplitude of 4mm) on the cardiopulmonary system and muscle metabolism and perceived responses compared to cycling with no vibration. Twelve healthy men (age: 25.3±1.6 years, weight: 74.2±5.9 kg, height: 181.0±3.7 cm, VO_2max: 56.9±5.1 ml/min/kg) performed two incremental cycle ergometer tests with and without vibration until volitional exhaustion on a cycle prototype. Absolute and relative oxygen uptake as well as minute ventilation increased significantly at 250 and 300 Watts with vibration ($p<0.05$). No statistical differences were found between the tests for lactate concentration, heart rate, rating of perceived exertion and perception of muscular effort ($p>0.05$). The findings show that a superimposed vibration stimulus on cycling compared to cycling without vibration leads to a higher respiratory demand. This phenomenon can result from micro-contractions of the limb muscle due to an enhancement of muscle fiber recruitment and tonic vibration reflex at higher workloads.

Key Words: Vibration, Oxygen Uptake, Ratings of Perceived Exertion, Muscle Sensation.

INTRODUCTION

Whole body vibration is a training method performed in rehabilitation and is reported as a counteracting measure to amyotrophia and bone loss during immobilization (1-3). Localized vibration activates the monosynaptic stretch reflex provoking the stimulated muscle to contract (4). Therefore, this vibration-induced muscular stimulus is used for enhancing strength in different exercise modalities. The effects of plantar superimposed whole body vibration on cardio-pulmonary and metabolic effects have been previously studied (3,5,6). A few authors have shown an increase in oxygen uptake and muscle metabolism during whole body vibration (6,7) and dilation of arterioles during exposure to whole body vibration (8). Only one study has examined the effects of vibration during dynamic cycling on heart rate, blood pressure and exercise time (9). In this study, a bicycle ergometer was mounted directly on a vibration platform transmitting vibration to the complete bicycle frame and initializing the stretch reflex. This design results in transmitting large amounts of vibration directly from the vibration platform through the frame, saddle and handle bars into the legs, arms and pelvis.

We constructed a special apparatus to reduce the amount of vibration waves transmitted mainly to the lower portion of the body. Adding vibration to cycling might influence the cardiopulmonary system and rating of perceived exertion respectively by activating a higher amount of motor units. This leads to an enlarged oxygen demand which in turn would lead to an increase in cardiopulmonary activity.
To our knowledge, there have been no studies to date that were designed to examine the cardio-respiratory, metabolic and perceptual effects of local vibration during cycling. The goal of the study was to evaluate whether local vibration affects cardiopulmonary and perceptual responses as compared to cycling with no vibration.

METHODS

Subjects

Twelve healthy, non-smoking physical education students (mean±SD, age: 25.3±1.6 years, weight: 74.2±5.9 kg, height: 181.0±3.7 cm) volunteered and gave written informed consent to participate in this study which was approved by the university's ethics review board. The subjects (relative VO_2max: 56.9±5.1 ml/min/kg) were fully familiarized with the laboratory exercise procedures as well as with bicycle ergometers. All participants were inexperienced in vibration training. On the test days they were asked to report to the laboratory well hydrated, at least 2 h following a light meal and not to have performed strenuous exercise 24 h prior to testing.

Procedures

The subjects performed an incremental test protocol on a cycle ergometer (Fig. 1) with and without vibration on two separate days in a randomly chosen order. The participants were asked not to perform any physical activity for at least 72 h between the two trials. In each session, the protocol consisted of cycling at 70 RPM with an initial workload of 100 Watts for 5 minutes and incremental 50W increases every 5 minutes until volitional exhaustion was reached. The seat height measured from the center of the bottom bracket to the top of the saddle was adjusted individually to 0.885 x of the inner leg length.

Equipment

For sessions with exposure to vibration, we developed a prototype platform in which only the bottom crank of the ergometer is attached to a vibration platform (Fig 1). The bottom bracket connects the crank set to the bicycle and allows the crank set to rotate freely. The frame is physically disconnected from any vibration stimulus reducing the shock waves to the muscles of lower body.

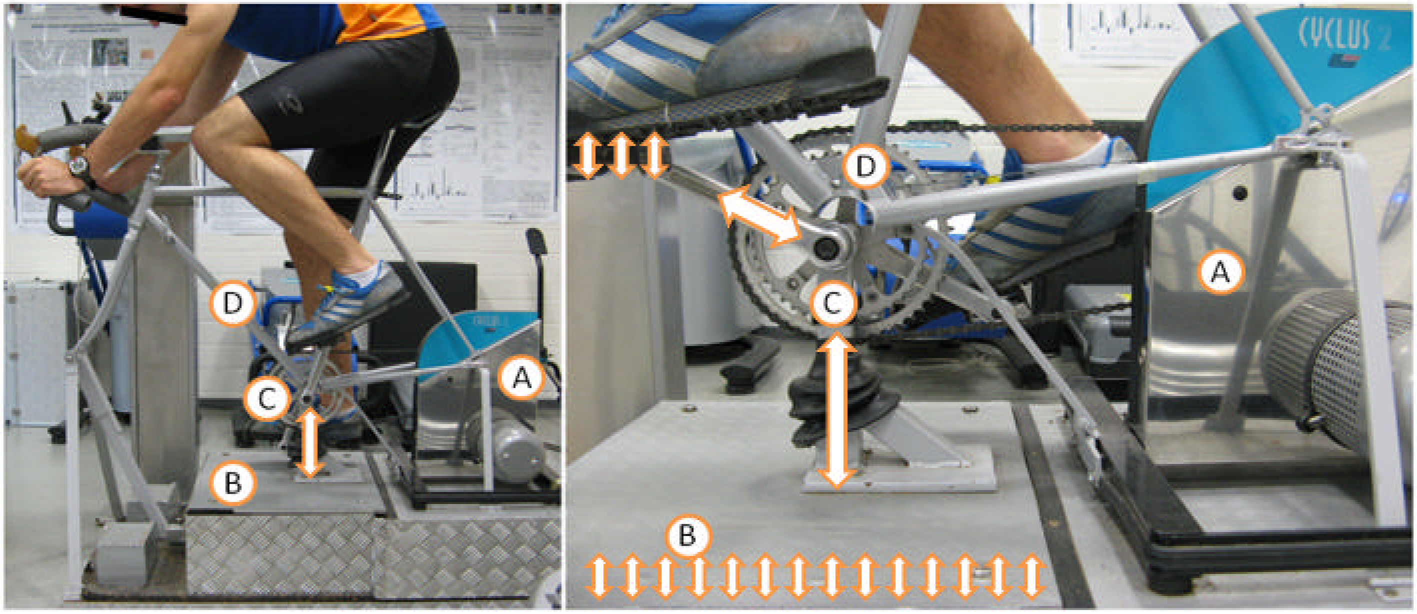

Figure 1: Vibration cycle prototype (Pat No.: DE 102004063495): The ergometer consists of an aluminum platform, a steel bicycle frame (D), a vibration platform (B) and a resistance unit (Cyclus2 Record, Germany (A)). The device is situated on foamed plastic (1200 x 600 x 17mm). The shock waves are generated by a vibration motor (HV 2/2-6, Würges). The bottom crank (C), with the attached pedals is mounted on the surface of the vibration plate and physically disconnected from the frame. The resistance unit is connected by the chain to the gear and pedals. Resistance is controlled automatically by the power control of the Cyclus 2 Record, Avantronic. The arrows indicate the direction of the vibration transmission; starting from the platform to the cranks, then to the pedals, and finally into the foot of the participant.

The frequency of the vibration, which was applied vertically through the crank into the pedals, was 20 Hz with an amplitude of 4 mm. Power output was measured using an SRM Powermeter Crank (SRM, Germany) and controlled by a Cyclus 2 Ergometer (Avantronic, Germany). Oxygen uptake and minute ventilation were measured with an open circuit breath-by-breath spirograph (nSpire, ZAN600USB, Germany) throughout the testing, using standard algorithms with dynamic account for the time delay between the gas consumption and volume signal. The spirograph was calibrated prior to each test using calibration gas (15.8% O_2, 5% O_2 in N; Praxair, Germany) comprised of the range of anticipated fractional gas concentrations. A 1L syringe (nSpire, Germany) was used for volume calibration. Heart rate was recorded in real time every 5 seconds during the tests using short-range telemetry (POLAR S 710, Finland). All respiratory and heart rate data were averaged every 30 seconds. A blood sample of 20µL from the right ear lobe was collected at the end of five minute intervals into a capillary tube (Eppendorf, Germany) and analyzed amperometric-enzymatically for the blood lactate concentration using Ebio Plus (Eppendorf, Germany). Additionally, the subjects were asked to rate their perceived exertion (BORG´s scale 6 to 20) (18), and their perceived level of pain in their thigh muscles using a seven point scale (0 = no pain to 6 = very painful).

Statistical Analyses

Traditional statistical methods were used to calculate mean values and standard deviation (Mean±SD). The effect of independent and dependent variables was analyzed with analysis of variance using Tukey´s Least Significant Difference. A Student's t-test was used to assess the effects of vibration on ratings of perceived exertion and muscle pain. Statistical significance was expressed as follows: $p<0.05$ (*), $p<0.001$ (**). The STATISTICA (version 7.1; StatSoft Inc., USA) software package for Windows® was used for all statistical analysis.

RESULTS

Greater absolute and relative oxygen uptake values and minute ventilation were found during cycling at 250 and 300 Watts with vibration when compared to the trials without vibration (p<0.05). Values at 100 to 200 Watts showed no difference. Heart rate (HR) at all levels was unaffected by the application of vibration as compared to without vibration (Table 1). Also, all lactate values remained unaffected by vibration compared to normal cycling. Rating of perceived exertion and the sensation of muscular effort were similar between sessions with and without vibration at all workloads.

Table 1: Physiological and perceptual responses (Mean±SD) at different workloads during cycling with and without vibration. Statistical differences between sessions with (+) and without (-) vibration p<0.05 (*), p<0.001 (**).

Parameter	Vibration	Power Output [Watt]				
		100	150	200	250	300
Absolute Oxygen uptake [l/min]	+	1.47 ± 0.07	2.05 ± 0.08	2.56 ± 0.11	3.17 ± 0.16	3.87 ± 0.20
	-	1.37 ± 0.13	1.99 ± 0.12	2.52 ± 0.11	3.07 ± 0.16 *	3.71 ± 0.20 **
Relative Oxygen Uptake [ml/min/kg]	+	20.0 ± 0.6	28.0 ± 2.3	35.2 ± 3.1	43.2 ± 3.7	53.7 ± 4.6
	-	18.6 ± 2.0	27.1 ± 2.2	34.3 ± 2.9	41.9 ± 3.7 *	51.6 ± 5.0 *
Minute Ventilation [l/min]	+	30.4 ± 2.5	44.5 ± 3.4	57.2 ± 4.0	78.0 ± 8.3	104.1 ± 12.4
	-	28.2 ± 3.3	42.6 ± 4.0	56.4 ± 4.4	74.8 ± 8.9 *	97.7 ± 9.7 *
Lactate [mmol/l]	+	0.74 ± 0.19	1.25 ± 0.81	1.98 ± 1.21	4.02 ± 2.00	7.81 ± 2.76
	-	0.96 ± 0.32	1.42 ± 0.60	2.31 ± 1.30	4.28 ± 2.00	8.21 ± 3.41
Heart rate [B/min]	+	115.4 ± 7.6	128.5 ± 6.1	146.7 ± 7.9	165.1 ± 7.3	177.2 ± 11.5
	-	117.5 ± 8.4	131.3 ± 8.6	150.5 ± 12.1	167 ± 8.8	182.3 ± 9.8
Rating of perceived exertion	+	9.3 ± 2.1	11.3 ± 1.8	13.9 ± 1.3	15.9 ± 1.3	18.0 ± 1.3
	-	9.2 ± 1.8	12.1 ± 1.5	14.0 ± 0.9	16.1 ± 1.2	18.9 ± 1.2
Muscle Sensation	+	0.7 ± 0.5	1.6 ± 0.5	2.5 ± 0.7	3.3 ± 0.7	4.2 ± 0.9
	-	0.6 ± 0.7	1.5 ± 0.5	2.6 ± 0.8	3.2 ± 0.8	4.0 ± 0.7

DISCUSSION

The main findings of this study are an increase in oxygen uptake and minute ventilation at higher workloads of 250 and 300 Watts (p<0.05) during cycling with vibration compared to normal cycling. There are no statistically significant changes in heart rate, lactate concentration, or ratings of perceived exertion and muscle perception.

Similar results were found in a study conducted by Samuelson and co-workers (9). They examined the effects of vibration while cycling on a vibration platform and also found no differences in heart rate and blood pressure. These authors referred to their apparatus design as a setup for whole body vibration with shock transmission from the vibration platform via the frame, saddle and handle bars into the legs, pelvis and arms. The ergometer used in our design refers to localized vibration into lower trunk muscle because of the fact that the bottom crank is dismounted from the frame. Pre-studies, conducted with one participants pedaling at 150 Watt and 50 RPM, showed a decrease in shock transmission from the vibration platform to hip and head of 93 and 95% measured with acceleration sensors (BIOVISION). Therefore, vibration waves in our design are mainly transmitted to the lower body. From documented data [9] and the present data on heart rate, it may be stated that neither vibration with greater shock transmission (9) nor vibration, localized to the lower torso, during cycling influences heart rate.

Other studies also found an increase in oxygen uptake during whole body vibration compared to non-vibration trials (7). It is well documented that primary afferent endings of the motor spindles are sensitive to vibration (10,11). It may be suggested, that exposure to vibration causes excitation of these afferents and recruits more receptors, which, in turn, activates a larger amount of a-motoneurons and leads previously inactive muscle fibers to contraction (12). Also, previously exhausted muscle fibers may be additionally reactivated through vibration stimulus (13,14). Mechanical waves transmitted from the pedals into the lower body will activate a great number of vibratory sensitive muscle receptors. As a result a large number of additional motor units will be recruited, leading to greater muscle or whole-body oxygen consumption especially during higher workload. This phenomenon may explain the increase in oxygen uptake at higher workloads of 250 and 300 Watts. Furthermore, minute ventilation rises significantly at 250 and 300 Watts in order to satisfy muscular oxygen needs, also indicating a greater respiratory response as demonstrated by the data.

These results indicate that adding vibration to cycling may be an enhancing stimulus for aerobic training. Suhr et al. (15) studied 12 men with the same vibration apparatus used in this study, underlining that mechanical vibration influences factors involved in the induction of angiogenesis. Therefore, adding vibration to cycling may have a positive benefit on aerobic training in athletes, as well as for patients suffering from arterial obstructive disease.

Further, the present findings reveal no difference in lactate concentration at all workloads, suggesting no shift in glycolytic energy turnover. A possible mechanism may be due to changes in muscular blood flow. Yue and Mester (8) demonstrate a considerable increase in blood flow in thigh muscles and dilatation of small vessels during whole body vibration. Hydrodynamic analysis offers the mechanism for the increase in blood flow through the deformation of vessels. As a reaction of compensation to vibration, more capillaries are opened in order to maintain necessary levels of cardiac output, resulting in more efficient metabolism between the blood and muscle fibers. The skeletal muscle is the major producer of lactic acid in the body, but its oxidative fibers also use lactic acid as a respiratory fuel (16). So, if vibration-induced cycling leads to an additional opening of vessels causing an increase in blood distribution, this would favor elimination of lactate within the muscle tissue (17).

On average, there was no statistical difference between both trials for ratings of perceived exertion and sensation of muscular effort. Although oxygen uptake increased 100-160 ml/min at higher intensity indicating a possible greater muscular activity, the participants did not rate their perceived exertion and sensation of muscular effort differently between both sessions. All data considered, the differences in oxygen uptake and minute ventilation between the trials are rather minute. The maximal difference between cycling with and without vibration ranges from 100-160 ml/min. Therefore, it may be considered that cycling during the presented vibration stimulus does not seem to affect ratings of perceived exertion.

CONCLUSIONS

The study demonstrates minimal yet statistically significant changes in oxygen uptake at higher workloads, but no changes in blood lactate and perceptual responses when vibration is added to cycling. Overall, the findings are in accordance to findings from vibration platform studies and reveals potential for oxygen uptake changes when vibration is added to cycling, especially at higher workload. Further research should focus on the chronic effects of cycling under vibration on aspects such as angiogenesis, muscle damage and changes in cardio-respiratory performance.

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