The Mechanical and Physiological Effects of Whole-Body Vibration through the Upper Extremity Muscles of Gymnasts

PhD Thesis

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1. INTRODUCTION

The acute residual and chronic effects of whole-body vibration through upper extremity muscles on the mechanical performance of gymnasts were studied. With regard to hormonal changes, the research covered the effects of acute residual vibration, and regarding the maintainance of static equilibrium it covered the effects of chronic vibration. The effects of vibration training are expressed in increased muscle strength and physical performance through the stimulation of the neuromuscular system. As a practical expert, I asked myself the following questions: what are those effects that can contribute to developing sports movements, effectively increase performance and decrease the harmful effects of load, and help coaches maintain a safe environment for sports activities.

In addition, the development of a gymnast's relative force is a basic requirement of the sport, in addition to the improvement of their vestibular and proprioceptive systems. The conditional background of graceful and harmonic movement is characterized by factors such as speed, maximal, endurance and explosive strength.

In the research we seek answers to how these abilities – strength, skilfulness, speed, balancing ability and endurance – can be developed with these new methods in gymnastics.
The performance-enhancing effects of vibration can be proven with a gymnast being in the air for a longer period of time and in their improvement in terms of volume of exertion.

My interest in the mechanical laws and their relationship to sports movements was aroused by a Finnish and by an international research group, which I had the chance to join. They studied the behaviour of elastic components of different vertical jumps with the help of an electrode spindle attached to the Achilles tendon.

Special literature covers the effect of lower extremity vibration on the whole body, an investigation of the motor system, and mechanical and biochemical indicators as a performance-enhancing training method.

The investigation of the physiological effects of whole-body vibration on upper extremities has not been studied by many researchers.

We presume that the mechanical performance of muscle contraction together with the effects of vibration training can also be increased in the elbow extensors with the regaining of elastic energy.

Hormonal response in the investigation of upper extremities has not been studied yet.

As far as the sense of balance is concerned on which the vibration has a primary effect, the sensory organs and the central nervous system are of utmost importance.

There are observations that show that the maintainance of balance improved as a result of the application of vibration; on the other hand, it is also influenced by physical condition. However, opinions in literature about the physiological effects of vibration on balancing ability are divided.

2. HYPOTHESES

2.1 Acute residual effect on mechanical indicators

- It is assumed that in the support position the mechanical vibration of the whole body on the muscles of upper extremity and shoulder has similar performance-enhancing effects as was demonstrated with regard to the vibration of lower extremities.
- It is assumed that mechanical vibration has a more significant effect on the chronological process of elbow flexion and extension in front support position if the exercise is performed with a range of motion chosen by the subjects compared to the exercise done with a full range of motion.
- It is assumed that for gymnasts who exercise regularly and with high intensity and load, mechanical vibration causes significantly greater improvement in performance than for those who do their sport activities with fewer training sessions and less load.
- It is assumed that the residual effects of mechanical vibration remain for ten minutes after the vibration, but the effects show a regressing tendency.

2.2 Acute residual effects on hormonal indicators

- It is assumed that the mechanical vibration applied to the upper extremity muscles and shoulder does not result in a significant change in testosterone secretion, which is based on the observation that a significant change in hormone level is mainly caused by the powerful contraction of big muscles.

2.3 Chronic effects of four-week mechanical vibration training

- It is assumed that a four-week intervention of three training sessions per week results in long-lasting changes (enhancement in performance) in well-trained gymnasts.

- It is assumed that mechanical vibration carried out every week results in significant acute residual performance enhancement mainly due to increased vibrational load and intensity.

2.4 Residual effect of mechanical vibration on standing stability

- It is assumed that mechanical vibration has no general effect on balancing ability, even though the vibrational effect succeeds through the nervous system. Notably, the vibration applied in the support position of the upper extremities does not have an effect on the stabilometric parameters in standing position.
- It is assumed that the acute residual effect of vibration applied in the support position through the upper extremities decreases body swing during the handstand.

3. MATERIALS AND METHODS

3.1 Subjects

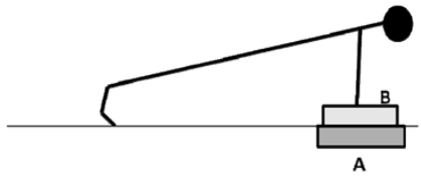
Thirty-eight (38) male gymnasts participated in the study. Table 1 shows their data.

Table 1 Mean and scattered plot values of age, weight and height

Research group / Indicator	Floor reaction force-time study (acute residual effect)			Hormonal study (acute residual effect)			Balance study, Floor reaction strength-time study (chronic)	
	V 1	**V2**	**C1**	**V1**	**V2**	**C2**	**V3**	**C3**
N	9	8	7	9	8	9	5	7
Age (year)	22.8±2.5	23.5±2.8	23.4±1.7	22.8±2.5	23.5±2.8	21.1±2.3	25.0±5.7	21.0±1.9
Weight (kg)	66.6±3.7	72.9±3.9	70.7±10.4	66.6±3.7	72.9±3.9	74.6±4.2	64.4±5.8	74.9±5.7
Height (cm)	172.2±3.2	174.9±3.3	174.3±3.0	172.2±3.2	174.9±3.3	176.3±3.1	168.8±4.0	182.9±5.6

3.2 Vibration training

The subject starts in a front support position with hands shoulder width apart, supported on the upper part of the vibration bench. Before performing the tests, the subjects' elbow joints and body are fully stretched, and the legs are closed. The body is supported on the palms and the balls of the feet (Figure 1).



The vibration device (B) is on the Kistler platform (A). The subjects performed the tests with push-up exercises from this starting position in CMJ: VA and TA range of motion. In starting position the weight strength of the body was measured on the vibration bench. The mean values were compared to the weight strength of the group measured in standing position and were calculated as a percentage.

Figure 1 Starting position of push-up exercise during the tests

3.3 Vibration protocol applied in the acute effect study

WBV training effect: Experimental groups V1 and V2 were exposed to vibration in front support position (30 Hz, 6 mm), five times for 30 seconds, with 60 seconds of rest intervals between the exercises. Elbows were flexed at 90 degrees during the vibration treatment. Gymnasts spent the rest interval period in a chair suitable for relaxing the upper extremity muscles.

3.4 Vibration training applied in the chronic effect study

WBV training effect: Experimental group V3 was exposed to vibration for four weeks, in 13 circuits altogether. The elbow was flexed at 90 degrees during the vibration treatment. When the subjects of V3 and C3 groups prepared for the test, they were exposed to vibration that changed weekly (25-30-35-25 Hz, 6 mm), and repetitions changed every week (5x-6x-7x-5x), for 30 seconds, with 60 seconds of rest intervals between the vibration sets (Figure 2). They spent the rest period in a chair suitable for relaxing the upper extremity muscles.

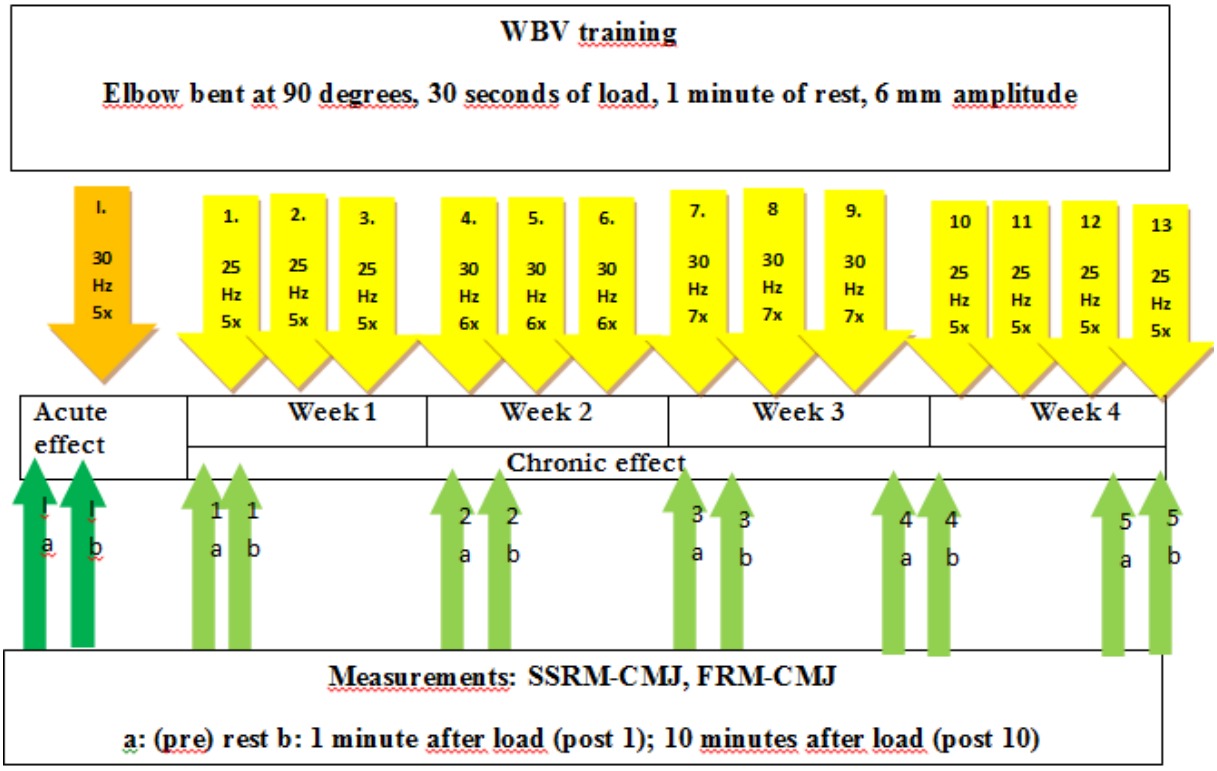


Figure 2. Intensity and frequency of WBV load and summary of test measurements

3.5 Tests of mechanical vibration

Elbow flexion and extension in front support

The subjects had an opportunity to choose the range of motion of the elbow flexion and extension (VA) in front support position (with small amplitude in general); then they extended the elbow by pushing off (counter movement jump = CMJ) the platform to arrive in a front support position with straight arms, if possible. The subjects were instructed to flex their elbows in such a way as to gain the fastest extension at the joint and to stay in the air for as long as possible.

With regard to pushing off (CMJ) the platform with full elbow flexion and extension in front support (TA), the exercise was correct if the chest touched the vibration platform. The students were asked to execute a push-off with maximum effort after elbow flexion and extension with full range of motion, and then arrive in front support with straight arm.

Defined variables

Duration of execution (Tc): This is the time span from the beginning of elbow flexion to the execution of elbow extension. This is the support phase of the tests.

Duration of flight phase (Tf): This is the time span from the execution of the elbow extension and the pushing off the platform to landing on the platform.

Volume of force exertion (F): This is the measured vertical force exertion value which represents the longest time spent in the air in the equivalent test sets.

Impulse: (I) This is the product of the average force multiplied by the time it is exerted; namely, this was the difference and average value of two force values following each other every moment when performing elbow flexion and extension without the values of the moment.

From the CMJ floor reaction strength-time curve, the time for transmission of force (Tc) and the flight time (Tc) were defined. The explosive strength indices were calculated by the quotient of Tf/Tc.

$$I = \int_{t_1}^{t_n} (F - G)_{(t)} \cdot dt$$

The area under the strength-time curve (**impulse**) was calculated without taking into consideration the force of gravity of the body.

F= vertical floor reaction strength,
G= force of gravity of the body measured on the platform,
t= time

To analyse every variable the best values of the tests were taken into consideration and compared.

Defining of hormonal concentration

For the hormonal examination, a fifty (50) millileter urine sample was taken from the members of the experimental groups (V1, V2 and C2) 10 to 15 minutes before the tests during the rest intervals to define the activity of testosterone and epitestosterone. Following the warm-up, the WBV training and the test exercises, urine samples were taken again in 10 minutes and were evaluated within one day. Urine samples were analysed by Pucsok et al. of Wessling Hungary Environmental Protection, Food Safety, Health Protection and Quality Ltd. Testosterone activity and testosterone concentration were defined with a gas-chromatography mass spectrometer.

Balance/Equilibrium tests

Romberg I (RI): Starting position: subject stands with feet closed and arms forward middle. Duration and condition of measurements: 60 seconds with eyes open.

Romberg II (RII): Starting position: subject stands with feet closed and arms forward middle. Duration and condition of measurements: 60 seconds with eyes closed.

Gymnast stance (TOR): Starting position: subject takes gymnast stance with arms forward middle. Duration and condition of measurements: 20 seconds with eyes open, heels off the ground, and knees flexed at 100-110 degrees.

Handstand (KA): Starting position: subject does handstand with hand support shoulder-width apart, fingers closed, thumbs on the surface of the platform, and fingers on the side of the platform. Duration and condition of measurements: 20 seconds with eyes open.

Description of defined variables

The anterior-posterior (AP) COP, medial-lateral (ML) direction of COP, the full length covered in 20 seconds and the circle radius ® including 95% of stabilogram were described from the stabilogram. Variables were defined with 0.1 mm accuracy. Data were recorded on a computer and processed later.

4. METHODS

4.1 Acute residual effects of mechanical vibration

The characteristics of force-time indicators of whole-body mechanical vibration on the upper extremity and shoulder muscles resulted in similar performance-enhancing effects in support position as its acute residual effects on lower extremity muscles. In push-offs from front support performance increased significantly by 12-21%, which was similar to vertical jumps where performance increased by 10-11%.

Mechanical vibration has a more significant effect on the process of elbow flexion and extension of front support applied as test exercise in VA mode than for TA mode. The acute residual increase in performance was measured in the professionally trained group whose time spent in the air increased by 10.1% and by 7.4%, one and ten minutes after vibration in VA, respectively, compared to TA mode.

Mechanical vibration caused a more significant change in the performance of gymnasts who trained with a heavy load every day than for those who trained using fewer repetitions and a less heavy load. Subjects at different training levels were exposed to the same vibration load and had different acute residual effects. Whole-body vibration has a more significant effect on the mechanical performance of professionally trained gymnasts in VA and TA mode. The effects of performance enhancement in the group which trained less could not be detected because of fatigue.

The residual effects of mechanical performance persisted for ten minutes after vibration. The effect showed a slightly regressive tendency. During the recovery time following the whole-body vibration treatment, the volume of push-offs decreased, but the decrease in the time spent in the air was significantly longer when performing the VA type test exercises. Ten minutes after the vibration the time spent in the air decreased by 3-6% in push-offs introduced with VA and TA motion. Parallel with the decrease of the neuromuscular effects, muscle stimulation also became moderated, but it did not decrease below the level it was at before the vibration treatment.

4.2 Acute residual effects on hormonal indicators

Mechanical vibration on upper extremity and shoulder muscles did not cause significant changes to testosterone secretion. On the basis of our research we firmly believe that changes in hormonal level cannot be detected with the application of vibration on the upper extremity muscles. As the muscle mass of upper extremities is relatively lighter than that of the lower extremity muscles, the changes in testosterone levels did not follow the tendencies of performance enhancement, and did not cause significant changes.

4.3 Long-lasting and residual effects on mechanical indicators

The intervention of three training sessions per week for four weeks caused a long-lasting increase in the performance of the group treated with vibration in spite of the fact that no acute residual effects in the vibration group were found. In this latter group, the time spent in the air compared to the group without WBV. An increase of 15-23% was observed at rest before the vibration and after 10 and 13 WBV treatments, which means there were long-lasting effects of WBV although they were not significant. The increase of the longer-lasting effect was due to the increase in the number of training sessions and the intensity of the vibration training; however, this shows the changes in performance (Tf) with greater individual scatter plots than the traditional training with the same volume.

During the weekly examinations, the acute residual effects of WBV caused a significant increase in Tf/Tc quotient in the vibration group. This indicator, which shows explosive exertion, is significantly bigger when performing a TA type test exercise (25 Hz). When the vibration stimulation was increased from 30 Hz to 35 Hz, and then was decreased to 25 Hz, we found that the residual effects of WBV did not increase mechanical performance when coupled with an increase in frequency and repetition because the time spent in the air and the impulse did not change significantly. This depends on the physiological adaptation of the individual in many cases.

4.4 Long-lasting and residual effects of maintaining balance

Mechanical vibration has no general effect on balancing ability, in spite of the fact that the vibration effect manifests itself through the nervous system. It was found that the application of the vibration on the upper extremities with the subject in support position has no influence on stabilometric indicators in standing position as maintaining balance in Romberg tests and the static gymnast’s stance typical for gymnastics did not improve. Our examinations indicate that the afferentation of the upper extremity has no close connection to

the afferentation of the lower extremity, and fatigue with a 25 Hz vibration load increases the values of body swing.

The residual effects of vibration treatment on the upper extremities with the subject in handstand position decreases body swing. The stability of the handstand increased by 18-33% at rest due to WBV treatment, without a significant change before the given measurement. This increase has no connection with the load, which varied weekly. On the other hand, the slight increase proved long-lasting. As a long-lasting effect, after WBV load the volume of body swing decreased by 3.6% to 30%, but the change was not significant. The increase in handstand stability resulted in the increased alertness of the brain by stimulating the proper areas within it and an increase in muscle tone which spread to the upper extremity and to the whole body, which decreased the body swing values.

5. CONCLUSIONS

Our research indicates that whole-body vibration can be used in gymnastics to achieve beneficial results in developing the explosive strength of the upper extremity muscles. The majority of our hypotheses are proved in the research. Our research shows that strength-time indicators have similar features with regard to the upper and lower extremity muscles when whole-body vibration is applied. The force exerted by elbow extensors increased and resulted in a longer time spent in the air with regard to both acute residual and long-lasting effects. Subjects work more effectively from a muscle contraction standpoint by performing elbow flexion and extension with a range of motion chosen by subjects rather than elbow flexion and extension with full range of motion because it not only strengthens the muscle, but the elastic energy gained from stretching the tendons also increases the volume of push-offs. It was found that the application of vibration on subjects of various physical condition has a greater effect on the more highly trained group. An increase in testosterone level is not experienced when the hormonal level from urine samples is measured.

We gained more information by learning that vibration has an effect on maintaining balance. Balance maintance showed a tendency to improve during long-term examinations, but no significant change occurs in every indicator.

The uniqueness of our research is that data about mechanical indicators during vibration treatment was collected in such a way that the vibration bench was attached to the Kistler force platform. Another unique aspect of our research is that the mechanical indices were

investigated together with the hormonal and balance maintainance indicators. In connection with stimulating the nerve tracks, our research indicates that there may be an opportunity to develop balancing ability (which is important in gymnastics) by using the method of vibration. The knowledge gained in this area is encouraging; however, further research is needed It can be stated that WBV, controlled in laboratory circumstances, is a method for enhancing performance which fulfils expectations and encourages us to do further investigations and to use findings in a practical way in training sessions.

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