Vibrationstraining: Benefits und Risiken

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Ziel der Studie:
Untersuchung ob ein Power Plate-Training die Maximalkraft und Sprungkraft günstig beeinflusst.

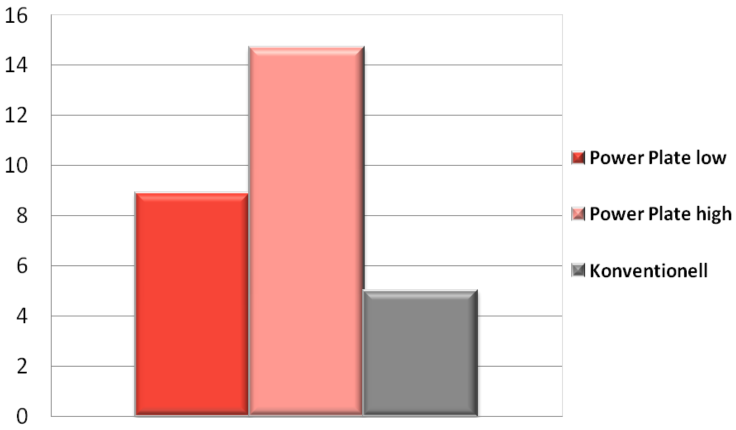
Methoden:
Diese 6-wöchige Studie wurde mit 42 männlichen Sportstudenten durchgeführt. Die Studienteilnehmer wurden in folgende Untersuchungsgruppen aufgeteilt:

1. Power Plate-Gruppe (low): Power Plate-Training 3 mal/ Woche mit 30-50 Hz
2. Power Plate -Gruppe (high): Power Plate-Training 3 mal/ Woche mit 30-50 Hz
3. konventionelle Krafttrainingsgruppe (KT): Konventionelles Krafttraining 3 mal/ Woche.

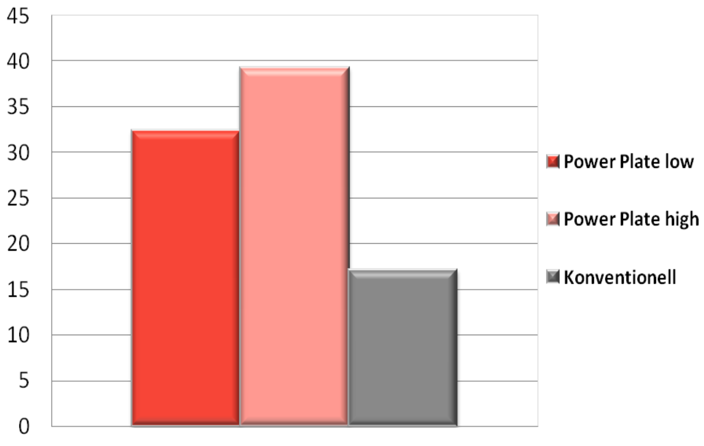
Gemessen wurde die isometrische Maximalkraft, die maximale Wiederholungszahl, der Squat-Jump, der Counter-Movement-Jump und der Drop-Jump.

Ergebnisse:
Im Vergleich zum traditionellen Krafttraining konnte bei den Parametern **Maximalkraft, max. Wiederholungszahl und Drop-Jump-Höhe ein deutlicher Vorteil des Power Plate-Trainings** festgestellt werden (Konventionell: +5,0 %, +17,1 %,+2,9 %; Power Plate [low] +8,9 %, +32,4 %, +13,3; Power Plate [high] +14,7 %, +39,3 %, +15,6 %). Bei den anderen drei untersuchten Parametern konnten keine Unterschiede beobachtet werden. Die Kontrollgruppe zeigte keine Verbesserungen.

Fazit:
Diese Studie zeigt, dass ein Power Plate-Training eine effektive und zeitsparende Methode darstellt, um die Maximalkraft und ausgewählte Sprungkraftfähigkeiten zu verbessern.



Prozentuale Verbesserung der isometrischen Maximalkraft



Prozentuale Veränderung der maximalen Wiederholungszahl

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Vibration training: benefits and risks

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Abstract

The main results of our recent several studies, i.e. the measurements of vibration training results for single case and group studies as well as the cardiovascular parameter measurements during vibrations and the corresponding hydrodynamic analysis, are summarized. Our studies and previous work all confirm that vibration training is an effective training method in order to improve maximal strength and flexibility as well as various other factors if the training is properly designed. Some recommendations regarding the proper ranges of frequencies, amplitudes and exposure duration of vibration training are made based on the existing vibration training practice and mechanism analysis, although much work remains to be carried out in order to set up clear rules for various groups of people so that maximal training results could be expected and in the meantime potential dangerous effects could be avoided.

Cardiovascular parameter measurements confirm that total peripheral resistance (TPR) to the blood flow is increased during body vibration. Hydrodynamic analysis offers the mechanism for the increase of TPR through the deformation of vessels. As a reaction of compensation, more capillaries are probably opened in order to keep a necessary level of cardiac output needed for the body, resulting in more efficient gas and material metabolism between the blood and muscle fibres. This might be one of the reasons for the various potential beneficial effects of vibration training.

Keywords: Training; Vibration; Cardiovascular effects

1. Introduction

Vibration, as a special method for strength training, has attracted attention for two decades. The vibration training design can be roughly described as follows. Some or some groups of subjects are chosen for single case or group studies. All the subjects are required to do vibration training a few times a week for some weeks. Certain parameters, e.g. the maximal force of certain muscle, the height of counter movement jump, the height of drop jump, contact time to the ground for drop jump, force endurance, etc. are taken as indicators of the training effects and measured before, during, and after the entire training period. For maximal muscle strength, most studies showed significant (10–50%) improvements due to vibration training (Armstrong et al., 1987; Becerra Motta and Becker, 2001; Becerra Motta et al., 2002; Issurin et al., 1994; Weber, 1997; Bosco et al., 1999; Kube, 2002; Berschin et al., 2003). A few studies (e.g. Müller et al., 2003) showed no significant improvements. For other indicators, e.g. the jumping height, some investigations showed moderate (up to 10%) improvements (Müller et al., 2003), while some other studies showed no significant improvements or even negative results (Künnemeyer and Schmidtbleicher, 1997; Kube, 2002). Obviously, different designs of vibration training made the difference to the training results. (For a more detailed review on the effects of vibration training, see Mester et al., 2003.)

In addition to the expectation of good training results, safety consideration is another issue related to vibration training. Actually, the laboratory investigations of various possible damaging effects to animals

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and humans caused by vibrations as well as those in the field of work science can be traced back to 1950s (Roman, 1958; Schaefer et al., 1959; Sass, 1969; Magid et al., 1960; Dupuis and Zerlett, 1987; Seidel and Heide, 1986; Griffin, 1994; Fritz, 1997; Treier, 1997). In the field of work science, the safety standard has been formulated as a region in the plane of acceleration vs. exposure time (ISO 2631-1, 1997).

It would be more difficult to formulate the corresponding safety standard for vibration training because many more parameters would be involved. These parameters would include the frequency, the amplitude of the vibrating facility, the intensity, the load and the duration of each training, the duration of the inter-training resting phase, the length of the entire training period, the body position with respect to the vibrating facility, and so on. A special issue of the safety consideration is resonance. Generally speaking, resonance should be avoided. Resonance frequency depends on the body weight, the stiffness of the muscles as well as the body position with respect to the vibrating facility etc.

In the final analysis, the purpose of the research for vibration training is to try to establish the guidelines in order to get maximal benefits from vibration training and in the meantime to avoid the potential dangers associated with vibration training. The body reaction during vibrations is not only biomechanical, but also physiological. Namely, all systems in the body, including neuromuscular system, cardiovascular system, etc., are reacting to the vibrations. Due to the complexity of this topic, the first and the major approach in this research field is direct measurement of the training results. This approach, referred to as Approach I hereafter, can be divided into two types: (1) single case study, and (2) group study. In single case study, a few subjects, usually of different levels, are chosen to do vibration training based on a certain design. The longitudinal change, i.e. the time history, of certain parameters will show not only the final training results, but also the adaptation process. In a group study, several groups of subjects are chosen randomly from a big population. One group serves as the control group, one group is given traditional training without vibration, the remaining groups are given vibration trainings with different designs regarding the frequency, amplitude, additional loading, etc. The comparison of the training results, also through some indicators, among different groups will reveal the effects of vibration training compared with traditional training and the differences made by different designs. The second and also important approach in this research field, referred to as Approach II hereafter, is mechanism analysis, which will help to have a deeper understanding of the training process and training results, and to make better design of vibration training. Approach II can also be further divided into two types: (1) measurement of some biomechanical and physiological parameters, e.g. electromyograph (EMG), pressing force on the vibrating platform, oxygen uptake, various cardiovascular parameters (heart rate, blood pressure, total peripheral resistance (TPR), lactate) during each vibration training or the entire training period, and (2) theoretical analysis in terms of model analysis and biomechanical calculations etc. The first type of mechanism analysis would help to find out the biomechanical and physiological reactions of the body during vibration training, while the second type, i.e. the theoretical analysis, would help to understand the mechanism of the potential benefits and dangers and to get the trends of various relations, e.g. the relation between the transmission factor and the frequency, the relation between the resonance frequency and the body mass as well as the stiffness of the muscles, the relation between the increased shear stress in the blood vessel caused by vibration and the size of the vessel as well as the vibration frequency, etc. For simplicity, the above-mentioned two types of studies in each of the two approaches will be denoted by types (I,1), (I,2), (II,1), (II,2) respectively, where for example (I,1) stands for type 1 of Approach I etc.

The methods and the results of our several recent studies will be presented in Section 2 and Section 3, respectively. Some further points will be discussed in Section 4. Conclusions will be drawn and recommendations will be made in Section 5.

2. Methods

For convenience, our several recent studies will be referred to as Study I, Study II, Study III and Study IV, which belong to types (I,1), (I,2), (II,1), (II,2) respectively. The specific methods of these studies will be outlined as follows.

2.1. Study I: single case study of the vibration training effects

One high-level female athlete and one low-level male athlete were given 2–3 times vibration trainings per week for 6 weeks. The vibrating facilities used for training were Novotec dumbbell and Power Plate platform. For Novotec dumbbell, frequencies of 20–25 Hz and amplitude of 4 mm were used, while for Power Plate platform, frequency of 35 Hz and amplitude of 2 mm were used. The 6 weeks of vibration training period was followed by 2 weeks of rest and 3 months of traditional training (once a week). Measurements of the corresponding forces for six exercises (Bench Press, Triceps Press, Neck Press, Latissimus Pulldown, Biceps Curl (right), Biceps Curl (left)) were made many times not only during the 6 weeks of vibration training period but also during the following 3 months and half in order to get the time history of the corresponding forces for the whole training and adaptation process.

2.2. Study II: group study of the vibration training effects

42 male sport students were randomly chosen from the population of the male students in German Sport University (Cologne). They were randomly arranged into four groups, so that each group had $n = 10$–12 subjects. First group ($n = 10$) was given traditional training without vibrations. The second ($n = 12$) and the third ($n = 12$) groups were given vibration training with amplitudes of 2 and 4 mm, respectively. The vibration training facility was Power Plate platform, and the frequency range was 30–50 Hz. The subject was only required to repeat squatting with certain weight (50% of 1RM, where 1RM stands for Repetition Maximum) held by hands above the head. The fourth group ($n = 10$) served as control group. Three training units per week were arranged for 6 weeks for the first three groups. For comparison, six parameters (Isometric Maximal Strength, Maximal Repetition Number, Height of Squat Jump, Height of Counter Movement Jump, Height of Drop Jump, Contact Time of Drop Jump), taken as indicators of the training effects, were measured for each subject in the four groups at beginning, during, and at the end of the 6 weeks of training period. The Isometric Maximal Strength was measured by Desmotronic Leg Press. The Drop Jump height was defined by the height of the centre of mass of the body reached by the subject as he dropped from the top surface of a box of 35 cm height to the ground and jumped up. A higher jumping height with the same contact time to the ground, or the same jumping height with shorter contact time, or higher jumping height with shorter contact time would all be regarded as an improvement. The average of the final values of a given indicator over a given group was compared with the average of the beginning values of the same indicator over the same group to get the average gain of this indicator for this group. This was done for all indicators and all groups. From the comparison of the average gains among different groups, it could be judged whether the differences made by vibrations were significant or not.

2.3. Study III: measurements of cardiovascular parameters during body vibrations

The measurements were carried out for two subjects (a healthy strong man of 43 and a healthy young woman of 24). The subjects were standing on the Power Plate vibrating platform freely when various cardiovascular parameters, e.g. heart rate (HR), systolic, diastolic and mean blood pressures (sBP, dBP, mBP), cardiac output (CO), TPR, as well as ECG were measured. Each such vibration test lasted 30 s, followed by a resting phase of 30 s. The tests were carried out for two amplitudes (2, 4 mm) and three frequencies (30, 40, 50 Hz). Thus, six tests were carried out for each of the two subjects. All the cardiovascular parameters were measured by Task Force Monitor 3040i, where TPR was defined by $\text{TPR} = \text{mBP}/\text{CO}$, and CO is equal to the product of HR and stroke volume (SV). The value of SV was obtained from the ICG (Impedance Cardiograph), based on the dependence of electric impedance of the chest upon the blood volume in aorta.

2.4. Study IV: hydrodynamic analysis for the effects of body vibrations on blood circulation

For a given piece of blood vessel and a given direction of vibration, the vibration can be divided into longitudinal (parallel to the vessel) and lateral (perpendicular to the vessel) components, which were treated separately. The longitudinal effects were studied by quantitative solutions of hydrodynamic equations with oscillating boundary condition. The blood vessel was treated as a rigid circular tube, and the blood was treated as incompressible uniform Newtonian fluid. [Since the vibration frequency, usually larger than 20 Hz, is much higher than the frequency of pulsation (about 1 Hz), the pulsation can be omitted as the first approximation and the vessel can be treated as rigid tube for the discussion of the longitudinal effects of vibration. The non-Newtonian property of the blood becomes important only for small vessels of diameters smaller than 0.5 mm (cf. Liu and Li, 1997), while the longitudinal effects are important only for large vessels (see Section 3.4). Thus, it is a good approximation to treat the blood as incompressible Newtonian fluid for the discussion of the longitudinal effects of vibrations.] The solution for the steady flow without vibration was known (Poiseuille flow). The equation and the boundary condition for the differences or perturbations caused by the vibration were established and solved. Once the distribution of velocity perturbation was obtained, the distribution of shear stress perturbation, which is proportional to the gradient of the velocity perturbation, could be calculated. Thus, the shear stress increase at the wall of the blood vessel caused by the vibration and the relation of such increase to various parameters, e.g. the frequency and local longitudinal amplitude of vibration as well as the radius of the vessel, could be found. For lateral effects, a qualitative analysis, taking into account the deformation of the blood vessels, was sufficient to reveal the effects of body vibration on TPR and therefore to indicate the possible effects of body vibrations on the global structure of blood vessels and the efficiency of metabolism.

3. Results

The main results of Studies I to IV listed in the last section can be outlined as follows.

3.1. *Results of study I: single case study of the vibration training effects*

The main results of Study I are shown in Figs. 1 and 2, where Fig. 1 shows the *final* gains, given by percentages, of the forces for the six exercises and the two subjects. Final gains were based on the comparison between the measurements before the training and the measurements when the entire adaptation time was over, i.e. about three and half months after the end of the 6 weeks vibration training. For each exercise, the left bar is for the high-level athlete and the right bar for the low-level athlete. The gains of the high-level athlete was much larger than the gains of the low-level athlete, averagely 30% vs. 10%. Fig. 2 shows the time history of the maximal strengths of the two subjects in Bench Press. The maximal strength, also given in percentage, was first decreasing tremendously, reaching the valley at the end of the 6 weeks of vibration training, and then increasing gradually, reaching the final maximal values three and half months after the end of the 6 weeks training period. Thus, Fig. 2 shows a typical adaptation process: loading → fatigue → recovery → overcompensation.

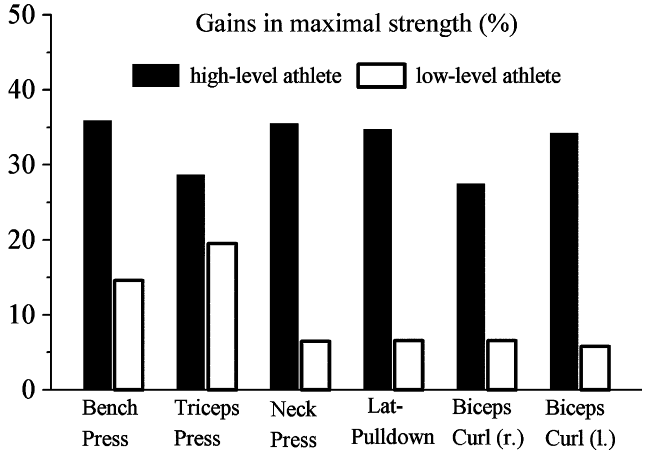


Fig. 1. Final gains in maximal strength for six exercises and the two subjects. For each exercise, the left bar is for the high-level athlete, while the right bar for the low-level athlete (modified from Wessel, 2003).

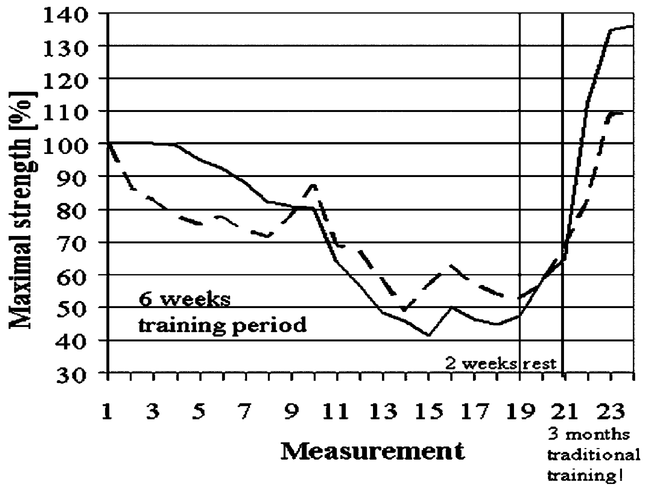


Fig. 2. Time history of the maximal strength in percentage of the two subjects in Bench Press, where the solid and the dashed lines are for the high-level and the low-level athletes, respectively (modified from Wessel, 2003).

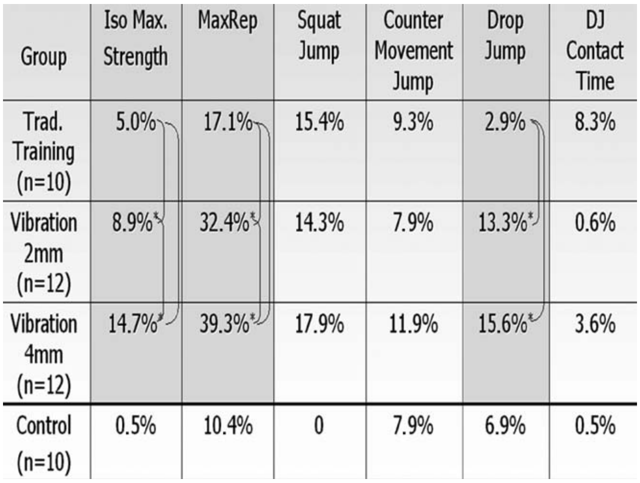
3.2. *Results of study II: group study of the vibration training effects*

The main results of Study II are shown in Table 1. For three parameters, Isometric Maximal Strength, Number of Maximal Repetitions and Height of Drop Jump, the positive effects of vibration were significant compared to traditional training. For the remaining three parameters, i.e. Height of Squat Jump, Height of Counter Movement Jump and Contact Time for Drop Jump, the differences made by vibration were not significant. For Study II, the measurements were unfortunately stopped at the end of the training period without going on further for some technical reasons. Even higher positive results of vibration training might be expected if the measurements had been continued for a longer time.

3.3. *Results of study III: measurements of cardiovascular parameters during body vibrations*

The main results of Study III are given in Figs. 3–5, which show the average values of CO, mBP and TPR during each vibration test compared with the values before and after the tests. The value after tests was defined by the average over the 30 s immediately after all the tests. The results for the two subjects have the following common features: (1) Except the last vibration test (50 Hz, 4 mm), TPR increased considerably for both subjects during vibrations compared with before the tests (Fig. 5(a) and (b)). This is an important effect of body vibration on the cardiovascular system. A hydrodynamic explanation can be given for this effect (see the next sub Section 3.4). (2) The mean blood pressure increased during vibrations for both subjects (Fig. 4(a) and (b)) in order to maintain a necessary CO. Actually, CO decreased slightly for the male subject and remained almost unchanged for the female subject (Fig. 3(a) and (b)). (3) After the vibration tests, TPR dropped to a value which was even considerably lower than before the tests for both subjects (Fig. 5(a) and (b)). A possible explanation of this feature and its implication to the

Table 1
Average gains of six weeks vibration training in each item and for each group



Group	Iso Max. Strength	MaxRep	Squat Jump	Counter Movement Jump	Drop Jump	DJ Contact Time
Trad. Training (n=10)	5.0%	17.1%	15.4%	9.3%	2.9%	8.3%
Vibration 2mm (n=12)	8.9%*	32.4%*	14.3%	7.9%	13.3%*	0.6%
Vibration 4mm (n=12)	14.7%*	39.3%*	17.9%	11.9%	15.6%*	3.6%
Control (n=10)	0.5%	10.4%	0	7.9%	6.9%	0.5%

The quantities connected by braces show significant differences (modified from Kleinöder et al., 2003).

potential benefits of vibration training will be discussed in Section 4.

3.4. *Results of study IV: hydrodynamic analysis of the effects of vibration training on blood circulation*

The longitudinal effects of body vibration on (a) velocity perturbation, and (b) shear stress perturbation in blood vessels, obtained from hydrodynamic analysis, are given in Fig. 6. (For an abstract of the longitudinal hydrodynamic study, see Yue and Mester, 2003a. Detailed mathematical formulation and derivation will be published in a separate paper.) These perturbations decay towards the centre of the vessel and they decay faster for higher frequency. Fig. 7 shows the maximal shear stress perturbation at the wall of the vessel against frequency, where both quantities have been properly scaled. *Thus, the increase of shear stress is more serious for high frequency and large vessels than for low frequency and small vessels.* As an example, for coronary artery, we can take $R = 1.5\,\mathrm{mm}$, $Q = 50\,\mathrm{ml/min}$, $\nu = 0.03\,\mathrm{cm}^2/\mathrm{s}$ (Beck et al., 1977), where R, Q, and ν are the radius, the flow volume of the coronary artery and the kinetic viscosity, respectively. Thus, for a frequency of 40 Hz and a local longitudinal amplitude of 0.2 mm, we would get $\tau_{1\mathrm{W,max}}/\tau_{0\mathrm{W}} = 1.4$. Namely, the maximal shear stress at the wall of coronary artery is increased by a factor $1 + \tau_{1\mathrm{W,max}}/\tau_{0\mathrm{W}} = 2.4$ due to such body vibration. (The small longitudinal amplitude 0.2 mm used in this estimate has taken the transmission factor from the vibrating platform to the location of coronary artery into account. If the longitudinal amplitude at the coronary artery turns out to be larger than 0.2 mm, then $\tau_{1\mathrm{W,max}}/\tau_{0\mathrm{W}}$ would also be larger proportionally.) The increased peak shear stress may increase the possibility of endothelial cell damage, e.g. in the diseased coronary arteries (cf. Beck et al., 1977).

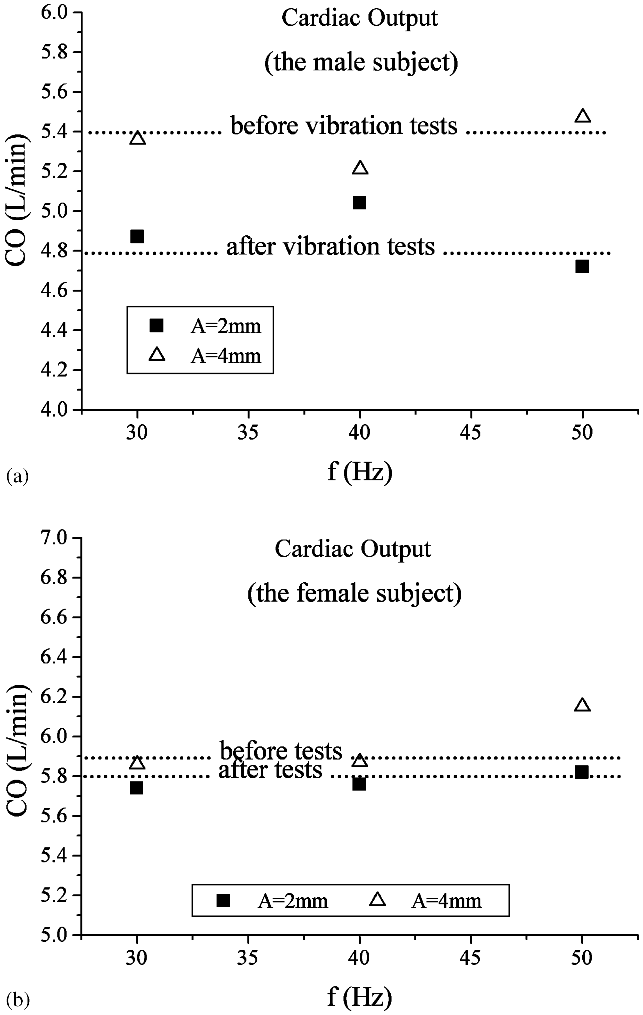


Fig. 3. Average value of cardiac output (CO) during each vibration test compared with the values before and after the six tests for the two subjects: (a) the male subject, and (b) the female subject.

The most important effect of the lateral component of vibration on blood circulation is the deformation of the vessels. During body vibrations, the external pressures acting on the walls of the blood vessels will not be isotropic. Therefore, the vessels will deform. Namely, the cross section of the vessel will not remain round, but change to more or less elliptic shape. The eccentricity of the ellipse changes periodically at the same frequency as the body vibration. This is true not only for all the vessels in muscles and inner organs, where the deformation of vessels follow the wobbling movements of the muscles and inner organs, but also for the capillaries in bones, where only the vessels deform due to the lateral oscillation of the bone which causes non-isotropic lateral pressure on the vessels, while the bone remains rigid. Hydrodynamic analysis has shown that the

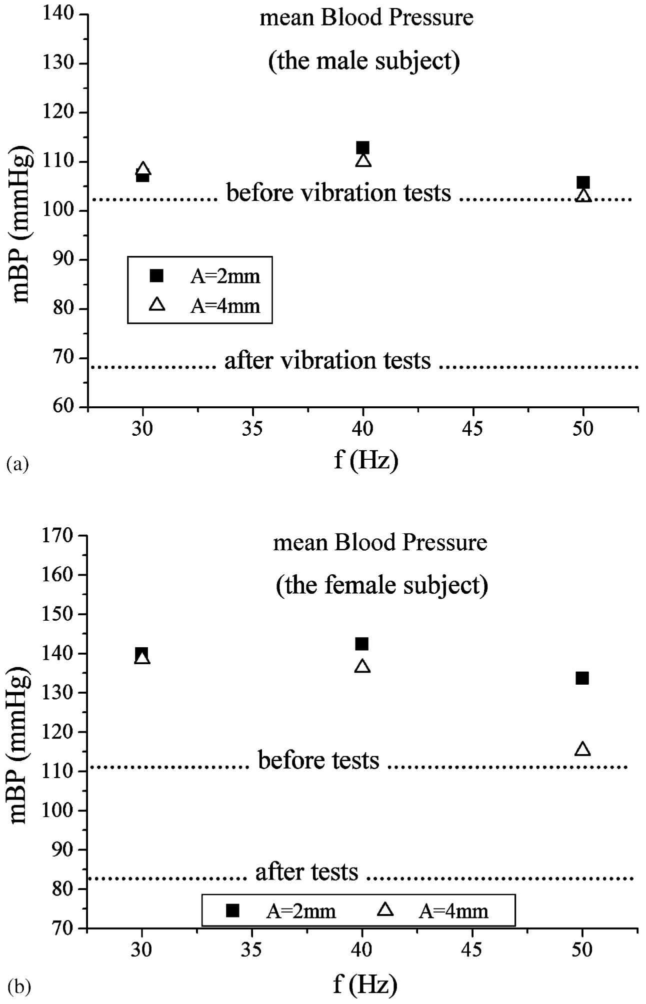


Fig. 4. Average value of mean blood pressure (mBP) during each vibration test compared with the values before and after the six tests for the two subjects: (a) the male subject, and (b) the female subject.

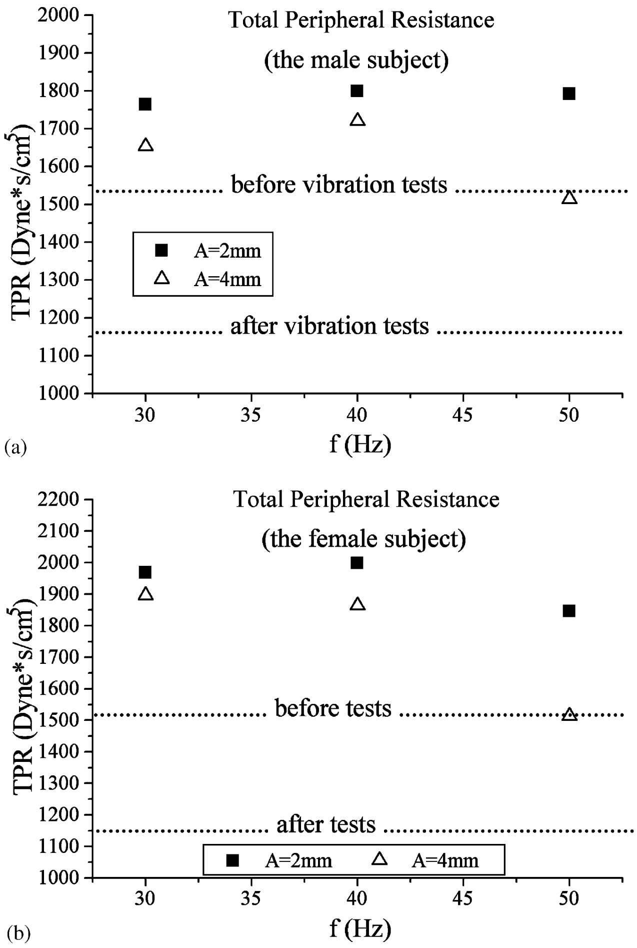


Fig. 5. Average value of total peripheral resistance (TPR) during each vibration test compared with the values before and after the six tests for the two subjects: (a) the male subject, and (b) the female subject.

resistance of a tube with elliptic cross section to the flow is larger than the resistance of a round tube with the same circumference (Fig. 8). In contrast to the longitudinal effect, the lateral effect is more important for small vessels, i.e. arterioles, capillaries, venules, than for large vessels because small vessels make the greatest contribution to TPR. Thus, the increased resistance to the blood flow caused by the deformation of vessels, particularly the small vessels, during body vibration gives an explanation of the increase of TPR during body vibration found by experiments (cf. Fig. 5(a) and (b)). Further physiological implications of this will be discussed in the next section.

4. Discussions

The results of our vibration training show that certain load is important in order to get significant positive effects. However, it is not clear how big the load should be, how long and how intensive each training unit should be, what frequency and what amplitude should be adopted, and how long the entire training period should last, for a given subject so that he or she would get maximal positive effects without being over-trained or suffering from any danger. As one example, the down-and-up behaviour of the curves in Fig. 2 is not always the case. It is not clear whether such a deep valley is necessary for reaching the peak afterwards, or under what condition it would be helpful instead of harmful. Much work of vibration training practice and mechanism analysis remain to be carried out before a clear answer could be addressed.

Muscle's contraction as a reaction to vibration stimulus, so-called "tonic vibration reflex" (TVR), was found in 1960s (cf. Hagbarth and Eklund, 1966). The increase of muscle activities as vibration is applied to the muscle can be measured by EMG (cf. Fig. 9 from Park and Martin, 1993. For a more extensive discussion on the neuromuscular response to vibration load, see e.g.

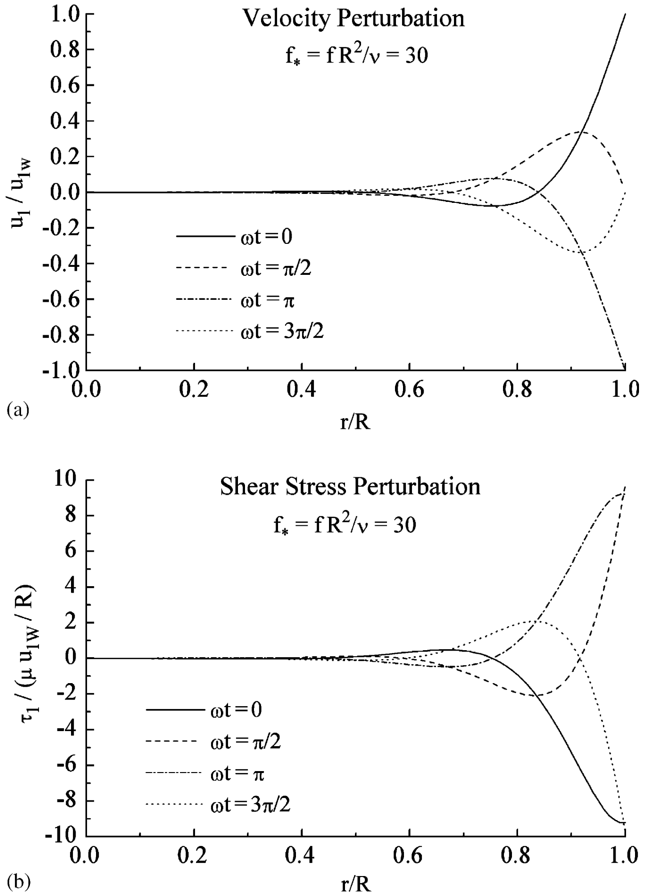


Fig. 6. (a) Velocity perturbation and (b) shear stress perturbation of the blood in the vessel caused by the longitudinal component of vibration, where r is the radial distance from the central axis of the vessel, R the radius of the vessel, u_1 the velocity perturbation, u_{1W} the amplitude of u_1 at the wall, τ_1 the shear stress perturbation, μ the viscosity, v the kinetic viscosity ($v = \mu/\rho, \rho$ the density). For blood, $v = 0.03\,\text{cm}^2/\text{s}$. As an example, for coronary artery ($R = 1.5\,\text{cm}$), $f_* = 30$ corresponds to $f = 40\,\text{Hz}$. $\omega = 2\pi f$ is the angular frequency, the four curves in each figure represent four different phases in one oscillation period.

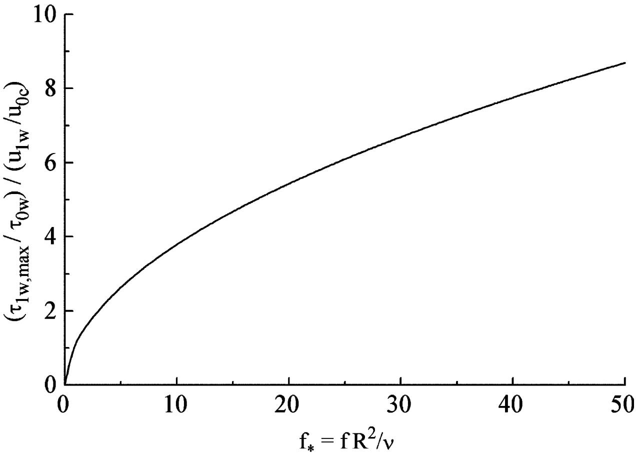


Fig. 7. Maximal shear stress perturbation at the wall of the vessel vs. vibration frequency, where $\tau_{1\text{W,max}}$ and $\tau_{0\text{W}}$ are the maximal shear stress perturbation at the wall and the undisturbed shear stress at the wall, respectively, $u_{0\text{c}}$ the undisturbed central velocity.

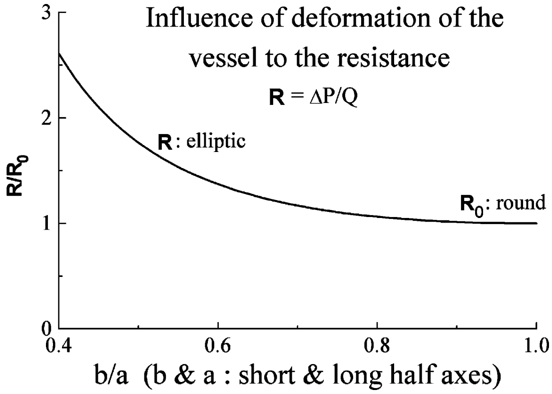


Fig. 8. Resistance of the vessel to the blood flow, defined by $\Delta P/Q$, vs. b/a, where ΔP is the pressure difference between the two ends of the piece of vessel under consideration, Q the flow volume, b and a the half short axis and the half long axis of the elliptic cross-section, respectively.

Mester et al., 2003). However, it is not clear yet what kind of physiological process holds the key to the additional growth of muscle strength obtained by vibration training compared to traditional training.

The deformation of blood vessels during body vibrations, as discussed in the last section through hydrodynamic analysis, causes the increase of TPR. This was also confirmed by the experiments (Study III, last section). In order to maintain a necessary cardiac output, the body has to either increase the blood pressure, or reduce TPR somehow, or do both. The existence of some kind of body reaction to reduce TPR has been confirmed by the drop of TPR to a value even considerably lower than before the tests (Fig. 5). The way to reduce TPR during vibration would be opening more capillaries or dilating some vessels or both. This would increase the total surface area of the micro-vessels in the muscles. Thus, the gas and material metabolism between the blood and the muscle fibres would be improved. This gives at least a hint to the mechanism for various potential benefits associated with vibration training.

Safety consideration is more important in vibration training than in traditional training. This is because too strong vibrations would lead to various damaging effects to the body, ranging from headache to internal bleeding or even death. Particular care should be taken for the head. Therefore, the transmission factor, or transmissibility, to the head, defined by the amplitude ratio between the head and the vibrating source, is important. However, the transmission factor to the head depends on not only the frequency, but also the position of the body with respect to the vibrating facility. For

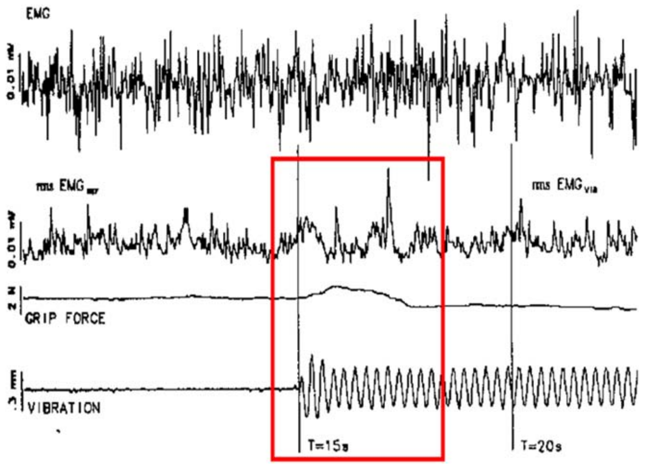


Fig. 9. Muscle activity influenced by vibration stimulus. Top: raw EMG signal; Middle: root-mean-square EMG and Grip force; Lower: vibration signal (modified from Park and Martin, 1993).

example, standing on a vibrating platform or doing push-up on the vibrating platform would have different transmission factors to the head for the same frequency. For given position, the transmission factor as a function of frequency is termed transfer function. The frequency where the transmissibility reaches maximum is termed resonance frequency. Fig. 10(a) and (b) show the transfer function from the model calculation (Yue et al., 2001) and from the measurements at German Sport University Cologne (2001), respectively. Fig. 10(a) and (b) show the same tendency that transmissibility decreases rapidly for high frequencies. Model analysis also shows that the resonance frequency increases with muscle stiffness and decreases with body mass, and the maximum of internal loads would be reached at a frequency somewhat higher than the resonance frequency because the phase differences among different parts of the body would be fully developed only when the frequency goes beyond the resonance frequency (Yue and Mester, 2002a, b, 2004). Since the resonance frequency for the whole-body vibration is in the range of 5–10 Hz, the frequencies lower than 20 Hz should be avoided in vibration training.

A systematic experimental study of the resonance frequencies for various different positions of the body with respect to the vibrating source and for different body weights as well as different muscle stiffness would be desirable. For safety, in such a study, the amplitude of the vibrating source should be set as small as possible, so that there would be no danger even in the resonance frequency range.

5. Conclusions

Vibration training is an effective training method in order to improve maximal strength and flexibility as well as various other factors if it is properly designed. This has been confirmed by the positive results carried out by other researchers and by our own group. On the other hand, improper design could be dangerous. Much work remains to be carried out in order to set up clear rules for vibration training for different groups of people.

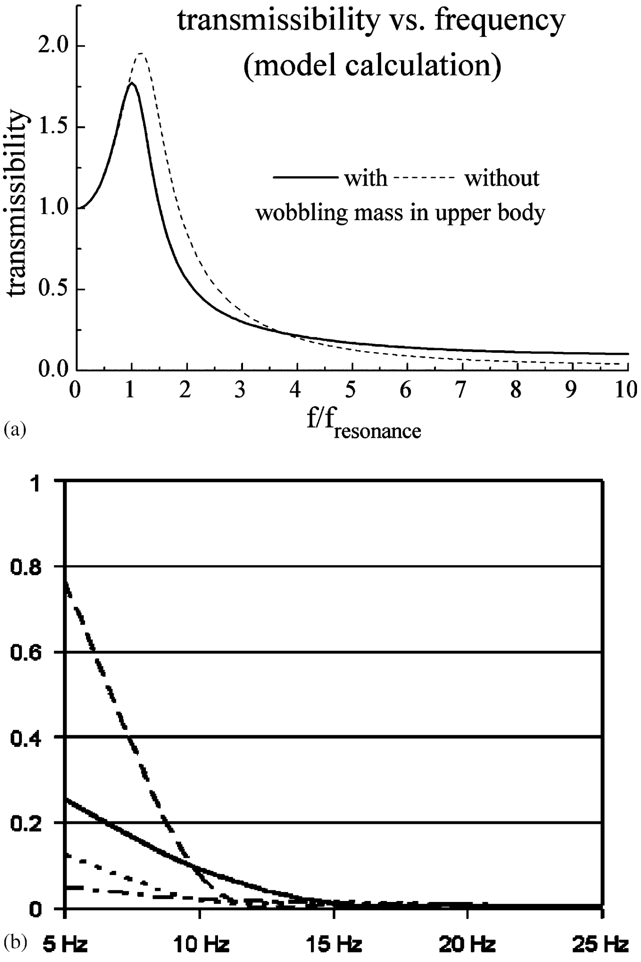


Fig. 10. Transmissibility vs. frequency: (a) from model calculation (modified from Yue et al., 2001), and (b) from measurements at German Sport University Cologne (2001), where different lines were for different subjects. The vibrating facility used for these measurements was Galileo, which generates seesaw-type vibrations. Thus, the frequencies should be doubled if compared with Power Plate Platform which remains horizontal during vibrations.

Nevertheless, based on the existing vibration training practice and the existing knowledge of resonance and cardiovascular reactions, some recommendations can be made as follows:

- High transmission factor to the head should always be avoided. Therefore, resonance frequency range should be avoided. Thus, the frequencies used in vibration training should not be lower than 20 Hz.
- Low amplitudes (1–2 mm) should be used in vibration training for leisure sport and as the starting point for elite sport.

- The exposure duration for each vibration training should be very short (20–60 s), especially when working with high additional loads.
- Vibration training should be avoided for the people who have existing coronary disease or hypertension.

In addition, a longer time period for the measurement of training effects, covering not only the training time but also the adaptation time, would be recommended in order to see the entire training and adaptation process and to avoid misjudgement of the final training results.

Cardiovascular parameter measurements confirm that TPR is increased during body vibration. Hydrodynamic analysis offers the mechanism for the increase of TPR through the deformation of vessels. As a reaction of compensation, more capillaries are probably opened in order to keep a necessary level of cardiac output needed for the body, resulting in more efficient gas and material metabolism between the blood and muscle fibres and the improvement of the maximal strength of the muscle. This might be one of the possible reasons for the potential beneficial effects of vibration training. Our experiments confirm that TPR right after the vibration tests is even considerably smaller than before the tests. This strongly supports the speculation that more capillaries are opened during vibrations. Nevertheless, it would be desirable to have direct observation to verify this speculation in the future.

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