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Influence of Vibration on Work Performance during Ergometer Cycling

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ABSTRACT

With a view to investigating how vibration affects dynamic working capacity, exercise tests were performed both with and without superimposed vibration. The performance of 8 healthy, non-smoking 20-year-old males exercising on a cycle ergometer at a constant load was studied on four occasions, with and without vibration in a randomly chosen order. The frequency of the vibration, which was applied vertically through the pedals, was 20 Hz and the acceleration was 20 m/s^2 RMS. The handlebars and saddle of the cycle were insulated from the vibration.

The exercise time averaged 47 min with vibration and 60 min without. The vibratory stress reduced the exercise time by 13 $\pm$ 2.9 min (mean $\pm$ SEM) ($P<0.005$). The average heart rate when the exercise was stopped was 180.3 beats/min with vibration and 180.7 beats/min without. The systolic blood pressure after 20 min averaged 188 mm Hg with vibration and 187 mm Hg without vibration. Both with and without vibration, 6 of the 8 subjects stated that leg fatigue was the cause of their inability to continue pedalling longer. Our conclusion is that in the performance of dynamic muscular work endurance may decrease under the influence of vibration.

INTRODUCTION

In many areas of industry workers are exposed to various types of vibration. This is partly due to the mechanization of the heavier types of work. However, by virtue of their modes of operation, the machines used for this purpose produce jolts and vibrations that are transmitted to the environment. In such environments there is usually an operator who holds or grips the machine as a tool or is standing on the same chassis.

The effects of vibration on the human body are of a very complicated nature and are incompletely understood in spite of a large number of studies. In the investigations that have been made, there is a heavy emphasis on how the vibration is introduced: i.e., effects on the whole body or parts thereof, posture and the composition, frequency, amplitude and duration of the vibrations (3, 4, 12, 15, 22, 25).

In a review, Hasan (17) has recounted how low-frequency vibrations affect certain physiological variables, e.g. oxygen uptake, ventilation and cardiac output. The studies that have been made invariably apply to the situation at rest and the findings are not always the same. None of the studies found in the literature were primarily designed to determine how superimposed vibration affects the capacity to perform dynamic work.

The aim of this study was to investigate endurance in submaximal dynamic work, with and without superimposed vibration. For this purpose 8 volunteers were studied during exercise on a bicycle ergometer with vibration introduced via the pedals.

METHODS

Eight healthy, non-smoking 20-year-old males were studied. The age range was 19 - 22 years and the subjects were of normal build and exercised regularly.

A cycle ergometer of the type described by von Döbeln (5) was used for the study. The cycle was mounted on a vertically vibrating table.

The frequency of the vibrations was 20 Hz and they were sinusoidal. This frequency was chosen because it corresponds with the natural frequency of the thigh muscles with the experimental design used. The frequency was determined from pilot trials and is in good agreement with data cited in the literature (13, 26). The acceleration was 20 m/s^2 RMS (28.3 m/s^2 peak). At 20 Hz this acceleration is equivalent to an amplitude of 1.8 mm.

The vibratory motion was controlled by a built-in feedback and control system in the table and an oscilloscope connected to an accelerometer held in position by a magnet (Brüel & Kjaer 4333). The movement of the different parts of the bicycle could also be measured with the accelerometer. Applied manually, the same accelerometer was also used to estimate the transmission of vibrations through the body from the feet. The frame (with crankcase) of the ergometer cycle was firmly bolted to the table. The handlebar grips were insulated with thick neoprene synthetic rubber. The saddle was sprung vis-à-vis the frame with coil springs and the saddle cushion was insulated with several thick layers of neoprene. With this arrangement the saddle and handlebar grips were well insulated from vibration. The height of the saddle was adjusted individually so that the legs were virtually straight when the pedals were in the lowest position.

The vibration-related accelerations in the vertical place were measured at the top of the foot and at the kneecap, iliac crest of the hipbone and top of the head by having an assistant press the accelerometer with one finger against the respective points on the body. The measurements were taken with the pedal in its highest position and the subject's back slightly bent with his hands on the handlebar. The accelerations were 20 m/s^2 at the foot, 8 m/s^2 at the kneecap, 3 m/s^2 at the hip and 2 m/s^2 (RMS) at the top of the head. Similarly, the vibration of the saddle during cycling was found to be 4 m/s^2. This value is below the level considered to cause fatigue and reduced working capacity according to the international standard for industry (ISO) (19) and is decidedly below the limit for vibratory acceleration considered to have a negative effect on health and safety.

The subjects exercised at a constant submaximal load and at a pedalling frequency of 60 r.p.m. until complete exhaustion. The loads were selected individually on the basis of pilot trials and in such a manner that the subjects could be expected to cope with an exercise period of about 45 min. It was also ascertained in the pilot trials that the physical condition of the subjects had been constant during the period of time immediately preceeding the study.

The study included recordings of the total cycling time, heart rate, systolic blood pressure and subjective assessments of general fatigue, leg fatigue and shortness of breath. The heart rate was determined every 10 min and at the end of the exercise from the continuous ECG recording. The systolic blood pressure was measured in the right upper arm by the cuff method after 20 min of exercise under all conditions.

Each subject performed 4 exercise tests with intervals of at least 4 days. Two tests were performed with vibration and 2 without in random order. The results are presented as means $\pm$ SEM. The respective means for each subject's 2 tests with and without vibration were calculated in the statistical analysis. Comparisons of the 2 situations were made with the aid of Student's t-test for paired observations.

RESULTS

The exercise time amounted to 59.5 $\pm$ 7.7 min (mean $\pm$ SEM) without vibration and 46.9 $\pm$ 5.3 min (mean $\pm$ SEM) with vibration. The reduction of exercise time amounted to 12.6 $\pm$ 2.9 min (mean $\pm$ SEM) ($P<0.01$) or 21%.

The heart rate at the termination of the exercise was not significantly different in the 2 situations: 180.3 with vibration and 180.7 without.

The systolic blood pressure after 20 min averaged 188 mm Hg with vibration and 187 mm Hg without (P>0.05).

The subjects' own subjective assessment of the primary cause of their not being able to pedal any longer were leg fatigue (n = 6), shortness of breath (n = 1) and general fatigue (n = 1). The assessments by all subjects were the same for the test with and without vibration.

T A B L E

Load, exercise time, final heart rate, systolic blood pressure at 20 min and subjective reasons for terminating exercise with and without superimposed vibration.

Subject	Load [W]	Exercise time (min) without vibr	Exercise time (min) with vibr	Final pulse (beats/min) without vibr	Final pulse (beats/min) with vibr	Blood pressure (mm Hg) without vibr	Blood pressure (mm Hg) with vibr	Subjective cause of stopping without vibr	Subjective cause of stopping with vibr
1.	230	68	53	175	174	190	190	Leg fatigue	Leg fatigue
2.	200	51	36	194	199	193	190	Dyspnoea	Dyspnoea
3.	210	37	27	195	189	190	190	Leg fatigue	Leg fatigue
4.	220	108	78	188	185	180	188	Leg fatigue	Leg fatigue
5.	190	54	47	173	178	187	195	Gen.fatigue	Gen.fatigue
6.	200	61	51	173	172	178	180	Leg fatigue	Leg fatigue
7.	220	53	41	180	177	180	175	Leg fatigue	Leg fatigue
8.	230	44	42	168	169	195	195	Leg fatigue	Leg fatigue
Mean:		59.5	46.9	180.7	180.3	187	188		

DISCUSSION

The present study shows that vibrations transmitted to working muscles reduce physical working capacity measured as endurance during bicycle ergometer exercise at a constant load. We have found no similar studies in the literature on the effect of vibration on physical working capacity involving dynamic work by large groups of muscles.

No effect of vibration was found in normal subjects on maximal muscle force and endurance in intermittent isometric work involving small muscle groups in studies by Färkkilä and co-workers (10, 11). In these studies the investigators recorded gripping forces during hand muscle contraction - relaxation at alternating intervals of 2.5 sec with and without superimposed vibration within a frequency range of 30 - 400 Hz. In a previous study of isometric muscle contraction (26) we found that superimposed vibration reduced endurance by 30%.

The demonstrated decrease in endurance during submaximal cycle ergometer exercise in the present study may be due to factors in the central nervous system or circulation or in the exposed working leg muscles. Two of the recorded circulatory variables, systolic blood pressure and heart rate, showed virtually identical values in the 2 test situations. The effect of vibration on central circulation during exercise has not been studied before, but it has been studied considerably during rest. Hood et al. (18) studied 4 reclining subjects exposed to 2 - 12 Hz vibration with 6 and 12 m/s^2 peak acceleration. They found a slight increase in mean arterial blood pressure, heart rate, cardiac output, oxygen consumption and minute volume of ventilation at 8 Hz that fell off at higher and lower frequencies. They drew the conclusion that the increase, which is equivalent to the circulatory effect of very slight body movement, was due to reflex induced movements of the musculature.

Both the present study and earlier ones would best be explained by work performance being limited by local effects in the working muscles or their nervous control.

It is known from studies of skeletal muscles at rest and during isotonic and isometric contraction that vibration produces neuromuscular effects (1, 2, 6, 16, 20, 21, 24). The so-called tonic vibration reflex (TVR) has been studied most thoroughly. This phenomenon, which imitates the tonic stretch reflex, gives rise to contractions that are considered to be due to stimulation of the muscle spindles.

The work of cycling consists of alternating and very strong contractions, mainly of leg extensor muscles while the flexor muscles are not much active. Vibration could hardly increase the strength of extensor contractions but it might activate the antagonist flexor muscles and in this way decrease the output of the leg, accelerating fatigue. But there are other possible explanations that have to be investigated.

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