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Original Research

Effects of 8-Week Intermittent Whole Body Vibration Combined with Sub-Maximal Resistance Training on Strength Capacities in Health-Related Training of Young Females

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Abstract

The authors recently were shown some positive effects of controlled whole body vibration (WBV) as an exercise modality. The purpose of the present study consists of revealing chronic effects (8 weeks) of intermittent whole body rotation vibration combined with sub-maximal static and dynamic resistance physical exercises on strength capacities of young females in health-related training. Thirty-seven healthy females 20-25 years old were randomized into two groups (experimental and control). Results showed the positive effects of dose using rotation whole body vibration in sub-maximal resistance physical exercises upon some characteristics of isometric, isokinetic strength, jumping power, and strength endurance for 24 sessions of training.

The 8-week program of young female sub-maximal resistance training combined with intermittent WBV appeared more efficient than the same content of conventional resistance training without WBV. Increasing strength capacities took place first of all during the first 4 weeks of training and was more essential in hand isokinetic and in isokinetic leg and jumping capacities than in isometric leg strengths. There was no significant increase of strength endurance in vibration group in comparison with the conventional training group.

Keywords: whole body vibration, strength capacities, young female, chronic effects, sub-maximal exercises

Introduction

In recent years the use of vibration stimulation during resistance training has gained in popularity. Whole body vibration (WBV) has been proposed as an alternative exercise stimulus of musculoskeletal structures to produce adaptive responses similar to resistance exercise [1-5]. The hypothesis of Bosco et al. [6] that vibration training produces the same effect as weight training gives vibration training much greater practical relevance. It may also represent an effective pharmacologic therapeutic intervention to target several physiological systems. Previous work has suggested that vibration exposure elicits small but rapid changes in muscle length, producing reflex muscle activity

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in an attempt to dampen the vibratory waves [7]. Effects of different types of vibration – vertical (sinusoidal), swing-like (inclined or rotation vibration) as well as of stochastic character have been studied [8-11]. WBV has gained attention as another exercise modality that may elicit acute improvements in performance for various types of strength, jumping, and running-related tasks [4, 9, 12]. For this reason, most of the studies have focused on examining the neuromuscular responses to WBV exercise [13]. Vibration training either produces potentiation at the level of the motoneurone pool, or increased efficiency of the Ia afferents in load compensation. In the first case, vibration training provides the potential of increasing force, speed and/or power in maximal contractions [6]. In the second case, the potential is restricted to contractions in which the Ia feedback could play a role in the build-up of force. The added value of vibration training combined with maximal or sub-maximal weight training is probably an increased excitation volley on the motoneurone pool, in comparison with traditional weight training [14, 15]. In addition, vibration training affects proprioception [14, 16, 17].

Vibration training has both an acute and a structural (chronic) effect on strength and power and on the range of motion of joints whose muscles experience vibration. The acute effect focuses on the changes immediately after a single session of vibration training, while a structural effect focuses on the changes after a few or more weeks of vibration training, sometimes combined with resistance training. Current findings suggest that vibration training may have positive acute and chronic effects on neuromuscular performance and training [1, 5, 18-21]. However, these facilitatory effects of vibration training are influenced by training protocols in terms of both vibration characteristics (method of application, frequency, and amplitude) and exercise protocol (training type, intensity, and volume). To the highest degree it's related to chronic effects of WBV training. In contrast to the acute effect, it is possible from a structural point of view that intramuscular super-compensation occurs after vibration training [6, 8, 22]. The greatest chance that this super-compensation will occur is when sub-maximal or maximal contractions are carried out during the vibration training. Super-compensation naturally only occurs after rest. This rest must be prolonged, especially in the initial phase of vibration training [5, 7]. Analysis of chronic effects may be complicated by the process of a motor learning effect developing with increased neuromuscular efficiency, possibly because mechanosensors (primary afferents of the muscle spindle) are able to convert a large volley of impulses more efficiently into the release of neurotransmitter in maximal contractions, and into using motor units that are normally left unused [6, 10, 23, 24]. The question is whether effects of this kind can take place as quickly as Bosco et al. presume [6].

Despite the positive findings, several investigators have also shown no improvement in performance measures following acute WBV, and this has led many investigators to question the value of this training stimulus [17, 19, 25]. It has traditionally been assumed that an effect of this kind can only develop after a period of weeks. But unknown optimal period of WBV training coupled with exercises [9]. The training effects may be related to an increase of the concentration of testosterone and growth hormone in the blood after vibration training [6, 7]. An increased testosterone concentration could cause facilitation at the level of neurotransmitters. Furthermore, a relationship has been shown between testosterone concentration and explosive force. Thus this effect of WBV training in females may be modified by a specific hormone. Currently information about such studies is limited. Some other questions of chronic effects of WBV are related to intensity of strength training and resting period between sessions. It is important that the combination of vibration training with maximal weight training without intervening rest days produces intramuscular damage [1, 6]. Other studies combine maximal or sub-maximal weight training with vibration training and speculate on a motor learning effect [4, 16, 26]. Therefore, it may be suggested that in health related training unloaded vibration training and sub-maximal strength WBV training is preferable. Maximal weight training combined with vibration training appears to provide no advantage over sub-maximal weight training combined with vibration training [5, 27]. It is therefore important whether subjects did on vibrating plate sub-maximal or maximal contractions and also whether the vibration training is undergone in a static position, or is actually applied during a dynamic contraction [8, 27]. The amplitude and acceleration of contraction are also important, because these factors determine the eccentric load.

Current research shows that effects of WBV training in chronic adaptation can have a number of useful suggestions for future study and the use of WBV in practice. But the effects of WBV following a series of bouts of WBV coupled with sub-maximal resistance training over an extended period on neuromuscular adaptation in fitness and health-related training are not clear. Some specific chronic effects of WBV training of females may be premised. So there is the possibility that the additional effects of WBV may be useful in programs of health related sub-maximal resistance training for increase of the triceps and quadricep strength performance and rising efficiency of conventional resistance training of females. We hypothesized also more essential effect on maximal strength and power than on strength endurance and time effects of WBV training during 8 weeks. The purpose of the present study consists in revealing chronic effects (8 weeks) of intermittent whole body rotation/inclined vibration combined with sub-maximal static and dynamic resistance physical exercises on strength capacities of young females in health-related training.

Materials and Methods

Subjects

Thirty seven young females aged 20-25 years (students) voluntarily participated in the study (Table 1). All testing procedures and the training protocol were

Table 1. Characteristics of subjects (n=37), mean (SD).

Groups	Age	Height	Body mass	Fat-free body mass	BMI
	(years)	(cm)	(kg)	(kg)	(kg/m²)
Vibration training group	23.25	166.15	63.61	46.45	23.07
	0.67	4.71	7.71	1.9	1.87
Control group	20.87	166.05	63.05	46.55	22.69
	0.23	5.54	7.55	2.41	2.58

explained and subjects gave written informed consent prior to participating in the study. All subjects were screened for contraindications to vibration training (i.e. recent fractures, taking supplements, enrollment in strength training programs or having metallic plates on their bones) prior to commencement of the study and were asked to replicate their physical activity level and dietary intake. During the period of studies daily motor activity of females was determined by standard training programs without loading elements. The subjects' morphological characteristics show no difference between two groups (one-factor ANOVA).

A planned training program was completed from the beginning to the end by 19 females of experimental group and 18 females of control group.

Study Design

Program of training included 24 training sessions to be performed in 8 weeks (3 sessions a week) and was based on basic principles of health-related training design [28]. A "Blind" method was used to divide the subjects into two groups. All subjects completed the controlled study protocol as designed. Subjects of vibration group (VG) performed the program of sessions with working vibration platform, whereas those of control group (CG) performed the same exercises with non-working (placebo) vibration platform. The subjects of CG stood on the vibration platform in the same positions as for the vibration treatment, except that in this instance, no vibration was administered. All other aspects of the protocol for the CG were identical to the protocol of VG. Duration of each session (40-50 min) and the content of exercises were the same in both groups. The workout regime was standardized to control for the effects of outside physical activity. The exercise protocol included the type of exercise, training intensity, training volume, number and duration of rest period and frequency of training. The same specially trained supervisor and instructor conducted sessions in both groups. Before the first training session, subjects were familiarized with the vibration platform and training exercises. This included familiarization with leg position on platform and specific body positions standing on platform.

Whole Body Vibration

The WBV training was administered using a commercially available WBV platform (LADY 1 Pro, Germany). The WBV platform (width 50 cm, height above floor 25 cm) provided rotation type of vibrations ("inclined vibration") at a frequency of 20 Hz and amplitude of ±2.0, ±3.5, and ±5.0 mm. Amplitudes were related to foot position on the swing-like vibration plate. This relation frequency and amplitudes near to optimal frequency for producing the greatest magnitude of response in EMG activity of vastus lateralis muscle during WBV in an isometric half-squat position [13]. Total duration of vibration load at one session constituted 10.5 (8-12) min. In order to enhance the strength component of exercises, elastic bands were used.

Training

The training consisted of 24 training days separated by 1-2 days rest using uniformity of schedule for a week. The subjects of experimental and control groups performed the same sub-maximal strength and power exercises to preferentially stimulated leg, hand, and trunk muscles as well as those of the back usually used in health related (fitness) training [28]. The content of the training program is presented in the Table 2. In order to enhance the strength component of exercises, elastic bands (tubes) were used in some exercises. In whole-body vibration training sub-maximal isometric and dynamic contractions were always used. Maximal effort has not been used with dynamic exercises. For the control group, the subjects stood on the vibration platform in the same position as for the vibration treatment, except that in this instance no vibration was administered. All other aspects of the protocol for the control group were identical to the protocol described above. In the primary part of the session, subjects completed a 5-min. standardized warm-up, the subjects undertook 4-min. light squatting, standing in erect position, standing with knee flexed, light jumping, standing on heels and 1-min. step-aerobic exercises on the vibrating platform without vibration impact. Total duration of vibration load at one session constituted 8-12 min. The seven exercises were used (Fig. 1). Three-minute rest intervals took place between each exercise. The longer rest interval was selected to ensure that the subjects had sufficient neural recovery between trials [2]. Subjects removed their shoes during the treatment period to ensure that the soles of the footwear would not dampen the vibrations and affect transmissibility. Each set was performed with subjects in an isometric half-squat position, with body mass distributed over the balls of the feet and heels raised off the vibrating platform to prevent vibrations being transmitted to the head.

Measurements

Baseline measurements were recorded with 12-min. rest between different testing procedures a day before the first training session. Measurements at 4 and 8 weeks were

Fig. 1. The exercises used in training:
1) Standing on the platform, V-foot, knee angle flexion 135º, isometric contactation. 2) One leg (right and left) flexion-extension, standing on platform, dynamic exercise, knee angle flexion 90-180º. 3) Standing on the platform, isometric half-squat position and dynamic squat, knee angle flexion 135-165º. 4) Extend the foot at 165º and pull calibrated tubes back. Vibration amplitude of arm/shoulder was about 0.5-2 mm, twenty repetitions. 5) Push calibrated tubes forward. Vibration amplitude of arm/shoulder was about 0-1 mm. 6) Push-up on the platform, vibration amplitude 2 mm. 7) Abdominals isometric stress in horizontal stabilization. Vibration amplitude 2-5 mm.

made a day after the last training session. Before the first training session, subjects were familiarized with the testing procedures. This included familiarization with devices for strength and power measurements and testing procedures. The following characteristics of strength capacities were measured under standard conditions:

1. The maximal isometric knee extension with both legs together measured by a strain gauge dynamometer (Globus, Ergo Meter, Codigné, Italy). The higher of two maximum voluntary isometric contactations was taken;
2. The maximal isokinetic both legs together and two arms together extension like push ups on the isokinetic dynamometer (DYNO 2). The DYNO is a flywheel designed to produce resistance levels suitable for isokinetic strength training and measurements. The DYNO has three basic positions: leg press, seated bench press, and bench pull. The device allow for testing of isolated performance of only two tricep muscles together or two quadriceps muscles together in single joint movements;
3. The maximal (as high as possible) counter movement jump ("explosive" strength) on Kistler platform;
4. The maximal isokinetic strength endurance (DYNO 2) and maximal jumping endurance (Kistler platform). Isokinetic strength endurance was determined as a percentage of average strength during 5 and 10 maximum repetitions of the index of maximum strength in 1 Repetition Maximum (RM). Jumping endurance was measured according to testing program of C. Bosco et al. [6]. The subjects completed two familiarization not maximal trials to ensure they could execute the correct technique for maximal strength and power testing.

Statistical Analysis

The results are expressed as means±SD. All data were found to be normally distributed; therefore, analysis was carried out using parametric statistical tests. A two-way analysis of variance (2-way ANOVA) with repeated measures was used. When significant results were obtained, post-hoc comparisons were made using a contrast method to identify any statistically significant differences with treatment (Control, WBV) and time (pre-, post-4, post-8 weeks) as within factors. Unless otherwise stated, values given in the text. Statistical significance was accepted at $p<0.05$. Statistical analyses were performed using the GraphPad Prism 4 (GraphPad Software, Inc.).

Results

Results of studies have demonstrated positive changes of strength capacities in both groups after completion of the training program. At the same time, the studies have indicated some specific training effects of vibration load for strength capacities of large muscle groups both in isokinetic and isometric type of work as well as in jump "explosive" power. Results of maximum isokinetic strength measurements are presented in Table 3.

Table 2. Content of the training program:
1. Standing on the platform V-foot, knee angle flexion 135º. 2. One leg flexion-extension standing on platform. 3. Standing on the platform, isometric half-squat position and dynamic squat. 4. Extend the foot and push calibrated tubes back. 5. Push calibrated tubes forward. 6. Push-up on the platform. 7. Abdominals in horizontal stabilization.

Type of exercise	1 week	2 week	3 week	4 week	5 week	6 week	7 week	8 week
1. Knee angle flexion (º)	165	100-180	150	100-180	135	100-180	135	135
2.	100-180	100-180	100-180	100-180	90-180	90-180	90-180	90-180
3	135-165	135-165	135-165	135-165	135-165	135-165	135-165	135-165
4.	165	165	165	165	165	165	165	165
1-4, 7. Platform amplitude (mm)	2.0	2.0	3.5	3.5	3.5	5.0	5.0	5.0
5.	0-2	0-2	0-2	0-2	0-2	0-2	0-2	0-2
6.	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
1. Duration of exercise (s)	60	60	60	90	60	120	90	180
2.	30	30	30	40	40	40	50	50
3.	60	60	60	90	60	120	90	180
4. Left-Right leg	30-30	30-30	30-30	40-40	30-30	40-40	40-40	50-50
5-7.	30	30	60	60	60	90	90	120
1,2. Rest between sets (s)	60	60	60	60	60	60	60	30
3.	60	60	30	30	30	30	30	30
4.	60	60	40	40	30	30	30	30
5-7.	30	30	30	30	30	30	30	30
1. Repetitions	-	20	-	20	-	20	-	-
2-3.	20	20	20	20	20	20	20	20
4.	-	20	-	20	-	20	-	-
5-7.	-	10	-	20	-	20	-	-
1-2. Sets	2	2	2	2	2	1	2	1
3.	2	2	2	2	2	1	2	1
4. Left-Right leg	2	2	2	2	2	1	2	1
5-7.	2	2	2	2	2	1	2	1
1. Type	Isometric	Dynamic	Isometric	Dynamic	Isometric	Dynamic	Isometric	Isometric
2.	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	Dynamic	dynamic
3.	Isometric	Dynamic	Isometric	Dynamic	Isometric	Dynamic	Isometric	Isometric
4.	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
5-6	Isometric	Dynamic	Isometric	Dynamic	Isometric	Dynamic	Isometric	Isometric
7.	Isometric	Isometric	Isometric	Isometric	Isometric	Isometric	Isometric	Isometric

As is obvious from Table 3 and Fig. 2, the training program has induced augmentation of maximum isokinetic strength in both groups. It should be mentioned, however, that this increase has occurred in subjects of vibration and control group after 4 and 8 weeks, respectively. The degree of increase (in %) for two-leg extension strength has been similar. But degree of increase for two-hand extension maximal strength was significantly higher ($p<0.05$) in vibration group – 14.3 (2.1)% *vs.* 3.3 (1.1)% in control group. Comparison analysis (test NIR Fisher difference between pairs) showed significant differences between VG *vs*. CG for two-leg isokinetic 1 RM ($p=0.0390$) and for two-hand 1 RM ($p=0.0098$). The character of isokinetic strength endurance changes is presented in Table 4.

Table 3. Changes of maximal isokinetic strength (1 RM) of young females within 4 and 8 weeks of physical training with and without application of whole body vibration (DYNO 2), (mean, SD).

Groups		Strength (extension) two-leg (1 RM), kg	Strength (extension) two-hand (1 RM), kg
Vibration group	Before	102.02*	38.41
		11.61	4.74
	4 weeks	107.71# *	43.80#*
		12.99	5.59
	8 weeks	108.85#	43.41#
		12.47	5.79
Control group	Before	90.06*	35.11*
		12.58	3.95
	4 weeks	93.90#	36.30#
		10.18	4.58
	8 weeks	94.11# *	37.72#*
		8.34	5.92

#significance of vibration and control groups for 4th and 8th weeks;
*significance of increment in the group (p<0.05)

As evident from Table 4, strength endurance during 10 maximum repetitions (10 RM) has not changed in both groups. Augmentation of isokinetic strength endurance took place for mean strength of 5 max repetitions (5 RM), but not for 10 RM in both groups. This enhancement was significant after 4 weeks only. Percentage increase in VG (14.06±4.2%) and in VC (12.4±3.9%) groups did not significantly differ. Percentage increase relation of 1 RM to mean of 5 RM was 10.34 ±3.6% in VG vs 7.80±2.8% in CG (ns). Comparison analysis (test NIR Fisher difference between pairs) showed significant differences (p=0.0144) between VG vs. CG for mean strength of 5 max repetitions (5 RM) only. Thus additional stimulation effect of vibration on isokinetic strength and strength endurance took place for two-leg extension 1 RM, for two-hand extension 1 RM, and for mean 5 RM. Definite specific effects of vibration training for strength development during isometric type of work have been also observed. These data are presented in Table 5.

It appears from Table 5 that maximal isometric strength of knee extensors has increased in both groups. Speed of strength development (T_{30} and T_{50}) has significantly increased already after 4 weeks of vibration training in vibration group (-26.3±4.1% and 20.7±4.2%, consequently for T_{30} and T_{50}), and after only 8 weeks of training in control group (-28.3±4.3%). Percentage increase in VG and in VC groups did not significantly differ. Comparison analysis (test NIR Fisher difference between pairs) showed significant differences between VG *vs*. CG for T_{50} (P=0.0464).

Concerning "explosive" power manifestations realized during jumping tests, some differences in training effect expression with respect to both maximum height and power of single jump and performance of 10 successive maximum jumps have been observed. These data are presented in Table 6.

Presented data indicate more apparent increase of "explosive" (jumping) power values (and in greater number of characteristics) in vibration group. The height of 1 JM and mean height (and power) of 10 JM were significantly increased in VG only (5.53±0.91% and 7.35±1.12%, consequently).

Table 4. Changes of isokinetic strength endurance for 10 and 5 maximum repetitions (RM) within 4 and 8 weeks of training with and without application of vibration load for the whole body of young females (DYNO 2), (mean, SD).

Groups		Strength endurance (two-leg extension)			
		Mean strength 10 RM, kg	% 10RM *vs*. 1RM	Mean strength 5 RM, kg	% 5 RM *vs* 1 RM
Vibration training group	Before	94.15	89.31	87.68*	86.01*
		8.53	2.92	12.31	3.12
	4 weeks	94.75	91.62	100.01*	94.91*
		11.66	2.41	15.1	3.21
	8 weeks	93.35	91.11	96.21	92.65
		10.88	1.79	11.9	2.96
Control group	Before	80.71	89.01	77.22*	85.74
		9.21	2.95	12.07	2.64
	4 weeks	87.07	92.55	86.81*	92.44
		9.11	1.47	11.9	2.89
	8 weeks	86.39	91.88	86.78	92.22
		7.14	2.44	8.78	3.01

*significance of increment in the group (p<0.05)

Table 5. Changes of isometric strength (knee joint extension) within 4 and 8 weeks of physical training with and without application of vibration load for the whole body of young females (mean, SD).

Groups		Max strength (Nm)	Time strength development, ms	
			T_{30}	T_{50}
Vibration training group	Before	111.3*	240*	291*
		23.23	27	46
	4 weeks	112.6	190*	241*
		37.01	28	97
	8 weeks	115.5*	160	205
		22.7	29	107
Control group	Before	98.1*	279*	326*
		27.3	39	126
	4 weeks	102.0	221	260
		30.2	37	80
	8 weeks	107.4*	145*	214*
		30.5	21	83

*significance of increment in the group (p<0.05)

Most of the above augmentation induced by vibration training had already occurred after the first 4 weeks of training. The changes of min time contact 1 JM and 10 JM (jumping endurance) did not differ in both groups. Comparison analysis (test NIR Fisher difference between pairs) showed no significant differences of maximal power (jumping) capacities between VG *vs*. CG. Changes of jumping endurance characteristics are presented in Table 7.

As we may see, a significant increase after 8 weeks of training were observed only in percentage of mean height 10 JM against 1 JM (jumping endurance) in both groups. Some jumping endurance improvement have been noted in VG and in CG. There were no differences between groups.

Those variables of strength capacities that statistical significantly differed between 0-4 weeks, 4-8 weeks, and 0-8 weeks of training in VG and CG (test Wilkes) are presented in Table 8.

The percentage changes of strength capacities characteristic after 4 and 8 weeks of training for VG and CG are presented in Fig. 2.

Discussion

The 8-week program of young females' sub-maximal resistance training combined with intermittent WBV appeared more efficient for increasing arm/shoulder and some leg strength and power capacities than the same conventional resistance training without WBV. So hypotheses related to additional effects of intermittent WBV in programs of health-related sub-maximal resistance training and to rising efficiency of resistance training of young females were accepted. The more essential and faster effect of additional vibration took place for arm/shoulder extension muscles than for leg muscles. There was no significant increase of strength endurance in vibration group in comparison to the conventional training group. The hypotheses related to time (chronic) effects of additional to conven-

Table 6. "Explosive" (jumping) power of one maximum jump (1 JM) and 10 maximum jumps (10 JM) during 4 and 8 weeks of physical training with and without application of vibration load for the whole body of young females (Kistler platform), (mean, SD).

Groups		Height 1 JM	Height mean 10 JM	Power 1 JM	Power mean 10 JM	Min time contact 1 JM	Mean time contact 10 JM
		(cm)	(cm)	(W/kg)	(W/kg)	(ms)	(ms)
Vibration training group	Before	36.6*	32.0*	43.6*	36.7*	204.1*	227.1
		4.1	3.3	7.6	6.3	28.3	30.4
	4 weeks	38.7*	34.5*	45.6*	39.1*	188.6*	224.9
		3.4	2.4	7.5	6.3	34.7	34.4
	8 weeks	37.,8	34.4	45.5	38.4	189.9	215.4
		2.4	2.5	6.5	5.5	29.7	29.8
Control group	Before	36.2	31.4	40.8*	34.1	235.5*	246.0
		5.6	3.6	7.8	5.7	51.8	39.1
	4 weeks	35.6	31.7	44.3*	35.2	208.4*	239.8
		4.1	3.9	4.5	4.4	20.3	21.7
	8 weeks	36.0	32.4	40.9	34.2	205.9	233.2
		4.1	3.9	5.8	5.0	24.5	42.0

*significance of increment in the group (p<0.05)

Table 7. Changes of strength endurance in jumping test of 10 maximum jumps (10 JM) relative to one maximum jump (1 JM) within 4 and 8 weeks of training with and without vibration for the whole body in young females (Kistler platform), (mean, SD).

Groups		% of mean height 10 JM against 1 JM	% of mean time contact 10 JM against min time contact 1 JM
Vibration training group	Before	87.4*	111.3
		2.9	4.1
	4 weeks	89.2	119.2
		3.0	3.9
	8 weeks	91.0*	113.4
		2.6	4.3
Control group	Before	86.7*	104.4
		3.1	4.7
	4 weeks	89.0	115.1
		2.9	5.2
	8 weeks	90.0*	113.2
		3.0	5.6

*significance of changes in the group ($p<0.05$)

tional resistance training impacts of WBV were not clearly accepted. The increasing of strength capacities took place first of all during the first 4 weeks of training.

Literature into the effects of WBV in human beings covers a broad range of topics and different responses have been reported, ranging from beneficial to dangerous. Data obtained earlier as the results of a given study indicate that vibration impacts for the whole body (with application of vibration platform) in combination with a special program of preferential strength exercises have positive influenced values of strength capacities. The key question of WBV training is the magnitude of amplitude and frequency of the original vibration that reaches the target muscle. With indirectly applied vibration [22, 25, 26, 29, 30], the amplitude and frequency may be attenuated in a non-linear manner by soft tissues during transmission of the vibration to the target muscle [1, 27]. This complicates analysis of whole body vibration training effects.

In the last decade several studies have suggested the positive effects of controlled WBV in strength and/or power development [3, 6, 22, 31]. It has been shown in untrained, postmenopausal women also [16, 18]. But other studies have not found significant improvements in strength and power in young men [19]. However, it is clear that there is a lack of research into chronic vibration training with a strict control group design. This area in particular requires addressing as chronic adaptation is the main aim of resistance training. Only some studies have appropriately examined the chronic effect of vibration on isometric strength. Their results are contradictory. Delecluse et al. [3] found that 12 weeks of whole-body vibration training could induce a significant increase in knee extensor maximal strength (16.6%), while the placebo group only produced a non-significant increase (5%). In contrast, however, de Ruiter et al. [19] reported no significant difference in knee extensor isometric strength between the vibration group and the control group after 11 weeks of training. The vibration frequency was similar in these two studies (35-40Hz [3] *vs.* 30Hz [19]), but the vibration amplitude was slightly smaller in the study that found the significant increase of maximal strength (1.25-2.5 mm [3] *vs.* 4 mm [19]). The study by Rittweger [8] also indicated that the enhancement of central motor excitability was elicited by whole-body vibration with sufficient amplitude (6 mm). This summary finding is likely to be equally applicable to chronic-based

Table 8. Statistically significant differences of variables (P values) between 0-4, 4-8, and 0-8 weeks of training.

Variables	Vibration group			Control group		
	0-4	4-8	0-8	0-4	4-8	0-8
Two-hand isokinetic extension (1 RM)	0.0053	–	0.0071	–	–	0.0194
Two-leg isokinetic extension (1 RM)	0.0085	–	0.0091	–	–	0.0095
Mean isokinetic strength two-leg 5 RM	0.0313	–	0.0487	0.0494	–	0.0244
% 5 RM isokinetic vs 1 RM	0.0026	–	0.0094	–	–	–
Max isometric strength of knee extensors	–	–	0.0082	–	–	0.0100
T_{30} of isometric knee extension	0.0115	–	0.0173	–	–	0.0097
T_{50} of isometric knee extension	0.0107	–	0.0098	–	–	0.0989
Height of 1 JM	0.0285	–	0.0107	–	–	–
Height mean of 10 JM	0.0160	–	0.0089	–	–	–
Min time contact 1 JM	0.0208	–	0.0177	0.0380	–	0.0178
% of mean height 10 JM *vs*. 1 JM	0.0183	–	0.0089	0.0420	–	0.0213

adaptations, as chronic adaptations are reflective of acute responses. However, no studies to date have directly examined this. In the present study the vibration amplitude was slightly higher, variable in different exercises and was increased during 8 weeks of training. The facilitating effect of this type of WBV training hardly comparison with above studies. Thus, it appears that vibration amplitudes and frequencies in this study are sufficient to activate the muscle. The difference in results of our and above studies may be due to the different exercise intensity, volume, and relation of isometric and dynamic exercises. In light of the general acceptance that dynamic training is more beneficial to neuromuscular development in athletes than isometric training, more studies should employ dynamic exercise [4, 12]. While it is difficult to identify the optimal vibration characteristics and exercise protocols for vibration training, some useful information about the effect of vibration methodology can still be obtained from the studies.

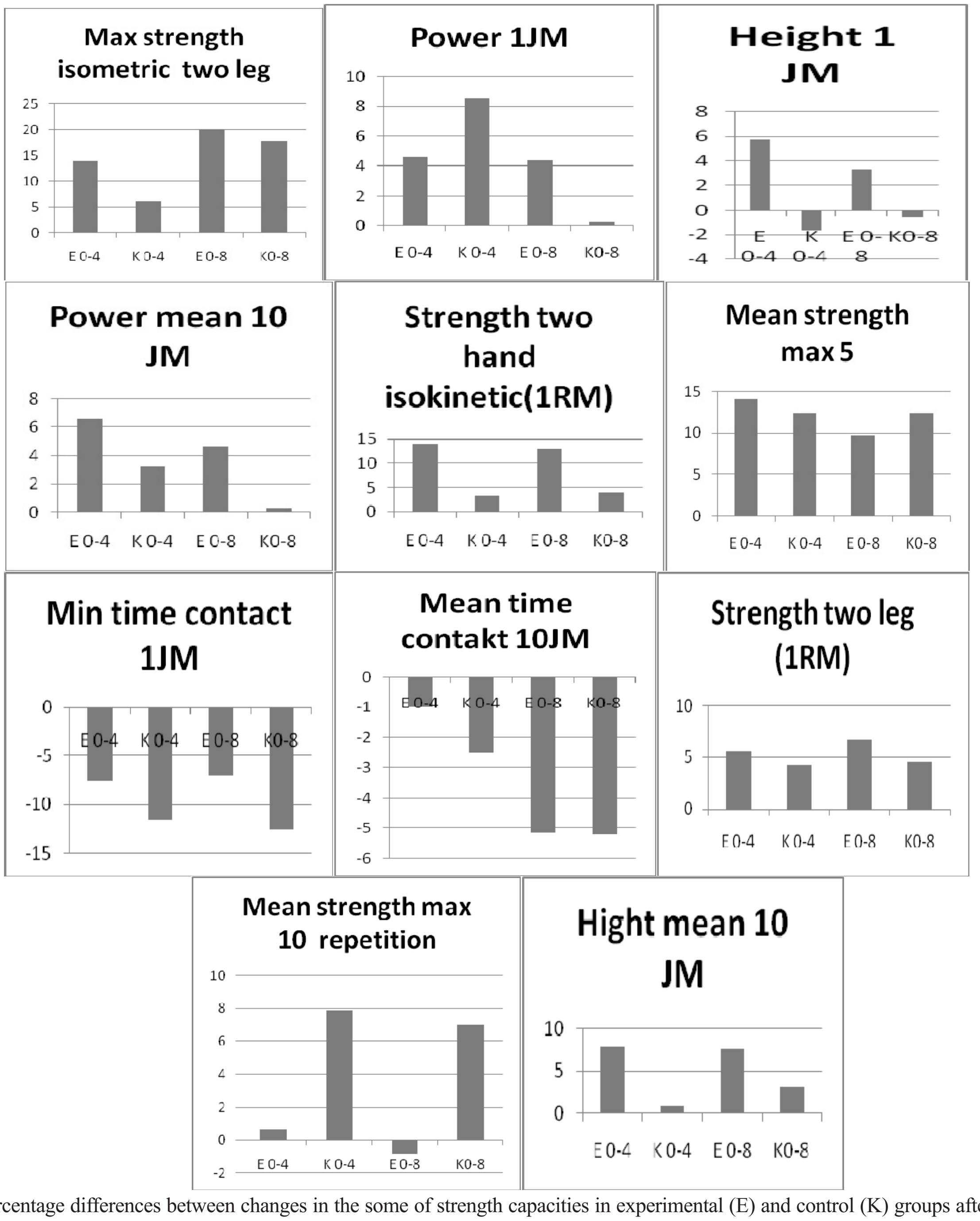

Fig. 2. Percentage differences between changes in the some of strength capacities in experimental (E) and control (K) groups after 4 (0-4) and after 8 (0-8) weeks. Significant differences: two-leg isometric 1 RM for 0-4 weeks, two-leg isokinetic 1 RM for 0-8 weeks, two-hand isikinetic 1 RM for 0-4 and 0-8 weeks, two-leg isokinetic mean of 5 RM – ns, power 1 JM – ns, height 1 JM for 0-4 weeks, power mean 10 JM – ns, mean strength of 5 RM – ns, min time contact 1 JM for 0-8 and for 10 JM – ns, mean strength of 10 RM increase in control group only for 0-8 weeks, mean of 10 JM height for 0-4 weeks.

The result suggests that low frequency (20 Hz) may be effective in activating the muscle in indirectly applied vibration (as it is in WBV) for 8 weeks of sub-maximal strength training. This data is supported by some other studies [13, 21], and suggests that low-frequency vibration may induce more muscle fatigue, possibly by activating muscle more effectively. As in the discussion of vibration amplitude, it is likely that the observation of greater enhancements from low frequency is applicable to chronic-based adaptations, although no studies have directly investigated this. This may be the reason that almost all vibration studies that have employed the indirect method of vibration application have used a low frequency – up to <50 Hz [9]. In the present study the effect of WBV training was manifested at low frequency 20 Hz in the same degree for the leg and arm strength capacities. These findings suggest that with indirectly applied vibration there may be a greater vibration training effect on the muscles closer to the vibration source because of the attenuation of the vibration by the body structures during transmission. This attenuation may also result in the vibration amplitude on the muscle groups further from the vibration source being less than the threshold level necessary for muscle activation. Moreover, the attenuation of vibration appears to be larger with the increase of vibration frequency [1, 13].

It is difficult to reach definitive conclusions about the chronic effects of whole-body vibrations on human strength capacity. It could be explained by the wide range of parameters utilized (frequency, amplitude, direction, or duration of vibration loads) and by the wide range of researched people and training designs [2, 5, 13]. In the given study, a guideline to vibration training design includes no more than three sessions a week in combination with sub-maximal isometric and dynamic strength training, in order to prevent intramuscular fatigue. It should be noted again that scarcely any muscle damage can be established if the vibration training is carried out unloaded or with sub-maximal load [1, 8]. In our study, after the first week of training there were no cases of muscle pain. Intramuscular fatigue mainly affects the isometric contraction force; it has much less effect on dynamic exercises (contractions), which were used in the study. It connected with the most important neurological structural effects of such exercises. In the other side, super-compensation, but fatigue as well, is to be expected less quickly when the vibration training is done in a static posture and without extra weight.

The analysis of intermittent WBV effects upon young females strength capacities show that augmentation of strength has been observed both in experimental and control groups. However, in the group subjected to WBV stimulation some of these effects have occurred faster and have been more expressed by the end of the training program. It is noteworthy that strength capacities increase especially during the first 4 weeks of training has occurred in both groups without any expressed augmentation of active body mass. The above allows suggesting a weakly expressed augmentation of muscular mass under the influence of applied programs of vibration exercises. This type of training stimulated "extension-tension reflex" of muscles related in women to neural factors of muscle strength [8, 30, 32] and to motor unit synchronization [3, 7, 10, 33]. Therefore, an increase of strength observed on this background should be attributed, perhaps, to neural rather than anabolic factors in males and females. It should be stressed as well that the content of strength character exercises of analyzed training program did not include realization of principles of anabolic direction impacts upon working muscles. The most apparent positive effects have been observed in those young females with relatively lower levels of analyzed strength values and excessive body mass. Training of control group subjects has provided effects of the same direction, but with respect to fewer values.

While analyzing the results of the given study, one should take into account the fact that during utilization of a complex program of physical exercises, development of single aspects and types of strength capacities has not been accentuated. Effects of the given program, however, have not been of universal character, i.e. positive effect upon not all analyzed aspects of strength capacities has been noted. Different aspects of strength capacities have demonstrated either improvement or acceleration. At the same time, universal character of the above effects of WBV has been less expressed without application of vibration stimulation. It may be related to WBV induced increase of energy metabolism. Investigating of the effects of different frequencies (18, 26 or 34 Hz) and amplitudes of vibration with different external loads showed an increase of oxygen uptake proportionally to the frequency increase [34]. Furthermore, VO_2 increased more than proportionally with amplitudes from 2.5 to 7.5 mm. A further increase was observed when the load was applied to the shoulders [34]. Currently, there is no clear consensus on the mechanism by which vibration may enhance neuromuscular performance; in fact, there is a lack of research in this area. However, a number of mechanisms have been postulated upon, including tonic vibration reflex, perceptual change by vibration, enhanced motor neuron excitability, increased muscle temperature and blood flow, increased hormone secretion and muscle hypertrophy. Vibration exercise enhances bilateral corticospinal excitability, as demonstrated by a shortened cortical silent period and lower cortical motor threshold in both exercised and non-exercised extremities [15]. In chronic adaptation, WBV influenced the reactive strength rather than coordination capacities [35].

Therefore, the findings indicate additional possibilities of strength capacity improvement and maintenance by means of supplementing the program of sub-maximal isometric and dynamic health-related physical exercises with different amplitudes of vibration impacts. In this case the same training effect can be achieved during a shorter time period. It may be suggested that realization of this idea requires relatively less time and subjectively perceived lower training tension [5].

Obtained data demonstrate that additional impacts of vibration for the whole body represent a factor reinforcing strength exercise effects. The current study showed that applied WBV over time influences the reactive strength rather than strength endurance in young females. One may assume that these approaches could be of greater importance for females of middle and senior age if one takes into consideration more intensive age-related decrease of strength capacities in females of the above age groups and some restrictions concerning application of common means of strength training [28]. Nowadays intermittent WBV protocols widely used in sport training or fitness facilities usually include the combination of different external loads, frequencies and amplitude. In the given study the above has been shown for sub-maximal strength training of young females. The increase in exercise intensity and volume tends to induce greater muscle performance improvement in chronic WBV training. However, because of the lack of chronic vibration training studies and the diversity of the training programs employed, the optimal vibration training program remains unclear. Further specific investigation of the degree of strength training impact and its vibration reinforced toning up effects may result in finding such types and regimes of strength training, which would be the most efficient with respect to long-term correction of age-induced changes in females of middle age, above all. It also seems that the methodology of prolonged WBV training, both the vibration characteristics and exercise protocols, plays an important role in eliciting WBV benefits.

Conclusions

Results showed the additional effects of dose using of rotation whole body vibration in sub-maximal resistance physical exercises natural for conventional health-related resistance training of females. There were effects upon some characteristics of isometric and isokinetic strength, and jumping power, but not on strength endurance for 24 sessions of training. The effects of intermittent whole body vibration combined with sub-maximal resistance training of young females were most essential in the first four weeks. Increase of isometric, isokinetic strength, jumping power and strength endurance has been observed in groups of females without WBV also, but in the group of young females subjected to WBV coupled with sub-maximal static and dynamic strength exercises some of these effects have occurred faster and have been more expressed. It is related to an increase of isokinetic strength for 1 RM of two-hand extension, two-leg 1 RM isometric strength of knee extensors, increase of power jump capacities for height of 1 JM and for mean of 10 JM height. The additional effect of WBV on increase of two-leg 1 RM isometric extension and decrease of T_{30} and T_{50} isometric knee extension occurred during the first 4 weeks, whereas without WBV – during 8 week only. So increasing strength capacities took place first of all during the first 4 weeks of training and was more essential in hand isokinetic and in isometric leg and jumping capacities than in strength endurance. There were no significant increases of strength endurance in vibration group in comparison with the conventional training group. It may be concluded that superimposed whole body vibrations in sub-maximal resistance training applied for short periods, allowing for increased gains in some strength capacities in comparison with conventional resistance training of young females.

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