1-1-2002

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Brach John Poston
University of Nevada, Las Vegas

THE EFFECT OF MECHANICAL VIBRATION ON ACUTE POWER OUTPUT IN THE BENCH PRESS

by

Brach Poston

Bachelor of Science
Southwest Missouri State University
2000

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science Degree
Department of Kinesiology
College of Health Sciences

Graduate College
University of Nevada, Las Vegas
August 2002

UMI Number: 1411205

UMI

UMI Microform 1411205

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Thesis Approval

The Graduate College
University of Nevada, Las Vegas

7-17, 2002

The Thesis prepared by

Brach Poston

Entitled

The effect of mechanical vibration on acute power output in the bench press.

is approved in partial fulfillment of the requirements for the degree of

Master of Science in Kinesiology

Examination Committee Chair

Dean of the Graduate College

Examination Committee Member

Examination Committee Member

Graduate College Faculty Representative

PR/1017-53/1-00

ABSTRACT

The Effect of Mechanical Vibration on Acute Power Output in the Bench Press

by

Brach John Poston

Dr. William R. Holcomb, Examination Committee Chair
Associate Professor
University of Nevada, Las Vegas

The purpose of this study was to investigate the effect of mechanical vibration on acute power output in the bench press. A total of 10 male subjects performed 3 sets of 3 reps of bench presses using a load equal to 70% one repetition maximum (1RM) on two occasions separated by 3 days. One occasion served as the experimental (vibration) condition while the other occasion served as the control (non-vibration) condition. The conditions differed due to a 30 second vibration stimulation period between bench press sets 2 and 3 in the experimental condition. The control condition incorporated a 30 second isometric hold with no vibration between bench press sets 2 and 3. Peak and average power output were calculated from the displacement versus time data in the bench press sets to see if differences existed in power performance following the vibration stimulation. The results were compared using a repeated measures ANOVA. Average power but not peak power was significantly higher following vibration stimulation compared to the control condition. Vibration stimulation also allowed for power output to be maintained in the last bench press set compared to the control

condition. It was concluded that vibration stimulation may allow for higher levels of power endurance.

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CHAPTER I

INTRODUCTION

Vibration is generally defined as oscillating motion (Steidel, 1989). The oscillating motion is not constant but greater or smaller than some average value and repeats after a certain time interval known as the period. Vibration can also be described by several other parameters such as frequency, amplitude, displacement, velocity, and acceleration. The number of cycles per unit time is termed the frequency, which is measured in cycles per second (c.p.s.) and is called hertz (Hz). Amplitude is the term used to describe the intensity or magnitude of vibration. Amplitude is defined as the maximal displacement of the object from the equilibrium point and can be expressed in (cm) or (mm). Other measures of vibration magnitude include velocity and acceleration. Of these, acceleration is currently the most commonly used measure of the intensity of vibration and it is usually expressed in m/s^2. In some cases, acceleration is expressed in terms of the number of gravity (g) where 1 g is equal to 9.8 m/s^2. For the purposes of this paper, vibration will only be quantified by frequency (Hz), amplitude (mm), and acceleration (m/s^2) or (g).

Vibration can be categorized in a variety of ways. Griffin (1994) breaks vibration down into two main types, deterministic and random. Deterministic oscillations can be described at any time by mathematical equations and are also sometimes called harmonic.

The simplest form of harmonic motion is the sine wave because the oscillations are regular and repeat themselves at set intervals. Random vibration, on the other hand, is irregular and unpredictable. In some of the literature the terms deterministic and sinusoidal are used interchangeably but sinusoidal vibration is usually considered a specific type of deterministic vibration. During the course of this paper, the term sinusoidal will be used to avoid confusion. The majority of research on vibration in general has used sinusoidal vibrations as opposed to random vibrations. It should also be mentioned that the research on vibration in sports training has been done with sinusoidal vibrations. However, in most real world situations vibration is random.

Vibration can be further categorized as whole body or local. Whole body vibration (WBV) is generally of a lower frequency and higher amplitude than local vibration. Whole body vibration occurs when the body is supported by a surface that is vibrating. This can occur while standing, seated, or lying. Therefore, whole body vibration occurs when the whole environment is undergoing motion and the effect of interest is not localized to any particular point of contact (Griffin, 1994). Common environments in which humans are exposed to whole body vibration include: riding in automobiles, boats and aircraft or while using heavy machinery. Local vibration, also called segmental vibration or hand-arm vibration, occurs when one or more of the limbs are in contact with a vibrating surface. An example of this type of vibration is when a person operates a hand tool. However, this categorization of vibration is not totally accurate because vibrations elicited by a chain saw have been shown to be able to be transmitted all the way to the ankles (Pyykko, Farkkila, Toivanen, Korhonen, & Hyvarinen, 1976).

Vibration Transmission

The transmission of vibration through the body can be very complex because it is affected by so many factors. The most important of these factors include: body posture, fat mass, muscle mass, degree of muscle contraction, body size, geometric configuration between body parts, and individual differences (Griffin, 1994). Resonance and damping are also two very important concepts that are related to vibration transmission. When an externally applied vibration at a certain frequency coincides with the natural frequency of the system, resonance occurs, which amplifies the motion. This causes large oscillations within the system which can have negative consequences. Since every structure has a resonance frequency related to its mass, all the body's structures including the internal organs have a resonance frequency. Conversely, damping occurs in all structures at all frequencies other than their particular resonance frequency (Chaffrin, Andersson, & Martin, 1999). Damping is defined as the dissipation of energy with time or distance. In the body, the muscles are responsible for most of the damping that occurs during vibration.

Humans have been exposed to vibration since the beginning of time. The effect of vibration on structures and human health has also been known for a long time. In the 17th century, vibration occurring during horse-coach riding was blamed for back pain (Mester, Spitzenfeil, Schwarzer, & Seifriz, 1999). In contrast, in the late 1800's, it was found that mechanical vibrations could be used for the treatment of pain (Granville, 1881). More recent research has confirmed Glanville's observations as it was shown that vibration stimulation significantly decreased pain in chronic pain syndrome suffers when compared to a placebo (Lundeberg, Nordemar, & Ottoson, 1987). These apparently

contradictory experiences on the association between pain and vibration demonstrate that vibration can be good or bad depending on frequency, amplitude, duration, and application. As elaborated in the next chapter, vibration in one form or another has been commonly used in the medical and rehabilitation settings since Glanville's early research.

In modern society the amount of vibration humans are exposed to has increased dramatically due to the increase in modes of travel and the use of hand held tools. A little known fact is that vibration is also common in many sports such as skiing, skating, and sailing. In skiing, for example, it has been shown that skiers are exposed to vibration frequencies of at least 30 hertz (Babiel, Hartman, Spitzenpfeil, & Mester, 2001). It is ironic that exposure to vibration has hardly been investigated at all in most of these sports compared to the amount of work done on vibration exposure in the work place.

Vibration Safety

Vibration safety has been investigated for many years in the field of ergonomics. However, due to the extremely complex reaction of the human body to vibration there is still much we don't know about the long-tem effects of vibration on human health. In regard to hand- arm vibration the most common physiological ailment is Raynaud's disease, otherwise known as vibration-induced white finger. Research is mixed on how long it takes to develop vibration-induced white finger due to the great differences in the parameters and latency time studied. However, it is generally accepted that vibration-induced white finger takes a relatively long time to develop. It seems to take prolonged exposure times of operation of hand tools such as grinders and chain saws at one's job over a period of at least a year or more for vibration-induced white finger to cause

significant problems. For example, an epidemiological study by Miyashita, Shiomi, Itoh, Kasamatsu, and Iwata (1983), found that the appearance of symptoms of vibration-induced white finger depend on the total time that one operates a vibrating tool. Symptoms did not appear until after 2000 hours of total exposure time with two to eight hours of exposure a day. Weighted acceleration of the tool is also used to determine the latency of vibration-induced white finger (Brammer, 1986). At an acceleration of $30m/s^2$ it took two years for symptoms to occur. In all vibration training studies conducted so far the total time spent under vibration to elicit a training effect has been hundreds of times less than these exposure times. Therefore, it seems that using vibration in training a few times a year in specific training cycles is very safe. In fact, local vibration has hardly ever been accused of causing any acute problems. Considering that all vibration training studies have not exceeded 100 minutes of total exposure time, hand arm vibration training would seem much safer than daily operation of a hand tool.

Whole body vibration, however, is not as safe as local vibration. Although very rare, acute cases of injury such as lung damage, gastro-intestinal bleeding, and heart hemorrhages have occurred in the research studies due to whole body vibration (Griffin, 1994). These studies, however, used unusually high magnitudes of vibration that humans are not normally exposed too. It should be noted that no negative effects have ever been reported in a vibration training study. One common concern in whole body vibration is that if the vibration frequency matches the resonance frequency of an internal organ the organ could rupture. While this is a valid concern, this has never happened in a whole body vibration training study or in any type of local vibration study. According to Griffin (1994), the scenario of vibration matching the resonance of an internal organ and

rupturing it can only happen when damping is low and resonance frequencies of the organ are known. Values for resonance frequencies have been reported but these vary so much with posture and the individual that it is very difficult to put an exact value on them for a given person. It would seem that if resonance was indeed a problem that rupturing of internal organs would be much more common due to the amount of whole body vibration that humans are exposed to everyday by riding in vehicles, boats, standing in buildings, and in operating heavy machinery in the workplace. However, this is simply not the case. In fact, Griffin (1994) one of the world experts on vibration, believes that elimination of vibration at the resonance frequencies of any specific internal organ is oversimplistic. In addition, it must be emphasized that the resonance frequencies of most organs lie in the low frequency range of 20Hz and below while all vibration training studies have used frequencies higher than that value. Thus, it would seem that as long as low magnitudes are used, some effort is made to avoid resonance frequencies, and total exposure time is short, vibration training can be very safe.

First Uses of Vibation in Sport and Strength Training

Research on vibration as a training aid or a specific training modality in sports is relatively new. The Russian scientist Nazarov is usually credited with being the first person to use mechanical vibrations for strength training (Nazarov & Spivak, 1987). These first applications of vibration were used in the training of gymnasts. This involved using motors to vibrate gymnastic beams, bars, and especially rings. Typically, the gymnast was required to perform exercises or hold certain postures such as the cross while the apparatus was under vibration (Nazarov & Spivak, 1987). Performing these

various exercises while exposed to vibration was believed to lead to faster strength increases than traditional methods. Only recently have western scientists begun to study both whole body and local vibration as a specific training aid for athletes. These studies have generally been of short durations ranging from one day to 6 weeks and have looked at the effect of vibration on strength, power output, hormonal responses, and posttetanic potentiation. Since the use of mechanical vibrations for eliciting activity-dependent potentiation in sport and strength training is the main topic of this work, these studies will be discussed in great detail in the next section.

Purpose of the Study

The purpose of this study was to investigate the effect of mechanical vibration on acute power output in the bench press. Of particular interest in this study was the specific research question: Can mechanical vibrations increase mean and peak power output by eliciting activity-dependent potentiation?

Activity-Dependent Potentiation

When discussing activity-dependent potentiation it is necessary to distinguish between potentiation, activity dependent potentiation, and posttetanic potentiation. Potentiation is generally defined as an increase in a force related parameter (power, rate of force development, or force itself) or the enhancement of a contractile response while activity-dependent potentiation is an enhanced contractile response which can be attributed to prior activity (Rassier & MacIntosh, 2000). Posttetanic facilitation is the enhancement of twitch active force following a tetanic contraction and implies that

tetanus occurred. Tetanus refers to the summation of all available motor units, and is brought about by intense muscular contractions or muscular contractions of long duration. Posttetanic potentiation is based on the fact that the contractile response of muscle depends on previous muscle activity or activation history. Activation history can cause fatigue and therefore decrease muscle performance or can result in potentiation and increased muscular performance (Abbate, Sargeant, Verdijk, & De Haan, A, 2000). In addition, fatigue and potentiation always exist together with one being predominant (Rassier & MacIntosh, 2000). Thus, it would seem that in resistance training there is an optimal magnitude, duration, and type of stimulus for evoking a potentiation response and increasing acute force production.

The idea of using the phenomenon of activity-dependent potentiation for weightlifting was popularized by Fleck and Kontor (1986). The training system was loosely termed complex training and essentially involved the contrasting of heavy and light loads within the same workout with hopes that the use of heavier loads would increase performance with lighter loads performed later. Loads of 85%-95% of one rep maximum in the squat were typically performed before unloaded or lighter movements of 30-45% of 1RM in jump squats. This was also done with squats and depth jumps. Another method utilizes similar movement patterns such as heavy jump squats and light jump squats (Baker, 2001).

These methods have proved successful as increases in short-term power output have been reported using this method of training (Baker, 2001; Young, Jenner, & Griffiths, 1998; Gullich & Schmidtbleicher, 1996). The reason there is a potentiation following tetanus is not clearly understood. Possible explanations include the role of

regulatory light chain phosphorylation (RLCs). These are found at the base of the myosin head and are able to accept a phosphate ion. This phosphorylation after a fatiguing stimulus changes the shape of the myosin head increasing the affinity of actin to the myosin head (Rassier & MacIntosh, 2000). With the present knowledge of the sliding filament theory this would suggest that this change in (RLC's) could increase tension produced by the muscle. Some other possible mechanisms include ion changes at the neuromuscular junction and elicitation of the H-reflex which could allow for greater activation of the muscles involved when superimposed over a voluntary M-wave. Another interesting possible explanation could be the stimulation of the nervous system following a heavy load. A heavy load could decrease the activation threshold of the Golgi tendon organ (GTO) (Baker, 2001). This decreased inhibitionary effect of the (GTO) could allow for the muscles to produce more force. Psychological effects cannot be ruled out because lifting a heavy load prior to a light load can make the light load seem lighter and allow for it to be moved in a more explosive manner as the traces in the central nervous system from the heavy load are still present. Since vibration has been shown to elicit reflex muscle contraction and possibly decrease (GTO) inhibition the possibility of vibration being able to evoke activity-dependent potentiation will be the focus of this study.

Specific Research Hypotheses

1. Average and peak power output will increase in the bench press set performed subsequent to vibration.

2. Average and peak power output will be similar in all bench press sets not performed after vibration.

In order to investigate these hypotheses, a series of test batteries were developed with a similar research protocol as previous studies investigating potentiation by other means (Young et al., 1998; Gullich & Schmidtbleicher, 1996).

Limitations of the Study

The following limitations apply to the study:

1. Limitations associated with collection of kinematic data through the use of a high-speed camera. These limitations could include movement of the LED light due to rotation of the bar during trials, small variations in range of motion within subjects from repetition to repetition, and rotation of the bar in the transverse plane by the subjects.
2. The design of the study limited the validity of the study. External validity was limited due to the small sample size of ten subjects, strength profile range of the subjects, and proficiency level of the subjects.
3. Only vertical measures of displacement, velocity, acceleration, force and therefore power were considered in this study. Horizontal measures were not analyzed since the bench press movement is primarily vertical. However, horizontal measures of power can contribute significantly contribute the power output depending on the weightlifting exercise studied. However, in the bench press exercise horizontal work can be neglected most of the time (Garhammer, 1993).

Assumptions of the Study

All subjects were assumed to be injury free in the upper extremities during the study. It was also assumed that all subjects performed the concentric portion of each bench press set as quickly and explosively as possible as per the directions given to them. Fatigue was also assumed to be minimal between bench press sets as 4 minutes of rest should have been adequate to ensure nearly complete neuromuscular recovery when working with the prescribed percentages of 1RM in this study. All instrumentation was calibrated prior to testing of each subject and was assumed to be accurate.

Definition of Terms

Acceleration-The change in velocity divided by the change in time.

Activity-Dependent potentiation-An enhanced contractile response which can be attributed to prior activity.

Amplitude- The maximal displacement of an object from an equilibrium point.

Damping- The dissipation of energy with time or distance.

Displacement-The change in position divided by the change in time.

Frequency- The number of cycles per unit time.

Posttetanic potentiation-The enhancement of twitch active force following a tetanic contraction.

Potentiation- An increase in a force related parameter (power, rate of force development, or force itself) or the enhancement of a contractile response.

Power-The rate of energy transfer. Work divided by time.

Resonance-Situation occurring when an externally applied vibration at a certain frequency coincides with the natural frequency of a system.

Tetanus- The summation of all available motor units, and is brought about by intense muscular contractions or muscular contractions of long duration.

Velocity-The change in displacement divided by the change in time.

CHAPTER II

REVIEW OF LITERATURE

In interpreting vibration training studies and studies on vibration in general it must be remembered that the vibration parameters of frequency, amplitude, and acceleration are often very different between studies. In addition, the way in which vibration was applied, the time under vibratory stimulation, the exercise type, the muscle contraction type, and many other factors are often very different between studies. Therefore, caution must be used when extending findings of studies in different settings and using different vibration parameters to situations involving different circumstances. Vibration training studies will be broadly divided into whole body and local vibration studies for the purposes of this review.

Local Vibration Studies

At the present time, there have been several well-controlled studies published on the effect of local vibration on muscle strength and/or power (Issurin, Liebermann, & Tenenbaum, 1994; Bosco, Cardinale, & Tsarpela, 1999a; Issurin & Tenenbaum, 1999). Of these studies two of them looked at a possible potentiation response from the vibration stimuli along with several other variables.

A local vibration training study by Issurin et al. (1994) investigated the effect of the vibration on maximal strength and flexibility. Subjects in this study were 28 males who were active in club or varsity sports on the college level. They were divided into three groups with group A performing flexibility exercise with vibration and the strength exercise with no vibration, group B performing the strength exercise with vibration and the flexibility exercise with no vibration, and group C (the control) performing irrelevant training activities such as basketball. The vibration apparatus was composed of a cable pulley system with the vibration being transmitted by the cable to a bar or a ring. Subjects undergoing the strength training aspect of the study held the bar while performing a seated bench pull exercise. Subjects undergoing the flexibility component of the study placed one foot in the vibrating ring while the other foot was on the floor. The amplitude of the vibration was 3mm but after cable transmission was damped to .6-.8 mm. Frequency was set at 44 Hz resulting in acceleration levels of approximately 22 ms^2 for the flexibility exercise and 30 ms^2 for the strength exercise.

The strength workouts were composed of six sets of sitting bench pulls with loads of 80-100% of 1RM with one group being exposed to vibration during the sets (superimposed vibration). The total work time was approximately 2 minutes for all sets combined. The sitting bench pull exercise was also used as the pre and post-test. The flexibility exercise was done for six sets of 40-90 seconds. The total time spent stretching was approximately 7 minutes per workout. This stretching exercise with the ring was also used for the pre and post-test along with the flex and reach test. All subjects in all groups performed their exercises three times a week for three weeks.

The results showed significant increases in strength for both groups. However, the vibration group increased 1RM strength by 49.8 percent while the non-vibration group increased only 16.1 percent. The flexibility group that was exposed to vibrations increased flexibility by 8.7 percent in the ring flexibility test while the non-vibration group increased only 2.4 percent. In the flex and reach test, the vibration group increased flexibility by 43.6 percent while the non-vibration group increased by 19.2 percent. The control group showed no significant increases in any of the tests at the end of the study. The researchers concluded that the huge gains in strength in the vibration group were due to neurological responses to the vibration stimulus. Based on previous research in the therapeutic setting they attributed the increase in strength as being due to increased activity of the primary endings of the muscle spindles. This would lead to activation of a larger number of motor units and possibly induce previously inactive motor units to contract. However, since no EMG's were taken these assumptions may or may not be true. The authors also attributed some of the strength gain to motor learning effects from merely performing the exercise. This infers that the subjects were initially not familiar with the exercise performed. While motor learning of the movement certainly played a role in such a huge strength increase of almost 50 percent in only 3 weeks it is hard to attribute a large portion of this increase to motor learning since the control group improved only about one-third as much as the vibration group. Regarding the flexibility increases, the authors attributed these increases to increases in the pain threshold, increases in blood flow, increases in muscle temperature, and increased relaxation of the stretched muscle. All of these factors were attributed to the vibration treatment and based on previous research in other settings. In conclusion, this study showed very large

increases in strength and flexibility that are not easily induced by other training means due to the inclusion of superimposed vibratory stimulation.

However, in contrast to Issurin et al. (1994), a recent study on the effects of vibration on flexibility by Kunnemeyer and Schmidtbleicher (1997a) it was demonstrated that vibration was no better than traditional methods in increasing flexibility. This study was carried out over a three-week period and involved a large sample size of 112 sportsmen and women. Subjects performed either traditional static stretches for the chest muscles or had vibrations at a frequency of 23Hz applied to the chest by a special device. These results are similar to a study by Atha and Wheatley (1981), where a traditional mixed static and dynamic stretching program for the hip flexors was compared to a vibration stretching program and a control group. The vibration was applied at a frequency of 44Hz and at an amplitude of approximately.1mm. This level of vibration was deemed moderately comfortable as subjects were allowed to read during the treatment. Results showed that vibration was effective in increasing flexibility in the hip flexors but no more than the traditional mixed static and dynamic stretching program. However, subjects considered the vibration treatment more comfortable and easier to perform than traditional methods. The authors concluded that vibration can increase flexibility, it is just as effective as traditional methods, and a 15 minute period of vibration can induce flexibility changes for 24 hours post-vibration. They theorized that the mechanisms behind the vibration induced flexibility gains were due to increased relaxation levels, increased tolerance to the pain of stretching, and alterations in the level of the threshold stimulus invoking pain.

Liebermann and Issurin (1997) conducted an additional study to examine the effort perception of lifting different loads both with and without superimposed mechanical vibration. The subjects consisted of 41 males who were divided into four groups based on their athletic expertise. The expertise levels were as follows: Olympic level, national level, amateur level, and junior level who were competitive on the national or international level at their younger age division. The vibration apparatus was composed of a cable pulley system with the vibration being transmitted by the cable to a bar. This vibration apparatus was identical to the one in the previous study except the subjects in this study performed isotonic elbow flexion exercises in a seated position instead of bench pulls. The amplitude of the vibrations was 3mm but after cable transmission was dampened to .6-.8 mm. Frequency was 44 Hz resulting in acceleration levels of approximately 30 ms^2 for the elbow flexion exercise. After 1RM testing on the exercise, subjects were required to perform the same exercise at 30, 60, 90, and 100 percent of the 1RM. This was done both under normal conditions and during vibration. The subjects were divided by expertise level for the subsequent data analysis. The perceived effort was measured using the Borg scale.

The results showed that subjects generally lifted more weight under vibratory conditions with the Olympic athletes benefiting the most from vibration. This could be viewed as unexpected because one would think that experienced athletes would be able to activate more motor units than lesser trained individuals and that vibration should not allow them to activate as many additional motor units as it would in less experienced athletes. In fact, the order of benefit was exactly the same as the level of expertise of the subjects. That is the Olympians benefited the most, followed by the national level

athletes, then the juniors, and finally the amateurs. Vibration also allowed for lower effort perception levels in all groups except the juniors.

Liebermann et al. (1997) concluded that along with the explanations mentioned in their previous study for strength increases during vibration, reduction of effort perception plays an important role as well. The reason for this reduction of effort perception was unclear but the researchers thought that attention diversion during the vibration and the increase in synchronization of motor units may have been the main factors involved.

In another follow up study, Issurin & Liebermann (1999) investigated the difference in how athletes of different experience levels respond to vibration and if vibration could elicit a residual effect. The subjects for this study were 28 males who were divided into two groups based on their level of performance. The first group consisted of national level athletes who were members of the Israeli national judo, wrestling, weightlifting, gymnastic, and track teams. The second group consisted of amateur athletes who participated in college club or varsity sports. Thus, the second group were power-trained athletes but not as well-trained as the first group. The vibration apparatus was composed of a cable pulley system with the vibration being transmitted by the cable to a bar. This vibration apparatus was identical to the one in the previous studies except the subjects in this study performed isotonic elbow flexion exercises in a seated position as in the second study. The amplitude of the vibration was 3mm but after cable transmission was dampened to .6-.8 mm. Frequency was 44 Hz resulting in acceleration levels of approximately 30 ms^2 for the elbow flexion exercise. These values were also the same as in the previous studies. Two separate series of the elbow flexion exercise were performed by all subjects and in a random order. Each series

was composed of three sets of three repetitions with a load of 65-70 percent of maximum. Rest periods of 2-3 minutes were allowed between sets and 8-15 minutes between series. The only difference between the two series of three sets was the inclusion of vibration during the second set of one of the series. Therefore, it would be easy to see if the vibration on the second set would produce higher power outputs than the first set and if the third set without vibration stimulation would be affected by the vibration stimulation in the second set. In other words, the acute effect of vibratory stimulation would be measured as the difference in power values in the second set with vibration and in the first without vibration. The residual effect would then be measured as the difference in power values between the third (after vibration) set and the first (pre-vibration) set.

Both groups improved power performance by similar values during the second set with superimposed vibrations. The elite group improved maximal power by 10.4% and mean power by 10.2% while the amateur group showed improvements of 7.9 and 10.7%, respectively. During the series performed with no vibration stimulation on the second set their performance was slightly lower than in the first set as opposed to the values above in the series with vibration on the second set. The third set, however, showed no improvement due to the vibration from the previous (second set) and was similar to the third set of the series with no vibration. In conclusion, this study showed significant improvements in performance in the set when vibrations were superimposed but no residual (post-tetanic facilitation) effect in a non-vibratory set following a vibratory set. The explanations given for increased strength during the superimposed vibration set were the same as the explanations for the strength increase in their two previous studies discussed above by the same researchers.

Bosco et al. (1999a) performed a training study to examine the influence of vibration on the mechanical properties of the elbow flexors. The subjects of this study were boxers from the Italian national team. They performed pre-tests with both limbs in the elbow flexion exercise. During the pre-tests, measures of mechanical output were taken along with EMG recordings. The limbs were then randomly assigned to the control condition of no vibration or the treatment condition with vibration. The vibrations were applied by requiring the subject to hold a vibrating dumbbell of 5 percent of bodyweight or 2.8kg. The elbow was kept in a semi-flexed position while in a standing position with a relative angle of approximately 2.5 radians. The frequency was set at 30Hz, displacement 6mm, and an acceleration of 34 m/s^2. Five sets were performed with the vibration lasting one minute each set. A one minute rest period was allowed between sets. After the vibration treatment, post-tests were conducted in the same manner as the pre-tests.

The results demonstrated significant increases in power output for the vibration condition while there were no significant differences in the control limb. The EMG readings during vibration showed enormous increases of almost 250 percent compared to merely holding the dumbbell before vibration. Interestingly, the post-test EMG readings were similar to the pre-test. However, when divided by the power output as an index it showed significant increases. In other words, following the vibration treatment the EMG's were similar in the post-test as in the pre-tests although power was improved significantly in the post-tests. The authors attributed this to increased neural efficiency due to the previous vibration treatment. In summary, vibration caused an acute increase

in maximal mechanical power output in this study indicating that localized vibration may induce a posttetanic potentiation effect possibly by enhanced neural efficiency.

In contrast to the aforementioned local vibration studies, a study by Samuelson, Jorfeldt, and Ahlborg (1989) demonstrated that superimposed vibration decreased the endurance of maximal isometric muscular contraction of the quadriceps. In this study, the vibration frequency was set at 20Hz with an acceleration of $20m/s^2$ and was applied until the subject was not able to maintain force at 90% of maximum or above. The endurance times were 22.5 seconds without vibration and 15.8 seconds with vibration. These results are in conflict with many of the studies mentioned above. The reasons for the lack of strength increase during superimposed vibration in this study were not clear but could have been due to the fact that the quadriceps were not in a fully stretched position during the isometric contraction (Issurin & Tenenbaum, 1999).

Whole Body Vibration Studies

Compared to local vibration studies, whole body vibration studies for the purposes of strength training have only been undertaken recently. Despite this fact, there is more published literature on whole body vibration than local vibration. These studies offer many insights into the general effects of vibration on the neuromuscular and cardiovascular systems. Of these studies, several have investigated if there was any potentiation present after exposure to whole body vibration.

The first study to investigate the effects of whole body vibration in strength training was carried out on team handball and waterpolo players (Bosco, Cardinale, Tsarpela, Colli, Tihanyi, von Duvillard, & Viru, 1998). The subjects were exposed to

five sets of vertical sinusoidal whole body vibration for between 90 seconds and 2 minutes for 10 consecutive days. The frequency of the vibration was 26 Hz, amplitude 10mm, and acceleration $27m/s^2$. After the 10 day treatment period, significant increases in maximal mechanical power output, highest rise in the center of gravity during a 5 second continuous jumping test, and the average height during the 5s continuous jumping test were observed in the vibration group. The control group who continued with their normal daily activities showed no differences between the pre and post-tests. The large increases in jumping ability and maximal power output were attributed to short-term neural potentiation. Since the study lasted only two weeks it was deemed highly unlikely that significant morphological adaptations could have occurred. This would be consistent with research into the effects of explosive power training and maximal weight training which has shown that neural adaptations predominate in the initial stages of a strength training program (Sale, 1992). Several other mechanisms of action were proposed including: stretch reflex potentiation, increased synchronization of motor units, improved cocontraction of synergistic muscles, increased inhibition of antagonistic muscles, decreased GTO inhibition, and conversion of fiber type. However, no EMG or muscle biopsies were performed so the contributions or relative contributions of the above mechanisms could not be determined.

Bosco, Colli, Introini, Tsarpela, Madella, Tihanyi, and Viru (1999b) investigated the acute effects of whole body vibration on the mechanical behavior of skeletal muscle. The subjects consisted of six national level female volleyball players. After a warm up, subjects performed maximal dynamic leg presses on a slide machine with absolute loads of 70, 90, 110, and 130kg with one leg at a time. Measures of average velocity,

acceleration, average force, and average power were calculated during performance of the leg presses with a testing apparatus connected to the slide machine. No significant differences in the test parameters were present between legs of each individual subject after the pre-tests. Each subject then had one leg assigned either to the treatment condition and the other to the control condition. The treatment consisted of vertical sinusoidal whole body vibrations with a frequency of 25 Hz, displacement 10mm, and an acceleration of 54 m/s^2. Ten sets of one minute of vibrations were applied with one minute of rest between sets. Subjects stood on the vibrating platform in a plantar flexed position with the knee angle set at 100 degrees of flexion.

Post-tests demonstrated significant improvements in average velocity, average force, and average power in the leg exposed to vibration. These significant improvements were observed at all loads used except for the average force measurement with the 70 kg load. In the control group, only the 130kg load showed a significant improvement (3 percent) in the post-tests. The results were attributed to the vibration treatment employed because the subjects were very familiar with the exercise and motor learning could not have played a significant role. According to the authors, the large improvements in average velocity, average force, and average power are normally only seen with many weeks of training. Therefore, the authors believed that the time under vibration with such a large acceleration (5.4 g) was a large factor in these increases. They calculated that an equivalent amount of traditional training would entail performing 150 leg presses twice a week with three times body weight for 5 weeks. Thus, it seems that vibration stimulation can elicit similar adaptations to strength training only in a much shorter time period. However, whether these acute increases in strength and power can

be extended to longer training periods of several weeks or months with steady improvement in the strength and power parameters has yet to be investigated.

The metabolic and cardiovascular effects of whole body vibration are not as well known as the effects of vibration on muscle strength and power. One study investigated these effects along with the acute effects of vibration on strength and power measures (Rittweger, Beller, & Felsenberg, 2000). Pilot work for this study had shown that whole body vibration at 26 Hz during squatting increased oxygen uptake by 5 ml O_2 min $^{-1}$ kg $^{-1}$ bodyweight as compared to squatting without vibration. The purpose of this study was to explore the limits of exhaustive whole body vibration on the metabolic system and to measure lactate concentration, heart rate, blood pressure, neuromuscular function, and skin blood flow.

The subjects consisted of 37 male and female university students. Subjects were tested in three different sessions. The first session consisted of control tests on a cycle ergometer with increasing steps of 50 watts every 3 minutes until exhaustion. Measures of arterial blood pressure, ECG, heart rate, oxygen uptake, carbon dioxide delivery, perceived exertion, and blood lactate concentration were taken before, during, immediately after, and 15 minutes post-exercise. The second and third visits consisted of exhaustive vibration exercise performed on a vibrating platform at an amplitude of approximately 1 cm, a frequency of 26 Hz, and an acceleration of $147 m/s^2$ (15g). The participants also had an additional load added to their bodies during the treatment of 40 percent of bodyweight for males and 35 percent of bodyweight for females. The treatment on the platform began with 30 seconds of standing followed by squats lasting six seconds per rep (3 second concentric, 3 second eccentric) until exhaustion. After

exhaustion, post-tests were taken. These tests were the same as the first visit with the addition of three trials of jumps for height with hands on the hips and knees flexed to 90 degrees. Cutaneous laser Doppler flow over the calf and over the foot for a period of 20 seconds, ten second maximal voluntary contractions of the knee extensors with torque and EMG measurements.

The perceived effort during vibration was higher than in the cycle ergometry tests performed during the first visit but were the same (18 on the Borg scale) after the respective exercise types. Heart rate increased significantly less during vibration than during cycle ergometry with no differences in the recovery tests. Oxygen uptake was also lower during vibration as was lactate concentration when compared to cycle ergometry. Systolic blood pressure was also lower during vibration than during ergometry work and no differences were apparent after the 15 minute recovery in the aforementioned parameters. The Laser Doppler Flow data was not normally distributed but some participants did develop erythema on their calves after vibration. Jump heights were decreased by about ten percent in males and females following the vibration application but only during the first two of the three jumps performed with five second rest intervals. Maximal knee extension torque was also reduced by ten percent in the first two seconds of the ten second contraction following vibration but not during the last two seconds.

The results of this study have many practical implications for the administration of vibration training protocols. Perhaps the most important is the lower rise in all the cardiovascular measures in response to whole body vibration exercise when compared to cycle ergometry. This is important because it means that the elderly can benefit from

vibration training without excessive concern over it having negative cardiovascular implications. Thus, they can derive many of the benefits of vibration training on muscle and bone without negative cardiovascular consequences. Regarding the neuromuscular effects, this study makes it evident that an optimal amount of stimulation and an optimal rest period after the stimulation are very important considerations in eliciting potentiation after vibratory stimuli. It seems that too much fatigue from vibration, too little stimulation, too long a rest, or too short of a rest period can negatively effect the potentiation response.

Another study reported a single case study of whole body vibration training on the performance of an elite alpine skier (Mester et al., 1999). The research group who conducted this research has considerable experience in analyzing the vibration load during skiing and are responsible for the majority of the work on vibration in this setting. However, in this study they also looked at vibration as a possible strength training aid in an elite skier over 21 days and 36 training sessions.

For this study, the researchers did not use one of the two models of commercially available whole body vibration devices but constructed their own model. The vertical sinusoidal vibrations were applied at a frequency of 24 Hz with an amplitude of 2.5mm. The training consisted of six cycles of equal length with vibration only being applied every other cycle. During the other cycles, the same traditional exercises were performed only not under vibratory conditions. Some of the exercises used were one-legged squats, lunges with dumbbells, and step-ups. These exercises are typical ones used in the strength training routines of alpine skiers. The pre and post-tests consisted of static leg press, squat jump, depth jump, and a vibration step test at which time measures of heart

rate, lactate, EMG, creatinekinase, urea, vibration transmission, and force were taken in each vibration session.

The results showed that during the vibration periods massive increases in creatinekinase and urea occurred as compared to non-vibration periods. This demonstrates a much larger demand on the muscular system during vibration. Strength in the static leg press test rose at first but then quickly returned to normal for the first two weeks of training. However, during the last week of training strength rose very sharply to a maximum of 43% of the initial level. Squat jumps also increased reaching an improvement from approximately 39cm to 47.8cm in only two weeks. According to the researchers, these results contradict other case and pilot studies by their group showing no strength or jumping improvement following vibration training. According to the researchers, the metabolic reactions in this study showed increases in oxygen uptake and lactate concentration but the values were nowhere near the maximum values that would typically be seen in a maximal treadmill or cycle ergometry test. This study lends support to the argument that, when used correctly, vibration can be a useful adjunct to strength training in increasing strength and power output.

However, not all studies have shown whole body vibration to be effective for strength gains or eliciting an activity-dependent potentiation. In one study, physical education students performed depth jumps both before and after 12 minutes of whole body vibration (Kunnemeyer & Schmidtbleicher, 1997b). Depth jump performance fell off drastically and contact time increased after the vibration treatment. Thus, in this study whole body vibration failed to ellicit a posttetanic potentiation response. This may have been caused by too much fatigue from the vibration treatment as the subjects were

exposed to an usually high volume of exhaustive vibration exercise. The amount of fatigue that this protocol elicited most likely predominated over any type of potentiation effect that could have occurred during the treatment. Thus, it would appear that as in weightlifting an optimal amount and duration of stimulation must be used to allow the potentiation effect to predominate over the fatiguing effect of previous exercise.

In another study by Schlumberger, Salin, and Schmidtbleicher (2001), the effect of whole body vibration on strength was investigated. Subjects trained three times a week for 6 weeks doing one-legged squats with a barbell. The control leg performed the one-legged squats in the traditional fashion while the experimental leg performed the one-legged squats on a vibration platform. Results showed significant strength increases of six percent in both legs but no difference between them. Therefore, vibration training was deemed by the authors to be no more effective than traditional methods. These results are clearly in conflict with many of the studies mentioned above. The reasons for the lack of strength increase in this vibration study are not clear. The study used similar vibration parameters and the same brand of vibration platform as in other vibration training studies that gave positive results. One possible problem with this study could be the use of one leg being a control leg and the other being an experimental leg. Since vibration can affect the central nervous system it could be argued that the vibration transmitted to the experimental leg could have caused a crossover effect in the other leg. However, a previous study (Bosco et al., 1999b) used one leg as a control and the other as the experimental condition in the same subjects and produced significant differences in the vibration leg while the control leg showed no improvements. Thus, more work is

needed in this area to uncover the possible mechanisms behind the conflicting research results.

Mechanisms of Action

In most of the vibration training studies conducted to date, the researchers provide several explanations for the large increases in performance seen by the use of mechanical vibrations. These explanations often rely on research conducted on vibration in other fields such as ergonomics and rehabilitation. Presently, most studies have focused on establishing the basic effect of vibration on certain performance parameters. Few studies have attempted to perform the basic science necessary to uncover the underlying physiological mechanisms of action behind the use of vibration in strength training. The proposed mechanisms discussed below are based on the limited research available on the mechanisms underlying the effects of vibration and the potential mechanisms proposed by vibration training researchers based on work in other fields.

Subjection to Simulated Hypergravity Conditions

The basis of strength training is to subject the body to demands that it does not normally encounter and progressively force specific adaptations in the neuromuscular system by providing optimal overload. If this process is administered in a progressive and systematic way over a period of time the body will continue to adapt to the imposed demands up to a certain point. When someone performs resistance training exercises, especially whole body standing free weight exercises or plyometric type exercises, it can be viewed as subjecting the body to simulated hypergravitational conditions (Bosco,

1992). In fact, in everyday life humans are continually subjected to the force of gravity which causes neuromuscular adaptations. From this perspective, it could be inferred that gravity provides the major stimulus for maintenance and improvement of the musculature during everyday life. In space flight, when humans are no longer under the force of the earth's gravity it is well known that there are declines in muscle tone, mass, strength, and endurance. So heavy resistance training type exercises or specialized strength training methods such as plyometrics could be viewed as ways in which the body is exposed to simulated hypergravity conditions which can force adaptations such as increased muscle size, strength, and power. These training methods, especially plyometric drills such as depth jumps, typically involve abrupt changes in acceleration to which the body must learn to adapt (Bosco, 1992).

Another way of subjecting the body to hypergravity conditions for prolonged periods is by wearing weighted vests. Almost all the research in this area has been done by Bosco and colleagues (Bosco, Zanon, Rusko, Dal Monte, Latteri, Bellotti, Candeloro, Lacatelli, Azzaro, Pozzon, & Nonomi, 1984; Bosco, 1985; Bosco, 1992). This method of training typically involved the subjects wearing a weighted vest of between eight and twelve percent of bodymass continually for 3 weeks. Typically, the only time the vests were taken off was during sleep and sometimes during specific sport skill training.

These studies have generally shown large increases in relatively short time periods in the lower body power tests such as the vertical jump, depth jump, and jumping with different loads in very experienced athletes. Increases of 10% or higher were obtained in international level sprinters, jumpers, and throwers in the aforementioned jumps. However, after 4 weeks of resumption of normal training without weighted vests

all improvements can be lost and the performance of all subjects return to previous levels (Bosco et al., 1984). These increases were attributed by the authors to rapid neural adaptations and possible conversion of fiber type. This assumption was based on work by Martin and Romond (1975) which showed that a chronic centrifugal force of 2g applied for 5 hours a day for 2 days initiated fiber type conversion from slower isoforms to faster isoforms in rats.

A study conducted by a group of American researchers also supports the studies on the pronounced effects of simulated hypergravity training (Sands, Poole, Ford, Cervantez, Irvin, & Major, 1996). Subjects included women track and field who wore weighted vests for 3 weeks and were tested weekly in the vertical jump during this time. Results showed that the experimental group improved vertical jump by 5cm while the control condition improved vertical jump only 1.4 cm. Interestingly, during the subsequent track and field season athletes in the experimental condition achieved 13 personal bests while control athletes managed only 3. The researchers cautioned, however, that many factors could have affected the achievements of personal bests and they should not be readily attributed to the preceding 3 week hypergravity training period.

The aforementioned studies clearly show that the application of simulated hypergravitational conditions can have large training effects in a short time period. Normally, the types of improvements observed in these studies can't be achieved by traditional methods in the same time period by such experienced athletes. These studies have been discussed in detail due the similarities between this type of training and

vibration training in simulation of hypergravity conditions. This relationship will be further elaborated on below.

According to Bosco et al. (1999b), gravitational manipulations such as the ones induced by simulated hypergravitational conditions can also be induced by mechanical vibrations applied to the whole body by a specially made vibrating platform. In all the research papers authored by Bosco and cited above, Bosco and colleagues concluded that the perturbation of the gravitational field was one major reason for the large increases in the mechanical behavior of the lower limbs. For example, the following calculation made in their first whole body vibration study compares the total time that the body was exposed to large accelerations during vibration compared to the abrupt changes in acceleration in depth jumps (Bosco et al., 1998). In this study, they calculated that the total time of the vibration was less than 100 minutes, however, the perturbation of the gravitational field was 2.7g for that whole time period. According to the authors, an equivalent length and intensity of training stimulus can only be achieved by performing 200 depth jumps from 60cm twice a week for 12 months. Even then the acceleration developed during these extremely stressful drop jumps would not equal the 2.7g that the administration of vibration achieved. The line of reasoning here is that to equal the total time under peak tension of 100 minutes under vibration it would take the number of depth jumps mentioned above to equal that since the contact time during depth jumps is extremely brief. In addition, there is no way one could safely perform that many depth jumps in a two week period. Along these same lines, another study by the same principle researchers applied even higher gravitational values of 17g in a one day period (Bosco, Iacovelli, Tsarpela, Cardinale, Bonifazi, Tihanyi, Viru, De Lorenzo, & Viru, 2000).

Increases in counter movement jump performance and in maximal mechanical power output during a leg press were reported over that very short time frame. The vibration treatment in this study consisted of 10 sets of 1 minute for a total time under vibration of 10 minutes. The authors concluded from the data that an equivalent length of training stimulus could only be reached by performing 200 depth jumps from 100cm twice a week for 5 months and the acceleration would only reach 5g during these jumps. This calculation was based on the assumption that on average during each depth jump the contact time is only 150ms. Similar calculations have been made in every vibration training study conducted by this research group. In summary, the authors have postulated that whole body vibration can expose subjects to high accelerations for relatively long periods of time and elicit similar training effects to other methods in a much shorter time period and with less effort by the subjects. While the methods of calculating these time periods of vibration and equating vibration exposure time to depth jump contact time can certainly be called into question, it is hard to argue that accelerations of 17g for 10 minutes a day could be a potent training stimulus and possibly elicit rapid neuromuscular adaptations.

Stretch Reflex and Golgi Tendon Reflex Interplay

The myotatic or stretch reflex and the Golgi tendon reflex are involved in a complex interplay of feedback systems that heavily affect muscle activity. The stretch reflex is responsible for length feedback and acts to prevent overstretching. The golgi tendon reflex is responsible for force feedback. It acts to prevent excessively high and possibly damaging muscle tension. The muscle spindles run parallel to muscle fibers and

are the myotatic reflex receptors. Due to their parallel arrangement to muscle fibers, the muscle spindles are stretched when the muscle is stretched by a force. Thus, the muscle spindles are highly stimulated vibratory stimulation (Matthews, 1966.) This causes a reflex contraction and the muscle returns to its original length. The Golgi Tendon Organ (GTO), on the other hand, inhibits muscle action as a protective mechanism. However, the threshold of the GTO has been shown to be able to be moved back with certain training methods. Two related studies, (Schmidtbleicher & Gollhofer, 1982; Gollhofer & Schmidtbleicher, 1998) showed that after a month of plyometric training the EMG activity of the gastrocnemius was enhanced. The rationale for this increase was that during the initial stages of depth jump training the subjects were not accustomed to the large increases in muscle tension in a short time period and the inhibition due to the GTO was limiting muscle activity. All subjects showed this phenomenon even though they began from different dropping heights that were individualized optimally for each subject. However, after training with depth jumps for a period of time the GTO's threshold was pushed back slightly which allowed for the higher EMG readings. Since depth jumps involve abrupt changes in acceleration (Bosco, 1992) and therefore muscle tension they have the unique ability to push back the GTO threshold. Other resistance training exercises are generally not regarded to have this ability (Zatsiorsky, 1995). However, whole body vibration as conducted in previously mentioned studies, produces accelerations of a much greater magnitude than depth jumps and therefore could push back the (GTO) threshold in a similar way to plyometrics but in a much shorter time period (Bosco et al., 1998).

Hormonal Responses

There is very little information in the literature on the effects of mechanical vibration on the body's endogenous hormone production especially on athletes. Only one study was found that dealt with the effects of whole body vibration on testosterone, growth hormone, and cortisol production in athletes (Bosco et al., 2000). In this study, male team sport athletes were exposed to vertical sinusoidal whole body vibrations at a frequency of 26 hertz, amplitude 4mm, with an acceleration of 17g. The vibrations were administered for 10 sets of one minute with a one minute rest period between treatments. A six minute rest period was allowed after the first five sets. A variety of pre and posttests were performed on the day of data collection. Blood samples were taken one minute following the last set of vibrations. Subjects were tested in the performance of three countermovement jumps following a general warm up and again after the vibration treatments. Maximal dynamic leg presses on a slide machine with 70 percent of 1RM were also tested with the average power being measured. EMG's were also taken from the vastus lateralis and rectus femoris muscles during the leg press exercises. The results showed significant increases in blood concentrations of testosterone and growth hormone after the administration of vibration. In addition, cortisol levels decreased significantly following the vibration treatment. Countermovement jump and leg press average power output also showed significant increases in the post-tests. These findings are very important considering that the vibration treatment elicited hormonal responses very similar to those seen during weightlifting sessions.

A few other studies on the hormonal effects of vibration have shown that epinephrine and norepinephrine can be found in unusually high concentrations in persons

exposed to vibration (Saito, Inuzuka, & Azuma, 1986). While prolonged high concentrations of these hormones should probably be avoided since they could enhance the development of atherosclerosis and hypertension (Vander, 1998), elevation of epinephrine during weightlifting could be a positive. The well-known fight-or-flight response associated with increased sympathetic nervous system activity causes heart rate increases, blood pressure increases, increases in blood flow to skeletal muscles, increased blood flow to the heart, increased blood flow to the brain, and release of glucose from the liver. These types of responses could aid in weightlifting performance and have been investigated before under different circumstances. According to Vorobyev (1978), stimulation of the adrenal glands by cold compresses on the abdomen and cold showers can cause acute increases in strength. In his textbook, he cites several studies showing this effect which was attributed to a biological protective reaction presumably due to the release of epinephrine due to the short-term cold exposure. Therefore, it is plausible that if vibration can increase epinephrine levels in a training session that this may be partly responsible for increases in performance seen with vibration training.

In conclusion, limited evidence shows that vibration training can increase endogenous testosterone and growth hormone production while lowering cortisol levels. Most would consider this to be a very favorable condition for both short-term and long-term strength gains but this area along with the effects of vibration on the adrenal hormones needs further investigation.

Protective Mechanisms of the Body

Although not specifically referred to in the literature, the increase in muscle activity seen with vibration could be a protective mechanism of the body. According to Griffin (1994), the muscles are the most important dampener of vibration. Therefore, it could be inferred that the muscles are protecting the inner organs by damping the vibration to prevent resonance of those organs. This involuntary response could be responsible for recruiting normally untapped motor units that would only be recruited in survival situations. This theory, however, needs further study before any type of meaningful conclusions can be made.

Tonic Vibration Reflex

It has long been known that vibration applied to single muscle or to its tendon elicits the tonic vibration reflex. When the tonic vibration reflex is evoked an involuntary reflex contraction of the muscle occurs along with a relaxation of its antagonist (Hagbarth & Eklund, 1966). The tonic vibration reflex is induced by the activation of Ia fibers of the muscle spindle. This tonic vibration reflex mainly occurs at frequencies near 100Hz. Therefore, it is unknown whether the lower frequencies used in all the vibration training studies including whole body and local elicit this response. Also it is not known whether eliciting the tonic vibration reflex would even be useful since the training of athletes is usually done with multi-joint movements not selective to one muscle (Issurin et al., 1994). This implies that vibration of a single muscle may have little practical significance to training athletes or for use in vibration training and is therefore more relevant to clinical settings only.

Increased Blood Flow and Muscular Temperature

Limited evidence also suggests that short-term vibration exposure can cause localized vasodilation of blood vessels resulting in increased blood flow and increased muscular temperature (Rittweger et al., 2000; Oliveri, Kenneth, & Chang-Zern, 1989; Nakamura, H., Okazawa, T., Nagase, H., Yoshida, M., Ariizumi, M., & Okada, A. (1996). Theoretically, this would aid in recovery during exercise by removing waste products and delivering nutrients to the working muscles at a faster than normal rate. Indeed, there have been reports of athletes in Europe using vibration as a specific warm up before athletic events which lends empirical evidence to the above suggestions of increased muscular temperature and blood flow during vibration exposure. Due to the very limited work in this area, further research in needed to validate these claims.

Other Applications of Vibration

Perhaps the most exciting application of vibration is in the use of vibration for preventing and treating osteoporosis. This application has recently been successfully investigated in several animal models and thus shows much promise in humans. This is a potentially important avenue of research as health care costs related to osteoporosis treatments are over 10 billion dollars a year in the U.S. and are expected to be over 250 billion over the next 50 years (Melton, 1995). The use of vibration to prevent and treat osteoporosis has potential advantages over other treatments. One major advantage is that vibration increases bone mass and density in the load bearing sites in standing humans. In contrast, treatments such as drugs cocktails indiscriminately affect the whole body which is very inefficient (Rubin, Turner, Bain, Mallinckrodt, & McLeod, 2001). Drug

cocktails also can have serious side effects on other bodily systems. Even normal exercise such as weight training can have disadvantages compared to vibration methods. Many populations, especially the elderly often have a hard time adhering to strenuous exercise programs involving weight training. Vibration training, on the other hand, is much easier to adhere to since merely standing on a vibration platform requires less effort and has a lower level of discomfort when compared to other exercise routines. Furthermore, in animal models the vibration magnitude needed to induce positive bone adaptations is only 1/3 of the force of gravity as opposed to past beliefs that strain levels had to be equal or exceed levels experienced during exercises such as running, jumping, and weightlifting (Rubin et al., 2001).

In the studies conducted so far vibration has been shown to prevent bone mineral density losses in rats (Flieger, Karachalios, Khaldi, Raptou, & Lyritis, 1997), increase bone formation rates in rats Rubin et al. (2001), and increase bone density in sheep (Rubin, Turner, Muller, Mittra, Mcleod, Lin, & Qin, 2002). Based on these results, the researchers concluded that vibration applied by special platforms could be used in such diverse applications as for prevention of osteoporosis, treatment of osteoporosis, and in spaceflight by astronauts.

From the research discussed so far it should be readily apparent that vibration can have many different and beneficial effects on muscle strength, muscle power, bone density, hormonal responses, flexibility, and pain management. However, vibration training is in its infancy and much work needs to be done to understand its effects and be able to use it safely.

CHAPTER III

PROCEDURES

The purpose of this study was to investigate the effect of mechanical vibrations on acute power output in the bench press. Specifically, the efficacy of using local mechanical vibration to increase mean and peak power output through elicitation of an activity-dependent potentiation response was examined.

Population

Ten experienced male recreational weightlifters (age 25.3+/-4 years; height: 1.8 +/- .1m; mass: 85+/- 7.8kg) participated in the experiment. To be eligible for participation, all subjects must have had at least 3 years experience in the bench press exercise and have a 1RM bench press of between 250 and 300 pounds. Subjects signed an informed consent form (Appendix II) approved by the Human Subjects Review Committee at the University of Nevada, Las Vegas.

Instrumentation

Vertical power output data were measured and recorded during explosive bench presses using an autodigitizer (MotionAnalysis, VP320). Digitized X,Y coordinates of the path of the barbell were recorded using the automated digitizing system at a sample

frequency of 200Hz, sample period of 10 seconds, and from a sagittal plane of view. An LED was secured to the end of the barbell so the camera could accurately track the bar path. The camera distance was 17 feet from the barbell.

Apparatus

The vibration apparatus consisted of a 1.5 horsepower electric motor mounted on one sleeve of a standard weightlifting bar. The weight of the motor was 45 pounds so a 45 pound plate was placed on the other end of the barbell to act as a counterweight. Vibrations were produced by an off-centered (eccentric) cam spun by the shaft of the motor. This produced vibrations with a frequency of 30Hz, amplitude 1.1mm, and an acceleration of 4g. The vibration characteristics of the apparatus were confirmed by the Engineering Department at the University of Nevada, Las Vegas with equipment commonly used for measuring vibration parameters. The frequency and amplitude of the vibrations could not be adjusted due to the design of the vibration apparatus. In addition, the cam attached to the shaft of the electromotor was covered by an 18 gauge steel cover for added safety. The motor was plugged into a standard outlet and the tester was able to unplug the motor at any time. During the vibration set, the pins of the power rack were set a few inches below the vibrating barbell for safety considerations.

Experimental Protocol

All subjects were asked to report to the Sports Injury Research Center on three occasions. The purposes of the first session were to determine a one repetition maximum (1RM) in the bench press exercise and to familiarize the subjects with the vibration

device. The tester also demonstrated the method in which the vibration device was to be used in the study. The 1RM testing was done with a free weight Olympic barbell and performed with the bench placed in an adjustable power rack with safety pins. The 1RM testing procedures were similar to previously published methods (Doan, Newton, Marsit, Triplett-McBride, Koziris, Fry, & Kraemer, 2002). Briefly, after receiving the bar at arms length and holding it stationary, the subjects were instructed to lower the barbell under control and to perform the concentric phase as quickly and explosively as possible. The bar was required to lightly touch the chest in the bottom position and the feet were required to remain on the floor throughout the lift. In addition, the subject's gluteus muscles had to remain in contact with the bench throughout the lift. A general warm-up consisting of cycling on a Monarch cycle ergometer at .5 KP for 3 minutes was performed followed by static stretching of the chest, shoulders, and triceps muscles. Each static stretch was performed for 3 sets of 30 seconds per muscle group. Next, all subjects were required to warm up in the bench press exercise by performing the following progression with 1 minute rest intervals between sets:

Set 1- 10 repetitions at 50% of expected maximum

Set 2- 5 repetitions at 70% of expected maximum

Set 3- 3 repetitions at 80% of expected maximum

Set 4- 1 repetition at 90% of expected maximum

Finally, three subsequent attempts with 3 minute rest intervals were performed to achieve a 1RM with each subsequent attempt depending on efforts required to complete the previous lift.

The second session was conducted three days after session 1 and session 3 occurred three days after session 2. The purpose of these sessions was to investigate if the use of mechanical vibration could elicit activity-dependent potentiation and therefore, acutely increase mean and peak power output in the bench press exercise in the post-vibratory period. During these sessions data were collected and the order of testing was altered to control for the order effect. In session 2, half of the athletes performed the control condition and half performed the experimental condition. Likewise, in session 3 the athletes who performed the experimental condition in session 2 performed the control condition and the athletes who performed the control condition in session 2 performed the experimental condition in session 3. The warm-up protocol for sessions 2-3 was identical to the 1RM testing protocol except the warm-up bench press sets were conducted as follows:

Set 1- 10 repetitions at 50% of 1RM

Set 2- 8 repetitions at 60% of 1RM

Set 3- 3 repetitions at 70% of 1RM

After a 4 minute rest interval the test battery for the day started. The test battery for the control condition consisted of the following with 4 minute rest intervals between each set:

Set 1- Bench Press: 3 repetitions with 70% of 1RM

Set 2- Bench Press: 3 repetitions with 70% of 1RM

Set 3- Isometric bench press hold just short of lockout: hold for 30 seconds, the load was 135 pounds and consisted of the vibration bar apparatus without vibration.

Set 4- Bench Press 3 repetitions with 70% of 1 RM

The test battery for the experimental condition consisted of the following with 4 minute rest intervals between each set:

Set 1- Bench Press: 3 repetitions with 70% of 1RM

Set 2- Bench Press: 3 repetitions with 70% of 1RM

Set 3- Isometric vibration bench press hold just short of lockout: hold for 30 seconds, the load was 135 pounds and consisted of the vibration bar apparatus with the apparatus vibrating.

Set 4- Bench Press 3 repetitions with 70% of 1 RM

Thus, the only difference between the two conditions was the vibration of the barbell apparatus during the experimental condition. In both conditions, subjects were instructed to perform the concentric portions of every bench press set as quickly and explosively as possible.

Data Reduction

Power Output Data

Displacement data with respect to time during the bench press sets (sets 1,2, and 4 in both conditions) were recorded by the camera and used to determine velocity, acceleration, force, and ultimately power output. All data processing was done using the Matlab 6.1.0.450 program (MathWorks, Inc). The raw displacement data were smoothed using a Butterworth 4^{th} order zero lag filter smoothing routine. The optimal cutoff frequency for each data set was determined by analyzing residuals according to the methods of Winter (1990). Velocity and acceleration were derived from the

displacement data. Force measurements were then calculated by multiplying the load lifted in kg by the sum of the acceleration due to gravity (9.81m/s^2) and the acceleration of the bar at each data point. Power output during the concentric portions was then calculated by multiplying the force and velocity values on a point-by-point basis. From the power data, peak power and average power of each repetition were subsequently calculated. Average power for each set was calculated by adding the average power output of the concentric portion of each rep and dividing by the number of reps. Peak power was calculated by taking the single highest power output that occurred during the concentric portions of each set regardless of the number of the rep in which it occurred. The beginning of the concentric portion was defined as the first data point showing a positive power reading. The end of the concentric phase was defined as the last data point showing a positive power reading. These points corresponded with the first data point following maximum displacement in the downward phase of each bench press repetition and the maximal displacement recorded in the upward phase of each bench press repetition.

Statistical Analysis

The mean and standard deviations of the power outputs were calculated for the concentric portions of each set of the bench press (Table 1). The study was a 2[Condition (Vibration, Non-vibration)] x 3[Trial (1, 2, 3)] within-subjects design. An ANOVA with repeated measures on both factors was applied to the peak and average power values to determine if differences existed in the power output in the set occurring consequent to the

vibration set when compared to the sets performed in the control condition and previous to the vibration set. Significance will be accepted at an alpha level of .05.

CHAPTER IV

RESULTS

Data were analyzed using a 2[Condition (Vibration, Non-vibration)] x 3[Trial (1, 2, 3)] ANOVA with repeated measures on both factors. The dependent measures of interest were peak and average power output as measured in the bench press exercise (Table 1). Of particular interest was to determine if differences existed in the power output in the set occurring consequent to the vibration set when compared to the sets performed in the control condition and previous to the vibration set.

The analysis revealed a condition main effect for average power output, $F(1,9) = 11.07$, $p = .01$ (Figure 1). The condition main effect for peak power output was not significant, $F(1,9) = 4.58$, $p = .06$ (Figure 2). Follow up testing using dependent t-tests confirmed that the difference across conditions for average power output was due to the higher power values recorded in trial 3 subsequent to the vibration intervention, $p = .02$ (Figure 3). There was no difference between the average power output values in trials one and two across conditions, trial 1 $p = .07$, trial 2 $p = .19$. In addition, follow up t-tests revealed that their was a significant difference in peak power output between the trial following vibration (trial 3) in the experimental condition compared to the trial following the isometric hold in the non-vibration condition (trial 3), $p = .01$ (Figure 4).

Table 1. Summary data of peak and average power output for trials 1,2, and 3 in the vibration condition and non-vibration condition. *denotes Vibration>Control

Condition	Vibration			Non-vibration		
Variable	Mean	SE	STD	Mean	SE	STD
Peak Power						
T1	827.4	44.9	142	794.3	50	158.2
T2	852.5	67.9	214.7	811.9	51.3	162.3
T3	859.3	48.7	154	789.3	44.2	139.7
Average Power						
T1	518.1	22.1	69.9	493	23.9	75.6
T2	529.8	24.9	78.9	507.9	23.7	75.1
T3 *	527.2	25.3	80.1	495.2	21.9	69.2

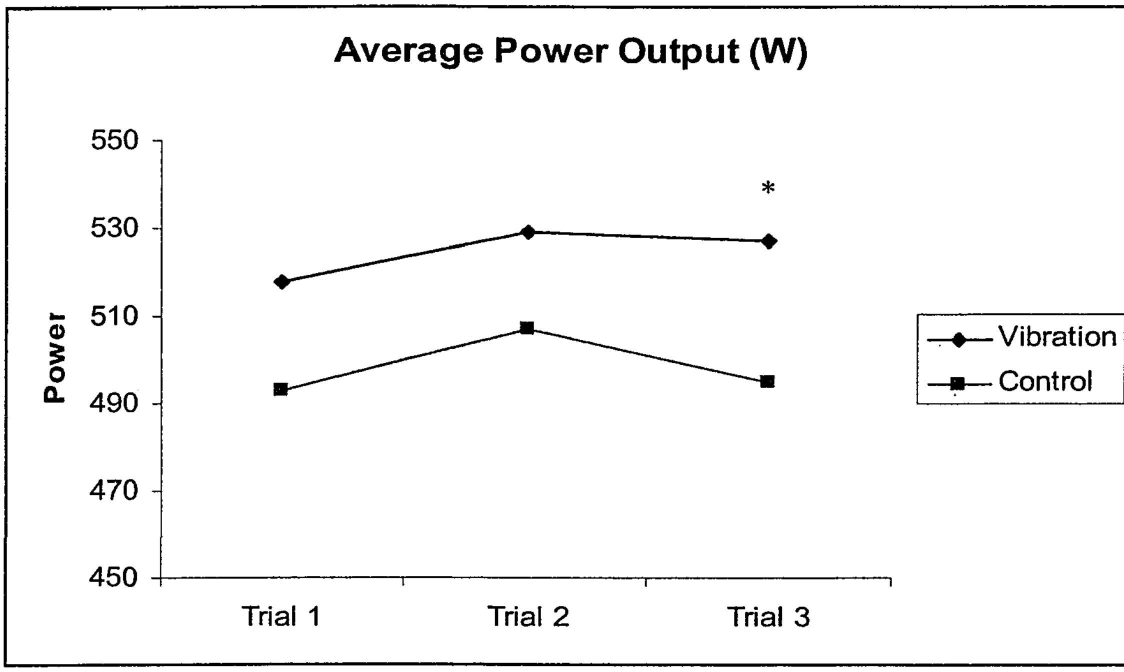


Figure 1. Average power output (W) means across subjects were each subject completed three trials in the vibration condition (condition 1) and the control condition (condition 2). * denotes Vibration>Control

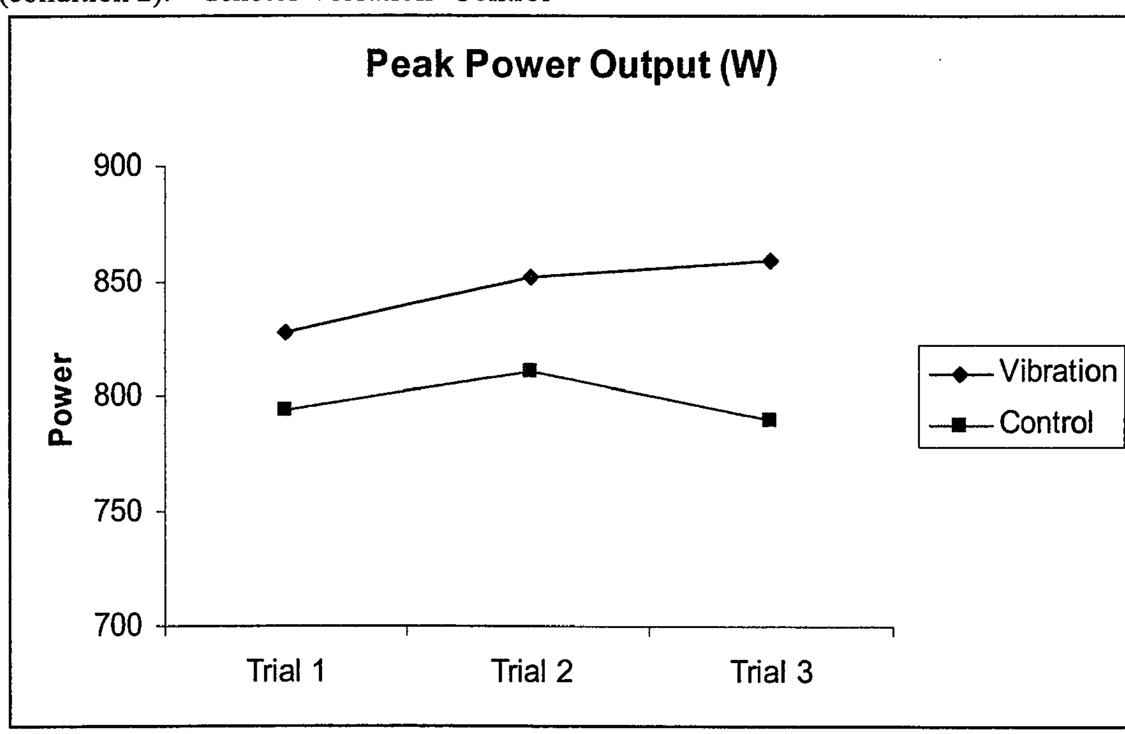


Figure 2. Peak power output (W) means across subjects were each subject completed three trials in the vibration condition (condition 1) and the control condition (condition 2).

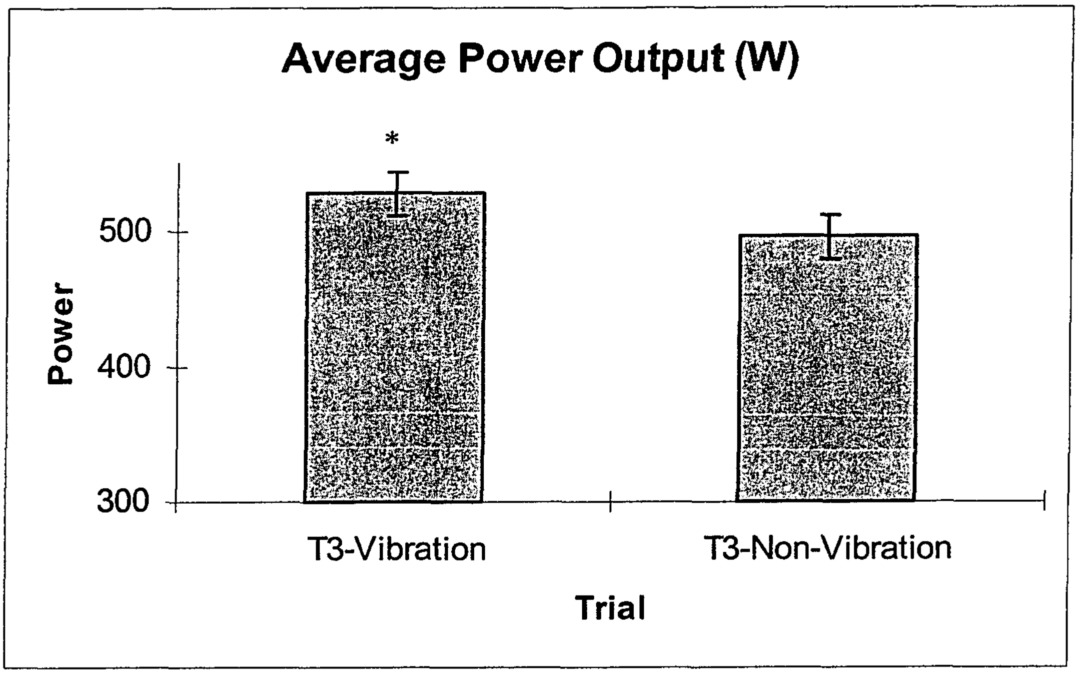


Figure 3. Average power output (W) means across subjects in the trials subsequent to the vibration set (condition 1) and the control condition (condition 2).

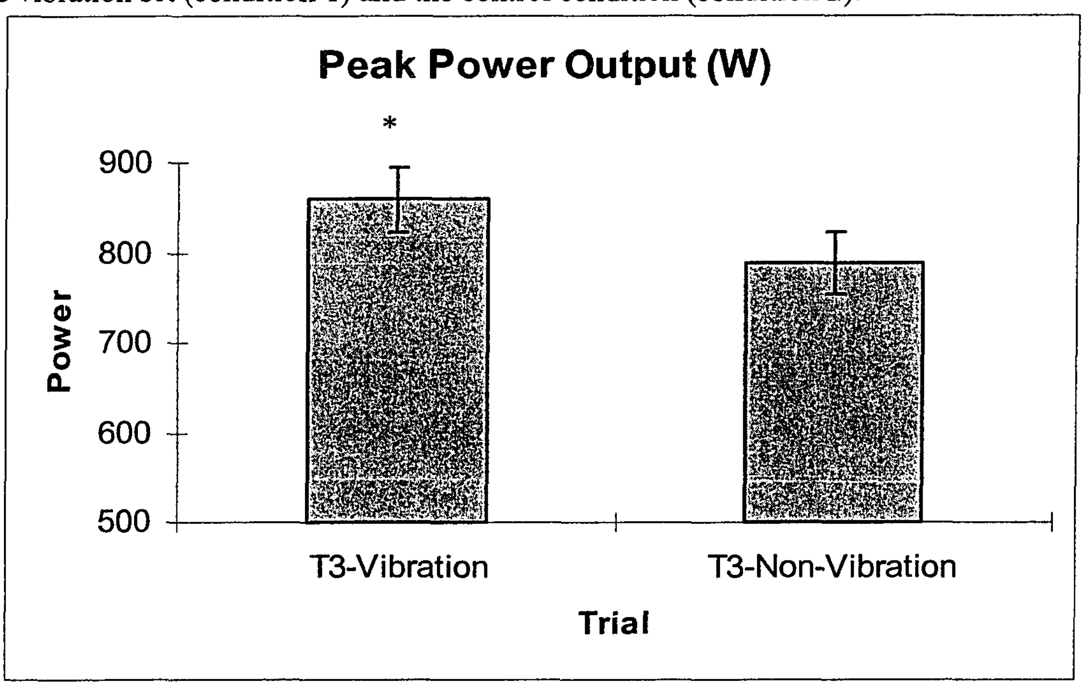


Figure 4. Peak power output (W) means across subjects in the trials subsequent to the vibration set (condition 1) and the control condition (condition 2).

CHAPTER V

DISCUSSION AND SUMMARY

Discussion of Results

The use of mechanical vibration as a specific strength training aid is a relatively new concept. While several studies using mechanical vibration have shown acute and short-term increases in strength and power performance (Bosco et al., 1998; Bosco et al., 1999a; Bosco et al., 1999b, Bosco et al., 2000; Issurin et al., 1994, Issurin & Tenenbaum, 1999; Mester et al., 1999), other studies have shown no effect from this type of training (Kunnemeyer & Schmidtbleicher, 1997b; Samuelson et al., 1989; Schlumberger et al., 2001). This study was conducted to investigate the effect of mechanical vibrations on acute power output in the bench press. Specifically, the efficacy of using local mechanical vibration to increase mean and peak power output through elicitation of an activity-dependent potentiation response was examined.

As expected no short-term increases in peak or average power performance were seen in the control condition following a submaximal isometric hold with no vibratory stimulation. This is not surprising as relatively long duration submaximal isometric contractions have not been shown to acutely increase power output. In contrast, the data obtained demonstrated that a short bout of vibration stimuli resulted in significant improvements in average power output but not peak power output in the bench press

exercise when compared to the control condition with no vibration stimulation. However, no differences were observed between set two preceding the vibration and set three following the vibration stimulation in the experimental condition. In the control condition decrements in power output were observed from set two preceding the isometric hold and set three following the isometric hold. Taken together, this suggests that the vibration intervention allowed the subjects to maintain their power performance in the third set while performance decreased in the control condition. Thus, it could be interpreted that vibration increased power endurance since no decrease in performance was observed in the trial following vibration. The increases observed in acute power output in the present study supports recent literature (Bosco et al., 1999a; Bosco et al., 1999b, Bosco et al., 2000).

Proposed Explanations of Results

There are many possible explanations of why the vibration intervention elicited short-term increases in power output. However, discerning which factor or factors may have contributed to the results and the relative contribution of each is a difficult task. Possible explanations for the short-term performance increases suggested in the literature has included: rerecruitment of fatigued motor units, recruitment of previous inactive high threshold motor units, exposure to hypergravity conditions, stretch reflex and GTO interplay, elicitation of the tonic vibration reflex, increased muscle temperature and blood flow, potentiation, and cognitive factors. These proposed explanations can be further divided into four major categories: motor unit activation, muscle temperature and blood flow, potentiation, and cognitive factors.

There is evidence that vibration stimulation can possibly allow for rerecruitment of fatigued motor units (Bongiovanni & Hagbarth, 1990). This proposed explanation has support from the results demonstrated in the present study since power performance was maintained following vibration while decrements were observed in the non-vibration condition. Thus, it may be that vibration stimulation is more effective in maintaining power performance during a set or group of sets as opposed to increasing power output beyond normal achievable levels in traditional exercise conditions. This proposed explanation has support from the results of Bosco (1998) in which two weeks of vibration significantly improved performance in a five second continuous jumping test but failed to improve countermovement jump performance. However, other studies have shown acute power output increases of magnitudes higher than under traditional conditions due to vibration stimulation (Bosco et al., 1998; Bosco et al., 1999a; Bosco et al., 1999b; Issurin & Tenenbaum, 1999). This is typically attributed to increased motor unit activation under vibration stimulation resulting in the recruitment of high-threshold motor units that are not normally recruited voluntarily (Bishop, 1974; Issurin et al., 1994). The mechanisms of this increased motor unit activation are not well-understood but could be due to several factors including: elicitation of the tonic vibration reflex, stretch reflex and GTO interplay, a protective mechanism of the body, and exposure to hypergravity and thus high forces while under vibration.

It has long been known that vibration applied to a single muscle or a tendon elicits the tonic vibration reflex. When the tonic vibration reflex is evoked an involuntary reflex contraction of the muscle occurs along with a relaxation of the antagonist muscle (Hagbarth & Eklund, 1966). Thus, this reflex contraction has been shown to increase

muscle force presumably through greater motor unit activation (Hagbarth & Eklund, 1966; Johnson et al., 1970). Although it has been suggested that the tonic vibration reflex can be elicited by low vibration frequencies (20-44Hz) this has never been proven (Bosco et al., 1999a). Since all vibration training studies including the present study have used relatively low frequencies it is doubtful that the tonic vibration reflex influenced the findings of these studies. In addition, studies evoking the tonic vibration reflex in rehabilitative and medical settings have used frequencies of 50-150Hz with values close to 100Hz being the most common (Bishop, 1974). Therefore, it would appear that the tonic vibration reflex was not evoked in the present study and the acute increases in power output cannot be attributed to this phenomenon.

Stretch reflex and GTO interplay is another common explanation for the increases in performance seen with vibration training (Bosco et al., 1998). Training methods that impose high stretch loads such as depth jumps are thought to push back the GTO's firing threshold and allow for higher EMG readings and muscle activity (Schmidtbleicher & Gollhofer, 1982; Gollhofer & Schmidtbleicher, 1998). Vibration training can also subject the muscles to a very high number of intense stretch loads in a short time period which may push back the GTO threshold in a shorter time period than performing depth jumps (Bosco et al., 1998). Thus, the increases in positive (excitatory) feedback from muscle spindles and the decrease in negative (inhibitory) feedback from the GTO could allow for greater motor unit recruitment and force output following a vibration training protocol.

Evidence also exists that acute and short-term vibration stimulation can increase blood flow to muscle and muscle temperature (Rittweger et al., 2000; Oliveri et al., 1989; Nakamura et al., 1996). Theoretically, this could aid in recovery during exercise by

removing waste products and delivering nutrients to the working muscles at a faster than normal rate. Due to the very limited work in this area, further research in needed to support this conclusion.

Cognitive factors attributed to vibration stimulation have also been shown to have effects on muscular performance (Liebermann & Issurin, 1997). It was found that effort perception was lower while force output was higher under superimposed vibration stimulation during isotonic contractions. Since questionnaires on effort perception were not given in the present study it is impossible to say if cognitive factors influenced the results.

Finally, the elicitation of an activity-dependent potentiation effect cannot be ruled out in influencing the results of the present study. The vibration treatment in this study could have evoked a potentiation response that predominated over fatigue. Indeed, the lack of decrements in power production from set 2 to set 3 in the vibration condition compared to the decrements in power production from set 2 to set 3 in the non-vibration condition lends support to this proposed explanation. The mechanisms by which vibration may induce such a response are unknown but could be similar to the way potentiation is evoked following submaximal and maximal voluntary contraction using weightlifting exercises.

Summary

In summary, many factors could potentially be responsible for the 9% increases in peak power and 6.5% increases in average power output following vibration stimulation when compared to the control condition. The underlying physiological mechanisms

behind these performance increases, however, could not be discerned in the present study because EMG's were not taken, muscle biopsies were not performed, and questionnaires were not administered. Further research should be conducted to uncover the mechanisms behind the acute effects of vibration training. In addition, long term studies on vibration training are needed as only one vibration training study to date has lasted longer than three weeks (Schlumberger et al. 2001).

Practical Recommendations

Vibration training has been shown to be a relatively safe and effective training method for athletes and other populations. The results of the present study indicate that coaches and athletes could use vibration training in addition to their current training regiments for several purposes. These could include: teaching athletes exposed to vibration in their sport to dampen vibration, elicitation of a potentiation response for use in power sports of short duration, use as part of a short peaking program (2-6 weeks) for an important competition, and as part of the warm-up to increase blood flow and muscular temperature. The use of vibration for these purposes should depend on the goals and specific needs of the athlete and type of vibration device available.

APPENDIX I

SUBJECT INFORMED CONSENT FORM

University of Nevada, Las Vegas

Department of Kinesiology

INFORMED CONSENT

General Information:
I am Brach Poston , a graduate student from the UNLV Department of Kinesiology. My advisor is Dr. William Holcomb from the UNLV Department of Kinesiology. I am the principle researcher on this project. You are invited to participate in a research study that will investigate the effect of mechanical vibrations on short-term bench press performance.

Procedure:
You are being chosen to participate in this study because you have at least 3 years experience in resistance training. If you volunteer to participate in this study, you will be asked to do the following: Report to the SIRC (Sports Injury Research Center) on 3 occasions each separated by four days. Each session will take approximately one hour and consist of several sets of sub-maximal bench presses. In the first session, a one repetition maximum in the bench press exercise will be performed. The 1RM testing will be done with a free weight Olympic barbell and performed with the bench placed in an adjustable power rack with safety pins. After a general warm-up consisting of stationary bike riding and static stretching for the upper extremities, you will progressively use heavier weights until they reach your 1RM. The 1RM testing procedures will be similar to previously published methods (Baker, 2001). During this session, you will also be familiarized with the vibration device. The investigator will demonstrate the method in which the vibration device will be used in the study.

Session 2 will be four days after session 1 and session 3 will occur 4 days after session 2. The test battery for the control condition will consist of the following with 4 minute rest intervals between each set:

Set 1-Bench Press: 3 repetitions with 70% of 1RM
Set 2-Bench Press: 3 repetitions with 70% of 1RM
Set 3-Isometric bench press hold just short of lockout: hold for 30 seconds, load will consist of the vibration bar apparatus WITHOUT vibration.
Set 4- Bench Press 3 repetitions with 70% of 1 RM

The test battery for the experimental condition will consist of the following with 4 minute rest intervals between each set:

Set 1-Bench Press: 3 repetitions with 70% of 1RM
Set 2-Bench Press: 3 repetitions with 70% of 1RM
Set 3-Isometric vibration bench press hold just short of lockout: hold for 30 seconds, load will consist of the vibration bar apparatus WITH the apparatus vibrating.
Set 4- Bench Press 3 repetitions with 70% of 1 RM

In the test battery mentioned above, you will be asked to hold a vibrating barbell for 30 seconds for one set. Questions about specific exercises or program organization will be answered at any time. Any personal information obtained during participation in this study will remain confidential.

Benefits of Participation:

By participating you will be exposed to a new innovative method of training. You will also receive an increased understanding of your power output capabilities in the bench press exercise.

Risks of Participation in:

There are no significant risks involved in your participation. This statement is based on numerous studies in many different populations and settings using the same severity of vibration for much longer periods of time. You may experience mild discomfort when holding the vibrating bar. In addition, there is a small risk of delayed onset muscle soreness. Any risk of muscle or connective tissue injury will be minimized by supervision and instruction of proper exercise by the primary investigator who is a qualified strength and conditioning specialist. The risk of injury will be further reduced with a prescribed warm-up.

The Effect of Mechanical Vibration on Acute Power Output in the Bench Press

INFORMED CONSENT (continued)

Contact Information:

If you have any questions about the study or if you experience harmful effects as a result of participation in this study, you may contact me at 895-2780 **or at 895-1015**.

For questions regarding the rights of research subjects, you may contact **the UNLV Office for the Protection of Research Subjects at 895-2794.**

Voluntary Participation:

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your relations with the university. You are encouraged to ask questions about this study at the beginning or any time during the research study.

Confidentiality:

All information gathered in this study will be kept completely confidential. No reference will be made in written or oral materials that could link you to this study. All records will be stored in a locked facility at UNLV for at least 3 years after completion of the study.

Participant Consent:

I have read the above information and agree to participate in this study. I am at least 18 years of age. A copy of this form has been given to me.

______________________________ ______________

Signature of Participant Date

____

Participant Name (Please Print)

APPENDIX II

SUBJECT INFORMATION

Subject	Age	Height (m)	Weight (kg)
1	23	1.8	81.6
2	32	1.8	99.8
3	22	1.7	72.6
4	32	1.8	92.5
5	25	1.8	86.2
6	24	1.9	86.2
7	26	1.8	77.1
8	25	1.8	86.2
9	18	1.8	77.1
10	26	1.8	90.7
Mean	25.3	1.8	85.0
STDEVd	4.0	0.1	7.8

Table 2. Subject demographic information.

APPENDIX V

ANOVA TABLES

The SAS System

AVERAGE POWER OUTPUT
Number of observations 10

The ANOVA Procedure
Repeated Measures Analysis of Variance

Repeated Measures Level Information

Dependent Variable	T1	T2	T3	T4	T5	T6
Level of cond	1	1	1	2	2	2
Level of trial	1	2	3	1	2	3

The ANOVA Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Anova SS	Mean Square	F Value	Pr > F
cond	1	9987.180167	9987.180167	11.07	0.0088
Error(cond)	9	8121.781500	902.420167		

						Adj Pr > F	
Source	DF	Anova SS	Mean Square	F Value	Pr > F	G-G	H - F
trial	2	1556.95600	778.47800	0.81	0.4611	0.4396	.4561
Error(trial)	18	17331.09733	962.83874				

						Adj Pr > F	
Source	DF	Anova SS	Mean Square	F Value	Pr > F	G - G	H - F
cond*trial	2	318.74533	159.37267	0.22	0.8039	0.8004	0.8039
Error(cond*trial)	18	12985.428	721.41267				

The SAS System

PEAK POWER OUPUT

The ANOVA Procedure
Repeated Measures Analysis of Variance

Repeated Measures Level Information

Dependent Variable	T1	T2	T3	T4	T5	T6
Level of cond	1	1	1	2	2	2
Level of trial	1	2	3	1	2	3

The ANOVA Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subject Effects

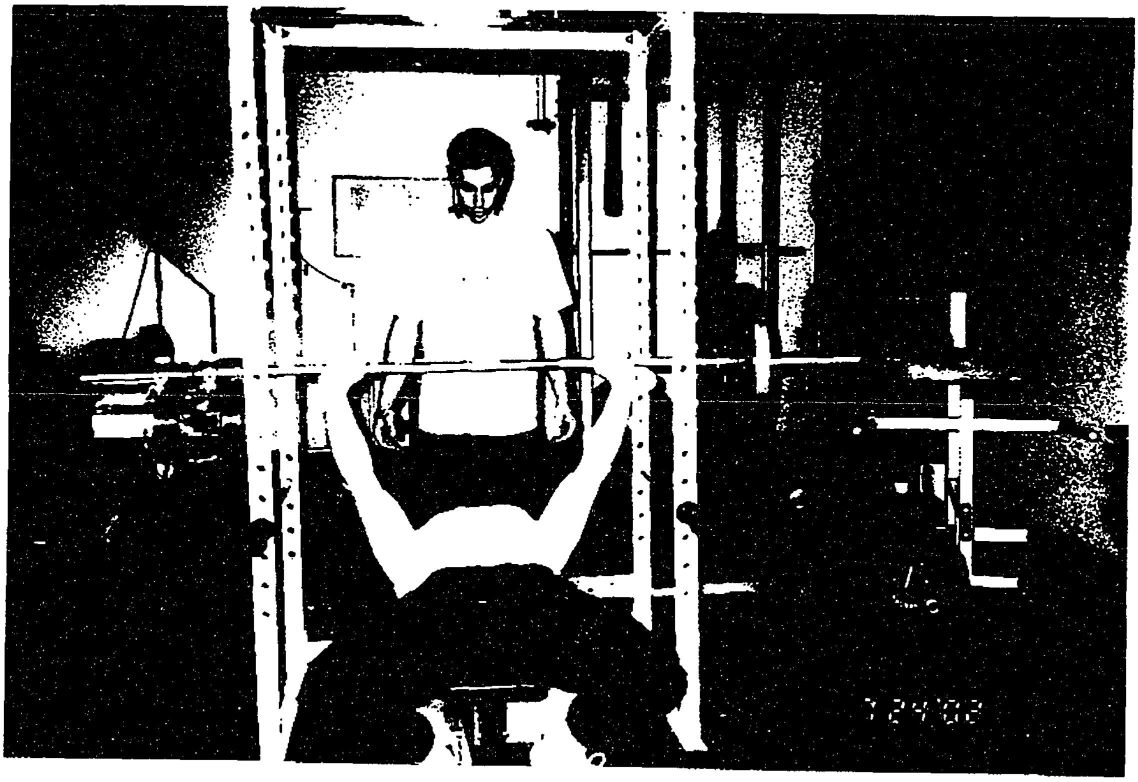
Source	DF	Anova SS	Mean Square	F Value	Pr > F
cond	1	34358.69400	34358.69400	4.58	0.0609
Error(cond)	9	67444.19267	7493.79919		

						Adj Pr > F	
Source	DF	Anova SS	Mean Square	F Value	Pr > F	G-G	H - F
trial	2	4696.7130	2348.3565	0.28	0.7571	0.7069	.7416
Error(trial)	18	149590.107	8310.5615				

						Adj Pr > F	
Source	DF	Anova SS	Mean Square	F Value	Pr > F	G-G	H - F
cond*trial	2	3803.66100	1901.83050	0.46	0.6396	0.627	.6396
Error(cond*trial)	18	74723.352	4151.29735				

APPENDIX VI

PICTURE OF VIBRATION TASK



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VITA

Graduate College
University of Nevada, Las Vegas

Brach John Poston

Local Address:
5250 S. Rainbow Blvd. Apt. 2127
Las Vegas, NV 89109
Phone: (702)-735-8573

Degrees:
Bachelor of Science, Physical Education, 2000
Southwest Missouri State University

Thesis Title: The Effect of Mechanical Vibration on Acute Power Output in the Bench Press

Thesis Examination Committee:
Chairperson, William R. Holcomb, Ph.D.
Committee Member, Mark A. Guadagnoli, Ph.D
Committee Member, Mack Rubley, Ph.D
Graduate Faculty Representative, Carl Reiber, Ph.D.