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The Effects of Whole Body Vibration Platform Training on Hamstring Flexibility

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THE EFFECT OF WHOLE BODY VIBRATION PLATFORM

TRAINING ON HAMSTRING FLEXIBILITY

by

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GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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As chair of the candidate's graduate committee, I have read the thesis of Travis Arthur Epperson in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

THE EFFECT OF WHOLE BODY VIBRATION PLATFORM TRAINING ON HAMSTRING FLEXIBILITY

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Master of Science

Very few studies have looked at the effect of vibration on flexibility, and no studies exist that have looked at stretching concurrently with whole body vibration (WBV) training. Therefore, the purpose of this study was to determine if whole-body-vibration training (WBV) done concurrently with static stretch (SV) is more effective than static stretching alone (SS), and to see if WBV training independently (SQ) improves hamstring flexibility without stretching. A secondary purpose of this study was to determine if retention of flexibility gains are maintained.

Forty-four subjects (31 males, 13 females) completed this study (age 22.5 ± 1.8 years; body mass 75.54 ± 13.18 kg; height 176.7 ± 8.06 kg). All subjects were randomly assigned to 1 of 5 groups: SV group (8 males, 3 females), SQ group (8 males, 4 females), SS group (8 males, 3 females), and the C group (7 males, 3 females). All subjects were measured bilaterally for hamstring flexibility using the lying passive knee extension test (LPKE) prior to group assignment. Subjects from each treatment group reported to lab 5

times per week for treatment. Subjects stood on the WBV platform for 5 repetitions of 30-seconds at with 30-seconds in between bouts. The SV group stretched hamstrings while standing on the WBV during the vibration bouts (at 26 Hz and 4 mm amplitude). The SS group did the same thing except the unit was not turned on. The SQ group stood on the WBV platform in a semi-squat position similar to most WBV training studies, without stretching, but with vibration. The C group stood on the WBV platform in a semi-squat without vibration.

A mixed models analysis of covariance (ANCOVA) was used while blocking on subjects to analyze data using the statistical program SAS (version 9.1). A Bonferroni correction was used for significance on all post hoc tests (p<.0001). At baseline there were no significant differences between groups for flexibility, showing that each group was similar in flexibility to start. Throughout the treatment period (3 weeks of stretching) both the SS and SV groups had significant increases in flexibility compared to SQ and C. Analysis of the slopes (rate of change) for the treatment period was significantly different between the SV group and all other groups (p<.0001 for all comparisons), showing that the SV group had a greater rate of change than all other groups. For the retention period there was no significant difference between the SV and SS group (p=0.0455), but there was a significant difference between both the SV and SS groups and all other groups (p<.0001 for all comparisons).

Stretching during WBV improves flexibility more than static stretching alone and at a faster rate. WBV on its own without stretching does not significantly improve hamstring flexibility.

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ABSTRACT

Introduction: Very few studies have looked at the effect of vibration on flexibility, and no studies exist that have looked at stretching concurrently with whole body vibration (WBV) training. Therefore, the purpose of this study was to determine if whole-body-vibration training (WBV) done concurrently with static stretch (SV) is more effective than static stretching alone (SS), and to see if WBV training independently (SQ) improves hamstring flexibility without stretching. A secondary purpose of this study was to determine if retention of flexibility gains are maintained.

Methods: Forty-four subjects (31 males, 13 females) completed this study (age 22.5 ± 1.8 years; body mass 75.54 ± 13.18 kg; height 176.7 ± 8.06 kg). All subjects were randomly assigned to 1 of 5 groups: SV group (8 males, 3 females), SQ group (8 males, 4 females), SS group (8 males, 3 females), and the C group (7 males, 3 females).   All subjects were measured bilaterally for hamstring flexibility using the lying passive knee extension test (LPKE) prior to group assignment. Subjects from each treatment group reported to lab 5 times per week for treatment. Subjects stood on the WBV platform for 5 repetitions of 30-seconds at with 30-seconds in between bouts. The SV group stretched hamstrings while standing on the WBV during the vibration bouts (at 26 Hz and 4 mm amplitude). The SS group did the same thing except the unit was not turned on. The SQ group stood on the WBV platform in a semi-squat position similar to most WBV training studies, without stretching, but with vibration. The C group stood on the WBV platform in a semi-squat without vibration.

Analysis and Results: A mixed models analysis of covariance (ANCOVA) was used while blocking on subjects to analyze data using the statistical program SAS (version 9.1). A Bonferroni correction was used for significance on all post hoc tests ($p < .0001$). At baseline there were no significant differences between groups for flexibility, showing that each group was similar in flexibility to start. Throughout the treatment period (3 weeks of stretching) both the SS and SV groups had significant increases in flexibility compared to SQ and C. Analysis of the slopes (rate of change) for the treatment period was significantly different between the SV group and all other groups ($p < .0001$ for all comparisons), showing that the SV group had a greater rate of change than all other groups. For the retention period there was no significant difference between the SV and SS group ($p = 0.0455$), but there was a significant difference between both the SV and SS groups and all other groups ($p < .0001$ for all comparisons).

Conclusion: Stretching during WBV improves flexibility more than static stretching alone and at a faster rate. WBV on its own without stretching does not significantly improve hamstring flexibility.

INTRODUCTION

Whole body vibration (WBV) platforms have been used to investigate, among other things: vibration's effect on bone mass (Torvinen et al. 2003b), muscle physiology (Cardinale and Lim 2003a; Roelants et al. 2006a; Seidel 1988), oxygen kinetics (Cardinale et al. 2007; Rittweger et al. 2000a; Rittweger et al. 2002a; Rittweger et al. 2001a), body composition (Roelants et al. 2004a), skin blood flow (Lohman et al. 2007), muscle blood volume (Kerschan-Schindl et al. 2001a), hormones (Cardinale et al. 2006b; Erskine et al. 2007b; Kvorning et al. 2006), balance (Torvinen et al. 2002a; Torvinen et al. 2002b; Torvinen et al. 2002e)**,** and muscular performance(Annino et al. 2007b; Bogaerts et al. 2007a; Bosco et al. 1998a; Cochrane et al. 2004a; Cormie et al. 2006b; de Ruiter et al. 2003c; Delecluse et al. 2005a; Kawanabe et al. 2007; Kvorning et al. 2006; Rees et al. 2007; Rehn et al. 2007a; Rittweger et al. 2003b; Roelants et al. 2004a; Roelants et al. 2004d; Rønnestad 2004; Russo et al. 2003a; Torvinen et al. 2003b; Torvinen et al. 2002e). Due to these studies, whole body vibration training has been touted as being a positive adjunct to training programs.

Despite the large amount of WBV training research, only a handful of studies have looked at the relationship between vibration or WBV and flexibility/stretching (Atha and Wheatley 1976a; Cochrane and Stannard 2005a; Cronin et al. 2007; Fagnani et al. 2006b; Issurin et al. 1994a; Jacobs and Burns 2009; Kinser et al. 2008; Sands et al. 2006a; van den Tillaar 2006b). Four of these studies used locally applied vibration (Atha and Wheatley 1976a; Cronin et al. 2007; Kinser et al. 2008; Sands et al. 2006a) by way of a vibration pad or specially designed vibration modules to show improved hip flexor mobility and flexibility, but used a sit-and-reach test (Atha and Wheatley 1976a), dynamic range of motion (ROM) test (Cronin et al. 2007), or a version of the splits (Kinser et al. 2008; Sands et al. 2006a) to measure flexibility. One study induced vibration through a cable pulley system (Issurin et al. 1994a) to show increased flexibility through a side split and flex-and-reach test while three other studies used a WBV platform in a squat position without any stretching protocol (Cochrane and Stannard 2005a; Fagnani et al. 2006b; Jacobs and Burns 2009), and simply measured sit-and-reach flexibility as a secondary variable of interest. One study, however, did have subjects perform bouts of stretching in between bouts of WBV platform training and showed significant increase in hamstring ROM using a straight-leg-raise test (van den Tillaar 2006b).

Only 3 studies have looked at concurrent stretching and vibration (Issurin et al. 1994a; Kinser et al. 2008; Sands et al. 2006a), although none of these studies used a WBV platform. Two of the studies (Kinser et al. 2008; Sands et al. 2006a) used a specialized vibration module placed under the leg being stretched when training for forward split flexibility in young gymnasts, while the other (Issurin et al. 1994a) used a combination of locally applied vibration through a vibrating cable in conjunction with static stretching, static stretching with body flexion, and ballistic stretching to show increased flexibility (as measured by a flex-and-reach test). There are no studies to date which have examined the effect of stretching concurrently with vibration on a WBV platform, even though this is a common suggestion from the different manufacturers.

Due to the popularity of WBV platforms and their use in training, the purpose of this study was to determine if WBV done concurrently with static stretching (SS) is more effective than SS alone, or WBV in a squat position alone in improving hamstring flexibility. A secondary purpose of this study was to determine how the flexibility gains are maintained after stopping all stretching intervention.

METHODS

Subjects

Forty-four subjects (31 males, 13 females) completed this study (age 22.5 ± 1.8 years; body mass 75.54 ± 13.18 kg; height 176.7 ± 8.06 kg). All subjects were students at Brigham Young University. Subjects were randomly assigned to groups by drawing out of a hat. There were 11 subjects in the static stretch with WBV group (SV) (8 males, 3 females), 12 subjects in the WBV without stretching group (SQ) (8 males, 4 females), 11 subjects in the static stretch without WBV group (SS) (8 males, 3 females), and 10 subjects in the control group (C) (7 males, 3 females). In order to qualify for the study subjects had to exhibit tight hamstrings. For this study, 'tight hamstrings' was defined as the inability to reach the toes in a straight leg standing stretch and range of motion of 70 degrees or less of hip flexion when screened using a single leg straight-leg-raise test. This project was approved by the Brigham Young University Institutional Review Board for Human Subjects. Each subject was informed of the possible risks and hazards of participating in this study prior to giving their written consent to participate.

Procedures

Testing Procedures

All subjects in all groups were initially measured for knee extension range of motion (ROM) (hamstring flexibility) using the lying passive knee extension test (LPKE). All flexibility measurements were made by a second researcher who was blinded to group assignment. The LPKE was performed by having the subjects lie supine on an examination table. The body was adjusted in position on the table so that the leg being measured was placed in 90 degrees of hip flexion so the thigh would lightly contact a cross bar that was built into the table. A mark was made on the lateral thigh with a permanent marker, corresponding to the position on the table. The combination of table position and cross-bar contact helped to ensure consistent positioning on the table for each follow-up measurement. The mark was redarkened on each treatment visit in order to maintain the mark throughout the study. The opposite leg was held firmly to the table by an assistant. Once the hip was positioned at 90 degrees, the subject was instructed to "relax" as much as possible. The inclinometer was placed on the tibia at the base of the tibial tuberosity for measurement. The examiner passively moved the tibia into terminal knee extension, which was operationally defined as the point at which the subject rated the stretch to be of "slight discomfort" in the hamstrings. At this point the knee extension value was recorded. Flexibility was measured for both legs prior to the start of any treatment assignment (baseline), after each week of stretching, and once per week for 3 weeks following treatment to monitor flexibility retention. Reliability for this method was determined using an intraclass correlation coefficient (ICC 3,1) prior to the study. An ICC of .96 was deemed to be appropriate for completing this study.

Static stretch with vibration treatment (SV). Subjects assigned to this group performed bilateral hamstring stretching by standing on the WBV platform (Galileo 2000, Orthometrix, White Plains, NY) and flexing at the hip to the point of slight stretch discomfort in the hamstrings while keeping the back as straight as possible. Subjects were also required to slightly flex their knees to minimize vibration transmission to the upper body and head. Subjects were asked to grasp a balance bar with both hands to help maintain position and to minimize the stabilizing contraction in the low back and hamstrings. Once the subjects reached the position of slight stretch discomfort the WBV platform was turned on for a 30-second cycle. Subjects repeated this 5 times with approximately 30-seconds in between bouts for a total stretching duration of 2 minutes and 30 seconds per session. Each 30-second vibration session was performed at 26Hz and 4mm amplitude.

Static stretch without vibration treatment (SS). Subjects assigned to this group performed a similar bilateral static hamstring stretch for 5 x 30 seconds as the SV group, except the platform was not turned on (See Figure 2).

WBV without stretching treatment (SQ). Subjects assigned to this group did not assume a stretch position. Subjects stood in a semi-squat position (between 30 to 40 degrees of knee flexion) for the same number of reps and sets of vibration as the SV group. Subjects were allowed to use the handrail for balance during the bouts (See Figure 3).

Control group (C). Subjects assigned to this group reported to the lab and stood on the vibrating platform in a semi-squat position without vibration or stretching for the same number of reps and sets as the SQ group. Subjects were allowed to use the handrail for balance during the bouts

Statistical Analyses

A mixed models analysis of covariance (ANCOVA) was used while blocking on subjects. Data were analyzed using the statistical program SAS (version 9.1). Neither gender ($p = 0.2289$) nor age ($p = 0.1886$) were significant, but height ($p = 0.0007$) and weight ($p = 0.0099$) were significant. Therefore, height and weight were both controlled for before testing the independent variables of interest (Time (7 periods), and treatment group (4)). The dependent variable of interest was hamstring flexibility (measured in degrees). Post hoc tests were used to determine the difference between groups within time periods and differences between slopes. A Bonferroni correction was used for significance.

RESULTS

At baseline there were no significant differences between groups for flexibility (see Table 1). After two weeks of treatment there was a significant difference between SV and C ($p = 0.0004$) and between SV and SQ ($p = 0.0011$). After 3 weeks of treatment, a significant difference continued between SV and both C and SQ ($p < .0001$ for both), and a significant difference also existed between SS and C ($p = 0.0014$) and between SS and SQ ($p = 0.0042$). After 1 week of no treatment there was a significant difference between SV and C ($p < .0001$) and between SV and SQ ($p < .0001$). After 2 weeks post treatment there was a difference between SV and C ($p=0.0049$) and between SV and SQ ($p = 0.001$). After 3 weeks posttreatment, no differences existed.

Slope or rate of change analysis for the treatment period was significantly different between the SV group and all other groups ($p < .0001$ for all comparisons), showing that the SV group had a greater rate of change than all other groups. For the retention period there was no significant difference between the SV and SS group ($p=0.0455$), but there was a significant difference between both the SV and SS groups and all other groups ($p<.0001$ for all comparisons), indicating that the rate of change (or loss of flexibility) was similar for both the SS and SV groups.

DISCUSSION

This research is the first to focus mainly on the effects of static stretching during WBV versus stretching without vibration. Our results show that the control group did not change over the course of the study and there was no significant difference in starting hamstring flexibility between groups (see Table 1), thus all groups had a similar potential for flexibility gains at the start. After 3 weeks of treatment, only the two stretching groups (SS and SV) showed significant differences from the C group, indicating an increase in hamstring flexibility over time. This was an expected result since numerous stretching studies have previously reported increases in flexibility with a variety of stretching protocols (Decoster et al. 2005).

We expected the SQ group to increase in flexibility as well since prior research (Cochrane and Stannard 2005a; Fagnani et al. 2006b; Jacobs and Burns 2009) reported increases in flexibility secondary to WBV training without stretching protocols. However, the SQ group does appear to show a slight trend of increasing flexibility (2.2 degree average increase after 3 weeks); this was not statistically significant, nor is it, in our opinion clinically significant. The relatively small changes that occurred appears to have dissipated completely by 2 weeks posttreatment (see Figure 1). These results may be contrary to prior research since we used a hamstring specific measure of flexibility rather than the sit-and-reach test used in these prior studies, which also incorporates hip and back flexibility. Based on our results it appears that vibration on a WBV platform in a semi-squat position is not a large enough stimulus to be considered a replacement for stretching of the hamstrings.

We found that static stretching of the hamstrings during WBV increased hamstring flexibility faster than the SS and SQ groups, when evaluating the rate of change (slope) of flexibility increase from baseline to week 3. This corroborates findings from these other previously mentioned studies, which also found increases in flexibility, especially in those studies which applied vibration to muscle groups being stretched. However, the rate of change during the retention period (from Post 1 to Post 3) was not significantly different between the SV and SS groups. After 3 weeks posttreatment the SV group had not returned to baseline, while the SS group had almost returned to baseline by 2 weeks posttreatment. However, this appears to be merely a function of total change rather than some retentive effect of vibration. We are not able to compare these findings to any other study since none of the previous vibration and stretching studies have ever measured retention.

The question arises, why did vibration with stretching result in greater increases in flexibility? Prior research has suggested 3 primary possibilities: Increase in temperature and muscle elasticity resulting from increased blood flow (Bosco et al. 1999a; Issurin et al. 1994a; Mester et al. 1999; Sands et al. 2006a); Increase in pain threshold (Issurin et al. 1994a; Sands et al. 2006a); and golgi tendon organ (GTO) excitation and antagonist inhibition (Bosco et al. 1999b; Issurin et al. 1994a). Based on prior research we also theorize that there is a possible interplay between pain perception and proprioception when stretching with vibration and that a lack of spindle response may also contribute to the success of stretching with vibration.

While prior research has shown that increasing muscle temperature increases muscle extensibility, further flexibility research has also shown that the use of different forms of heat as adjunctive treatment improve stretching results (Draper et al. 2004; Henricson et al. 1984). Recent studies have also reported increases in blood flow and volume due to vibration application (Kerschan-Schindl et al. 2001a; Lythgo et al. 2009; Zhang et al. 2003), with blood flow rates even doubling after 9 minutes of WBV in the popliteal artery (Kerschan-Schindl et al. 2001a). This increase in blood flow would result in a concomitant increase in muscle temperature, and hence, muscle extensibility (Issurin et al. 1994a; Sands et al. 2006a). Cochrane et al. (2008) reported that increases in blood flow increased muscle temperature (as measured in the vastus lateralis) twice as fast as cycling when vibration is coupled with repeated squats. Further research is needed to determine if similar results occur in a static stretch of the hamstring muscle group during WBV training. This possibility may help explain the increases in flexibility reported by Van den Tillaar (van den Tillaar 2006b) when alternating stretching and WBV bouts, and may also explain the increases seen in our study.

Stretching with vibration may inhibit pain perception, thus resulting in greater range of motion during the stretch. It has been reported that nociceptive sensitivity gradually declines as vibration amplitude increased and that vibrations ranging from 20 to 230 Hz interfere with nociception (Hollins et al. 2003). Vibratory rates as low as 30 Hz have been reported to significantly increase pain threshold even after stimulation in the hand (Zoppi et al. 1991), and activation of deep and superficial receptors is proposed to interact with nociceptive processing at many levels of the nervous system, including those of the spinal cord (Dahlin et al. 2006). Thus, it is possible that vibration alters the sense of stretch perception and pain through a variety of mediating factors. In our study, subjects in both treatment groups were asked to stretch and hold a position that was "slightly uncomfortable" but not painful. This intensity of stretch is quite common in the stretching literature. The mechanically induced muscle contractions by vibration most likely stimulated Ia afferents and resulted in increased intensity of the stretch. Prior research on vibration has also reported that the muscle group on stretch would exhibit an increased firing rate (Burke et al. 1976).

While it is known that Ia afferents inhibit motor neurons to the antagonistic muscle (Mester et al. 1999), vibration also induces a tonic vibration reflex (TVR) and increases muscle stiffness (Cronin et al. 2004; Mester et al. 1999). A study done without use of any type of vibration showed increased muscle stiffness is related to decreased stretch tolerance and repeated stretches only temporarily reduce muscle stiffness (Magnusson et al. 1997). Localized vibration at higher frequencies has demonstrated an increase in muscle stiffness during vibration (Burke et al. 1976; Ribot-Ciscar et al. 1998). Increased stiffness and intensity may affect GTO activity since the GTO responds to vibration and their capacity to follow vibration frequencies increases with muscle stretch (Burke et al. 1976). It has been suggested that WBV application may induce changes to muscle stiffness (Cardinale and Bosco 2003), which has been used to try to explain other performance changes seen with WBV training.

Many studies have suggested that the spindle response is responsible for improved performance following WBV training. However, the success in WBV application improving other performance factors such as power and strength is also disputed in the literature. It has even been reported that the effects of neural potentiation from WBV disappear within an hour (Torvinen et al. 2002a), but the idea that enhanced muscle spindle response, primary Ia recruitment and the tonic vibration response (TVR) are the primary cause of such increases is arguable since the Ia system appears to be involved in complex (mono and polysynaptic) spinal pathways, and the role of central or supraspinal input and integration has not been adequately studied. Recent studies have reported that WBV treatment does not affect the timing or amplitude of the quadriceps stretch reflex (Hopkins et al. 2008a), and does not enhance muscle spindle sensitivity as determined by the inability to alter peroneus longus electromechanical delay, reaction time or peak and average EMG.

We suggest that the vibration variables of duration, total time, frequency and amplitude may be more person specific than previously thought. For example, de Ruiter et al. (de Ruiter et al. 2003a) reported an inability to increase maximal voluntary knee extensor contraction or maximal rate of force rise when using a similar vibration protocol as Bosco et al. (Bosco et al. 1999b; Bosco et al. 2000a). Cardinale and Bosco (2003) suggest that shorter durations of WBV (4-5 sets x 60 seconds with 60-second rest intervals) may be an important factor for producing positive training effects, however, both studies by Hopkins et al. (2008a; 2008b) and the study by Cronin et al. (2004) used this protocol. The apparent discrepancy in results between Bosco (199b; 2000) and these other studies (Cronin et al. 2004; de Ruiter et al. 2003a; Hopkins et al. 2008a; Hopkins et al. 2008b) may lie in the type of population studied. It is possible that the fitness level and physiological make-up of the population undergoing WBV has a significant impact on potential neuromuscular response. Prior studies by Bosco (1999b; 2000) used very fit individuals currently involved in team training while the other studies (Cronin et al. 2004;

de Ruiter et al. 2003a; Hopkins et al. 2008a; Hopkins et al. 2008b) used sedentary to recreationally active subjects. Since prolonged vibration stimulation does result in force reduction capacity of the muscle (Cardinale and Bosco 2003; Rittweger et al. 2000a) it is possible that the training and fitness level of subjects may also affect vibration related stretching protocols, but this has yet to be explored. Even though the SV group in this study averaged a greater increase in flexibility, this "average" was made up of individuals who had small responses and a few who had very dramatic increases in flexibility. Thus, the duration, repetitions, frequency and amplitude used in this study may have affected individuals differently. Further research is needed to determine frequency specific responses for WBV training protocols.

Our study is limited to a recreationally active college-aged population. Whether or not these results can be attributed to older populations warrants investigation. Further studies should also investigate if a smaller amplitude would produce similar results. A smaller amplitude would most likely make the stretch position more comfortable and more applicable to other populations.

Practical Applications

The results of this study suggest that concurrent WBV and static stretching is a more effective regiment to increase flexibility than static stretching alone. Retention of flexibility gains does not appear to be improved by vibration, however, the greater increases in flexibility that occur will take longer to lose, merely as an effect of the overall gain. The application of stretching concurrently with WBV training increased flexibility of the hamstrings faster than static stretching alone, but vibration alone does not replace the need for a stretching protocol.

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Table 1. P-values for comparisons between groups but within each time period

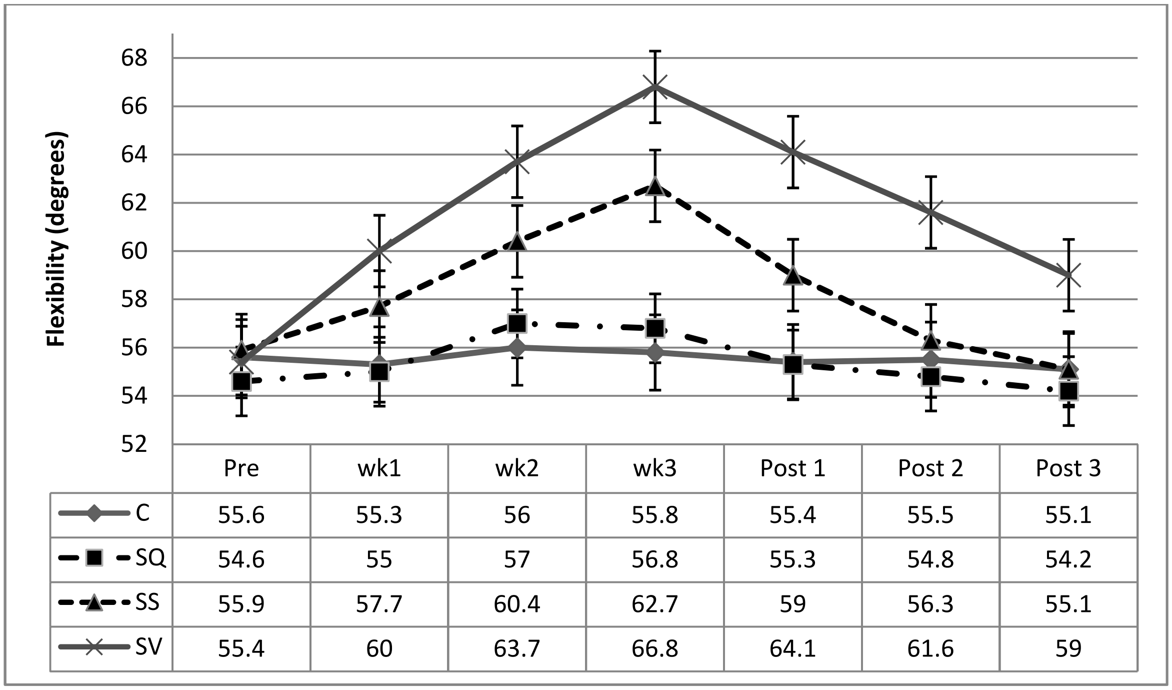
	Pre	**Wk 1**	**Wk 2**	**Wk3**	**Post 1**	**Post 2**	**Post 3**
C vs SQ	0.6549	0.8790	0.6420	0.6448	0.9507	0.7303	0.6835
C vs SS	0.8914	0.2820	0.0416	0.0014	0.1009	0.7265	0.9922
C vs SV	0.9463	0.0312	0.0004	<0.0001	>0.0001	0.0049	0.0706
SQ vs SS	0.5474	0.2011	0.0989	0.0042	0.0760	0.4721	0.6678
SQ vs SV	0.6966	0.0160	0.0011	<0.0001	<0.0001	0.0010	0.0209
SS vs SV	0.8346	0.2669	0.1130	0.0485	0.0154	0.0154	0.0653

C = control
SS = static stretch only
SV = vibration with static stretch
SQ= squat vibration

Pre= baseline
Wk1= after 1 wk of treatment
Wk2= after 2 wks of treatment
Wk3= after 3 wks of treatment
Post1= 1 wk after cessation of treatment
Post2= 2 wks after cessation of treatment
Post3= 3 wks after cessation of treatment

Table 2. Weekly Changes in Flexibility (measured in degrees as mean± S.D.)

	Pre	Wk 1	Wk 2	Wk 3	Post 1	Post 2	Post 3
Control	55.6 ± 0.30	0.3 ± 0.30	0.7 ± 0.30	0.2 ± 0.30	0.4 ± 0.30	0.1 ± 0.30	0.4 ± 0.30
SQ	54.6 ± 1.09	0.4 ± 1.09	2.0 ± 1.09	0.2 ± 1.09	1.5 ± 1.09	0.5 ± 1.09	0.6 ± 1.09
SS	55.9 ± 2.65	1.8 ± 2.65	2.7 ± 2.65	2.3 ± 2.65	3.7 ± 2.65	2.7 ± 2.65	0.8 ± 2.65
SV	55.4 ± 3.77	4.6 ± 3.77	3.7 ± 3.77	3.1 ± 3.77	2.7 ± 3.77	2.5 ± 3.77	2.6 ± 3.77



	Pre	wk1	wk2	wk3	Post 1	Post 2	Post 3
C	55.6	55.3	56	55.8	55.4	55.5	55.1
SQ	54.6	55	57	56.8	55.3	54.8	54.2
SS	55.9	57.7	60.4	62.7	59	56.3	55.1
SV	55.4	60	63.7	66.8	64.1	61.6	59

Figure 1. Average flexibility (measured in degrees) for each group at each time period throughout study with S.E. bars.

C = Control Group
SQ = WBV without static stretch Group
SS = Static stretch without WBV group
SV = Static stretch with SBV Group

Figure 2. Semi-squat without vibration position

Figure 3. Stretching position for static stretch only and static stretch with vibration groups.

Appendix A

Prospectus

Chapter 1

Introduction

Vibration has been studied for several decades, and initially was geared toward determining its ill-effects on the body (Parks 1962; Shoenberger and Harris 1971). Body vibration research, performed on vibrating seats, looked at vibration as an occupational hazard (Shoenberger 1972, 1974) and also looked at its adverse effects to the musculoskeletal system (Carlsöö 1982). Locally applied vibration, using multiple apparatuses, was also studied. (Claus et al. 1988; Lundeberg et al. 1984; Marsden et al. 1969; Oliveri et al. 1989; Pantaleo et al. 1986) Several of these studies used high vibration frequencies, between 60 Hz and 110 Hz (Oborne et al. 1981; Oliveri et al. 1989; Pantaleo et al. 1986). In general, in more recent research, lower frequencies have been used to examine areas such as the physiological effects of vibration. (Rittweger et al. 2001b)

Recently, body vibration studies have moved from using localized vibration and vibrating seats to using whole body vibration (WBV) platforms (Rittweger, Mutschelknauss, & Felsenberg, 2003; Torvinen, Sievanen, Jarvinen, Pasanen, Kontulainen, Kannus, 2002) . Whole body vibration platforms have been used to investigate vibration’s effect on bone mass (Torvinen, Kannus, Sievanen, Jarvinen, Pasanen, Kontulainen et al., 2003), muscle physiology (Cardinale and Lim 2003b; Roelants et al. 2006b; Seidel 1988), oxygen kinetics (Cardinale et al. 2007; Rittweger et al. 2000b; Rittweger et al. 2002b; Rittweger et al. 2001b), body composition (Roelants et al. 2004b), skin blood flow (Lohman et al. 2007), muscle blood volume (Kerschan-

Schindl et al. 2001b), hormones (Cardinale et al. 2006a; Erskine et al. 2007a; Kvorning et al. 2006), balance (Torvinen et al. 2002c, d; Torvinen et al. 2002f)**,** and muscular performance (Annino et al. 2007a; Bogaerts et al. 2007b; Bosco et al. 1998b; Cochrane et al. 2004b; Cormie et al. 2006a; de Ruiter et al. 2003b; Delecluse et al. 2005b; Kawanabe et al. 2007; Kvorning et al. 2006; Rees et al. 2007; Rehn et al. 2007b; Rittweger et al. 2003a; Roelants et al. 2004b; Roelants et al. 2004c; Rønnestad 2004; Russo et al. 2003b; Torvinen et al. 2003a; Torvinen et al. 2002f). Whole body vibration has been touted as being beneficial in training due to these studies and a variety of physiological responses.

There have been very few vibration and flexibility/stretching studies (Atha and Wheatley 1976b; Cochrane and Stannard 2005b; Fagnani et al. 2006a; Issurin et al. 1994b; Sands et al. 2006b; van den Tillaar 2006a). These studies are very different in their methodologies. The majority measured flexibility as a secondary variable and no stretching was performed in conjunction with vibration. For example, one of the earliest studies (Atha and Wheatley 1976b) used a vibration pad (44 Hz @ amplitude .1 mm) to show that vibration can be as effective in improving hip flexion as a typical manual mobilizing program. Three other studies (Cochrane and Stannard 2005b; Fagnani et al. 2006a; van den Tillaar 2006a) had subjects standing on a WBV platform for standard positional exercises but did not use a stretching program during vibration. Two of these studies (Cochrane and Stannard 2005b; Fagnani et al. 2006a) did not have any stretching protocol incorporated into their study. Flexibility (as measured by the sit-and-reach test) was merely a secondary variable of interest. However, van den Tillaar (2006a) did have subjects perform contract-release stretches after a WBV training session and measured hamstring flexibility as a primary variable of interest. They found that stretching following vibration yielded significant improvements in flexibility. Another study by Issurin et al. (1994b) used a combination of static stretching, static stretching with body flexion, and ballistic stretching in conjunction with locally applied vibration through a vibrating cable to show increased flexibility (as measured by a flex-and-reach test). Other than Issurin et al., the only study to look at stretching during vibration is Sands et al. (2006b). In this study, a specialized vibration module was used to rest under the leg being stretched. They report that flexibility (as measured by forward splits for both legs) increased more while using the module during static stretching (SS) than without.

While prior research has reported that bouts of WBV performed separately from stretching exercises does increase flexibility greater than stretching alone, there is no published data to show whether or not SS done concurrently with WBV has a greater effect on hamstring flexibility than SS done with adjunct WBV.

Problem Statement

The purpose of this study is to determine if WBV done concurrently with SS is more effective than WBV done separate from SS alone in improving hamstring flexibility. A secondary purpose of this study is to determine how long the flexibility gains are maintained.

Null Hypothesis

The following null hypothesis will be tested:

> There will be no differences in improvement of hamstring flexibility between the vibration + concurrent stretch groups and vibration + adjunct static stretch group.

Assumptions

This study will assume the following:

> The lying passive knee extension test is a representative measurement of hamstring flexibility in each subject.

Delimitations

This study will be delimited to

1. A college aged population, 18-30 years old;
2. Most likely all Caucasian;
3. Persons with a specific level of hamstring tightness (the inability to touch the tops of their feet from a standing position with the legs straight and 70^0 or less on a straight-leg-raise test);
4. Stretching 5 days/week for 4 weeks only

Limitations

1. Results may only be attributable to a population with similar characteristics.
2. Results are limited to vibration effects of the Galileo machine only and may not be attributable to other WBV platforms.

Terminology

WBV – Whole-body vibration, achieved by standing on a vibrating platform at various frequencies

Static stretch – Stretching to mild discomfort and holding the position for a set period of time

Galileo – A vibrating platform which tilts on a central axis to create the vibration

Significance of the Study

There is an abundance of studies that have looked at a variety of stretching protocols and techniques. There are also many studies that have looked at the use of adjunctive modalities (i.e., heat, cold, massage) in conjunction with stretching. Many of these studies have not shown adjunctive modalities to be beneficial. Initial vibration related research appears to enhance flexibility. This study will investigate whether whole body vibration in conjunction with static stretching produces faster rates of improved hamstring flexibility and how long those improvements are retained. The clinical significance would be to help decrease the treatment time by combining stretching and vibration and increasing the retention of gains made.

Chapter 2

Review of Literature

Vibration has been studied for several decades for a variety of purposes. Although current research is more widespread in both purpose and design, most of the initial studies done from the 1960s through the 1970s dealt with the physiological effects of seated body vibration, such as reflex response and areas of discomfort (1966; Marsden et al. 1969; Whitham and Griffin 1978; Zagórski et al. 1976). Whole body vibration, though listed as the type of vibration used in many of these studies, generally referred to subjects seated on a vibrating chair or plank as opposed to the whole body vibration platforms commonly used today for whole body vibration studies. (Parks 1962; Shoenberger 1974; Whitham and Griffin 1978)

Brief History of Vibration Studies

Seated WBV was used because many studies during the 1960s and 70s focused on occupational hazard aspects of vibration that were of particular interest to the military (Parks 1962; Shoenberger 1972, 1974; Shoenberger and Harris 1971). As a result, many of the subjects in these early studies were young and fit, with several using Air Force military personnel as their subjects. (1977; Shoenberger 1974; Shoenberger and Harris 1971) These studies done for the military used relatively low frequencies in vibrating chairs in their studies to correspond with the vibration felt during flight as a pilot (Shoenberger and Harris 1971). Shoenberger & Harris (1971) used frequencies from 3.5 – 20 Hz while Parks (1962) used frequencies from 1-27 c/s. Specifically, levels of tolerability and the ability to perform flight-related tasks during seated WBV were looked at extensively (Buckhout 1964; Parks 1962).

Other early studies used higher frequencies in order to elicit the desired physiological reactions. One study applied localized vibration to “the achilles tendon or by electrical stimulation of the medial popliteal nerve” while the subject lay on a table, face down, with their feet hanging off of the end of the table (Marsden et al. 1969). This was done in order to achieve tonic contraction of the calf muscle. The vibrator was mounted to the table and the frequency used was 100 c/s, with an amplitude of only 1-3 mm. (Marsden et al. 1969)

During the 1980s, vibration research became more diverse in its aims, with more research having been done to figure out the means by which vibration achieved its effects. Several studies found the vibration to mainly affect the extero- and proprioceptive receptors as opposed to the vestibular organs (Gauthier et al. 1981; Roll et al. 1980). Other topics included vibration’s effect on heart rate after either sinusoidal WBV on a seat vibrating at 5 Hz or a stochastic WBV between 2.8 and 11 Hz (Manninen 1984), sensitivity to brain stimuli during vibration of the right abductor digiti minimi muscle (Claus et al. 1988), and the interacting effects of noise, temperature, and vibration using a vibrating chair which vibrated at frequencies between 2.8 and 11.2 Hz (Manninen 1985). In addition to the use of EMG in order to determine the effects of vibration in areas such as the paraspinal muscles (Seroussi et al. 1989) researchers started to find new ways of describing and modeling vibration and its effects. One study created three-dimensional images using double-exposure holographic interferometry in order to allow measurement of the body movements between vibrations (Wangenheim et al. 1984). Another study used finite segment modeling in order to create images of the body (Amirouche 1987).

While some research continued to look at the adverse effects of vibration, for example to the musculoskeletal system (Carlsöö 1982), there was a movement to look at the positive effects of vibration in increasing pain tolerance (Pantaleo et al. 1986) and pain relief (Lundeberg et al. 1984; Oliveri et al. 1989). When evaluating pain tolerance, Pantaleo et al. (1986) used localized vibration on the vastus medialis muscle at frequencies from 30 to 110 Hz, but only used an amplitude of 2 mm. They showed that even at such low amplitudes, high frequencies can increase muscular pain threshold.

Occupational Hazards

Occupational hazard was mentioned earlier as a reason for the military studying the effects of seated whole body vibration. More recent studies have looked at other occupations, such as tractor drivers and subway drivers (Bovenzi and Betta 1994; Johanning et al. 1991). One study looked at subjects' ability to accurately perceive different vibration frequencies (Oborne et al. 1981). Important progress has been made in the realm of the effects of different frequencies, specifically 2-64 Hz on a vibrating seat, on the different locations of discomfort felt by the subject (Whitham and Griffin 1978). Also, the effect of the direction of vibration, moving from the z-axis to the x- and y-axes, has been studied. (Dupuis 1989; Whitham and Griffin 1978) These studies (Dupuis 1989; Whitham and Griffin 1978) showed that the direction of vibration changes the location of discomfort felt and also the amount of resonance produced in the body. Dupuis (1989) studied subjects both sitting and lying down while exposing them to vibration. While seated, the chair vibrated at a frequency between 0.5 and 31.5 Hz, while vibrating between 1 and 63 Hz as the subjects were lying down. He found that posture, similar to direction of vibration, affected the amount of resonance produced in the body (Dupuis 1989).

Workers exposed to hand-transmitted vibration (HTV) have been shown to have more symptoms and signs of disorders of the vascular, neurological and musculoskeletal systems of the upper limbs (Bovenzi 2006). Workers that are exposed to long-term seated whole-body vibration in the workplace have increased risk for disorders of the lower back (Bovenzi 2006). The relationship between low-back disorders and occupational vibration exposure has been well-documented (Bovenzi and Hulshof 1999; Hulshof and van Zanten 1987; Lings and Leboeuf-Yde 2000; Pope et al. 1998). These studies either relied on epidemiological research or reviewed studies in order to find an association between low-back disorders and occupational vibration exposure. Due to the design of these studies, no cause-effect relationship has been definitively established between low-back disorders and occupational whole body vibration, but there is definitely an increased risk for not only low-back disorders, but sciatic pain and degenerative changes in the spinal system as well (Bovenzi and Hulshof 1999).

WBV and Physiological Effects

More recent vibration studies have been performed using a WBV platform. Since the late 1990s the amount of research done in this area has significantly increased. A WBV platform is generally has a base which is 2-3 feet wide and 2-3 feet long. Most have a handle to hold on to for help balancing. There are many brands of machines and several ways in which the platform vibrates. The two most common used in research are the Galileo machine (Orthometrix, White Plains, NY) and the Power Plate machine (Power Plate North America, Northbrook, Illinois). The Galileo platform vibrates by the platform tilting left and then right on a central axis while the Power Plate uses tri-planar, but mostly vertical movement of the whole platform to create the vibration. The Galileo can be adjusted to use frequencies between 5 Hz and 30 Hz and the amplitude can range from 2mm to 7 mm depending on foot placement (away from the center axis point). The Power Plate uses frequencies between 35 Hz and 50 Hz and only has two amplitudes settings, 2mm and 5 mm. The whole plate vibrates uniformly, rather than the reciprocating or teeter-totter type action of the Galileo.

Many of the physiological effects of WBV have been studied, including oxygenation, blood volume, hormonal response, balance, mobility, strength and power, and flexibility.

Oxygenation and Blood Volume

Although the differing methods make direct comparisons difficult, WBV has been shown to increase specific oxygen uptake. WBV at 26 Hz and an amplitude of 6 mm showed a 4.5 ml/kg/min increase in specific VO_2 (sVO_2) (Rittweger et al. 2001b). A linear increase in sVO_2 was seen as frequency was increased from 18 to 26 to 34 Hz (Rittweger et al. 2002b). When the effect of amplitude on sVO_2 was researched, there was actually a more than proportional increase when amplitude increased from 2.5 to 5 to 7.4 mm (Rittweger et al. 2002b). Both of these studies further confirmed that an increase in muscle activity causes an increase in muscular metabolic power (Rittweger et al. 2002b; Rittweger et al. 2001b). Rittweger, Beller & Felsenberg (2000b), like in the previous two studies, used squatting on a vibration platform to test the effect of vibration on sVO_2, but they compared the results to progressive bicycle ergometry to exhaustion (Rittweger et al. 2000b). Oxygen uptake from exhaustive vibration exercise was 48.8% of that of the progressive bicycle ergometry, though the perceived exertion for both exercises was 18 on Borg's scale (Rittweger et al. 2000b). Another study looked at the oxygenation of specific muscles due to WBV through near-infrared spectroscopy (Cardinale et al. 2007). Squatting on a vibration platform was again used as the intervention, with frequencies between 30 and 50 Hz and an amplitude of 4 mm.; but the research showed that WBV had no effect on the oxygenation of the gastrocnemius medialis or the vastus lateralis (Cardinale et al. 2007). Using short duration (three minutes), high frequency (30 Hz), and high amplitude (5-6 mm) WBV, skin blood flow to the lower extremities significantly increased for at least 10 minutes following the intervention (Lohman et al. 2007). Even using a lower frequency of 26 Hz and a lower amplitude of 3 mm showed an increase of blood flow to the thigh and calf muscles immediately following the intervention. (Kerschan-Schindl et al. 2001b)

Hormonal Response

Research has also looked at the hormonal response to WBV. Kvorning et al. (2006) performed a long-term, 9-week training program with three groups, one performing squats with resistance, progressing from one session per week of 3 sets of 8 repetitions the first week to 3 sessions per week of 6 sets of 8 repetitions. The other two groups performed the same routine either without resistance or without vibration, respectively. They found that WBV alone, at 20-25 Hz, increased growth hormone, though there was no increase in maximal isometric voluntary contractions as measured by a leg press exercise (Kvorning et al. 2006). Another study used a single session of a squatting exercise on a WBV platform vibrating at a frequency of 30 Hz and found no significant changes in salivary concentration of testosterone (T) or cortisol (C) (Erskine et al. 2007a). Other studies have had subjects simply stand on WBV platforms vibrating at frequencies between 26 and 30 Hz and amplitudes between 1.5 and 4 mm and found differing results. One study looked at serum T and insulin growth factor 1 (IGF-1) levels and found no change after WBV at a frequency of 30 Hz (Cardinale et al. 2006a). Another study showed a slight decrease in plasma glucose and increased plasma norepinephrine after WBV, also at 30 Hz, but no change in the levels of other hormones, including insulin, cortisol (C), epinephrine, growth hormone (GH), IGF-1, free and total cholesterol (Di Loreto et al. 2004). An earlier study used a lower frequency of 26 Hz and found significant increases in plasma T and, like Kvorning et al. (2006), who used slightly lower frequencies of 20-25 Hz, an increase in GH, but decreased plasma C

(Bosco et al. 2000b). The studies that used lower frequencies of 20-26 Hz rather than 30 Hz showed increased GH.

Balance and Mobility

Whole body vibration's effects on balance and mobility, is a currently developing area of research, especially among the elderly (Bautmans et al. 2005; Kawanabe et al. 2007; Runge et al. 2000). One study used a 2-month intervention where elderly subjects stood on a WBV platform for 2 minutes, 9 times per week, to decrease the amount of time it took to stand from sitting on a chair. This decrease was due to increased muscle power of the lower extremities (Runge et al. 2000). Another 2-month study had elderly subjects stand on a WBV platform for 4-minute sessions, but only once per week, in addition to muscle strengthening, balance, and walking exercises to improve the walking ability of the elderly, as measured by walking speed, step length, and the maximum standing time on one leg (Kawanabe et al. 2007). One study used 6 weeks of various light squat and calf exercises performed on a WBV platform to show improved times in the timed up-and-go test (Bautmans et al. 2005). Another study also used the timed up-and-go test, but with subjects with multiple sclerosis (Schuhfried et al. 2005). That study found that even one week after five 1-minute sessions on a WBV platform with 1 minute rest in between the time required to perform the timed up-and-go test significantly decreased (Schuhfried et al. 2005). One long-term study had subjects perform light exercises on a WBV platform and found they had improved postural control after both 6 months and 12 months of training (Bogaerts et al. 2007c); while a different study showed improved balance in elderly women after standing on a WBV platform for only 3 min/day, 3 times/week for 3 months. (Cheung et al. 2007)

Several studies have used similar methods as each other but found different results in regard to balance. Two studies using frequencies between 25 and 40 Hz found no change in body balance though one was continued 3-5 days per week for 4 months and the other was done in two 2-day sessions with 1-2 weeks between the 2-day sessions (Torvinen et al. 2002d; Torvinen et al. 2002f). Another study using the same protocol as the short-term study just described but with decreased frequency between 15 and 30 Hz and using a Galileo 2000 rather than a Kuntotäry machine found a 15.7% improvement in balance (Torvinen et al. 2002c).

Strength and Power

A large amount of research has been done in the area of WBV's effects on strength and power. One of the most common measurements of strength and power used is vertical jump. Many studies using various frequencies and duration of training sessions have shown that WBV does increase vertical jump ability (Annino et al. 2007a; Bosco et al. 1998b; Cormie et al. 2006a; Kvorning et al. 2006; Roelants et al. 2004c; Rønnestad 2004; Torvinen et al. 2003a; Torvinen et al. 2002d). There have also been conflicting reports that WBV has no effect on vertical jump ability (Cochrane et al. 2004b; de Ruiter et al. 2003b; Torvinen et al. 2002f), while one study actually showed a decrease in jump height (Rittweger et al. 2000b). These studies are difficult to compare since they vary in duration from one session to one year and frequencies of 20 to 40 Hz.

There was a study done that showed that increases in vertical jump were seen when vibration training occurred at 20 or 30 Hz, but that training at 40 Hz actually decreased vertical jump ability (Da Silva et al. 2006). Another study showed that even though vertical jump ability increased, the effect was transient and was manifest two minutes after training, but not 60 minutes after training (Torvinen et al. 2002c).

Differing methods were used to show improvements in jump height. Cormie et al. (2006a) used only one treatment of 30 seconds at a frequency of 30 Hz and tested jump height immediately following the treatment, while several others used much longer time periods. Annino et al. (2007a) used 8 weeks of intervention, with vibrations at a frequency of 30 Hz as well for five 40-sec intervals 3 times per week to show improvements. Torvinen et al. (2002d) had subjects train on a WBV platform for 4 minutes, 3-5 times per week at 25-40 Hz for 4 months and found significant increases in jump height, and Torvinen et al. (2003a) had subjects train for 8 months, training for 2 minutes at 25-30 Hz at the beginning and working up to 4-minute sessions at 25-40 Hz on the WBV platform for the last 4 months and showed similar gains as those in the previous study who trained for only 4 months, total.

Of the other studies that showed improved jump performance, two used loaded squat exercises, but one went for only 5 weeks and used a frequency of 40 Hz (Rønnestad 2004) while the other went for 9 weeks and used frequencies of only 20-25 Hz (Kvorning et al. 2006). One study went for 24 weeks and had subjects perform knee-extensor exercises without any load at frequencies of 35-40 Hz. (Roelants et al. 2004c) A short-term study found that even 10 days training each day for five 2-minute sessions (a total of 10 minutes per day) increased jump performance (Bosco et al. 1998b).

Two of the studies that showed no change in jumping performance were of much shorter duration than those that found improvements. Torvinen et al. (2002f) used 2 interventions 2 weeks apart of 4 minutes at 25-40 Hz and found no change in jump height, while Cochrane et al. (2004b) had subjects train for 5 days consecutively at 26 Hz, rest for 2 days, then train for 4 more days consecutively at the same frequency of 26 Hz, but found no improvements in jump performance. de Ruiter et al. (2003b) had subjects train for 11 weeks, training in one minute sessions for 5-8 minutes cumulatively 3 times per week at 30 Hz, but still found no improvements in jump performance. The one study that showed decreased jump performance used completely different methods. They had subjects perform 30 seconds of standing on a WBV platform and then perform squats with an additional load until exhaustion and then perform tests for jump height immediately following exercise (Rittweger et al. 2000b).

Another measurement that has been used extensively to measure strength and power of the lower extremities after WBV is isometric extension strength. While some studies have shown increases in isometric extension strength at frequencies between 25 and 40 Hz (Bogaerts et al. 2007b; Torvinen et al. 2002d), several have shown that the effects of WBV are comparable to standard exercise programs from 2 months to 2 years, respectively (Rees et al. 2007; Roelants et al. 2004c). One study suggested that in order for the benefits of WBV to be comparable to a standard exercise program, the standard exercise program must consist of cardiovascular and resistance training (Roelants et al.

2004b). There have also been several studies that have shown no improvements in isometric extension strength from WBV using frequencies between 25 and 45 Hz (de Ruiter et al. 2003b; Delecluse et al. 2005b; Torvinen et al. 2003a).

Electromyography (EMG) activity of the lower limbs has been shown to increase during WBV, especially at frequencies between 30 and 35 Hz (Cardinale and Lim 2003b; Roelants et al. 2006b), though one study suggested that 30 Hz was the maximum frequency that should be used in order to elicit maximum muscle activity during WBV (Cardinale and Lim 2003b). Several studies have also shown no increase in muscle activity during WBV at frequencies between 25 and 40 Hz, as measured through EMG, though both studies lasted 2 weeks or less (Rittweger et al. 2003a; Torvinen et al. 2002f).

Special attention has been paid to older populations due to increasing evidence of the benefits of WBV. Whole body vibration at a frequency of 26 Hz and an amplitude of 5-8 mm has been shown to decrease the time required to stand from a chair after a training program done 3 times per week for 2 months (Rees et al. 2007). It has also been shown to increase overall muscle mass and strength of the upper leg after a one-year training program with three training sessions per week at frequencies between 30 and 40 Hz (Bogaerts et al. 2007b). Another study showed improvements in postmenopausal women, who showed a 5% increase in muscle power after training with WBV at frequencies between 12 and 28 Hz for three 2-minute sessions twice per week for 6 months (Russo et al. 2003b).

Flexibility

Flexibility has not been researched as much as many of the preceding topics. Given the purpose of this study, the studies published involving vibration and flexibility will be reviewed in more depth. With regard to flexibility, researchers have mostly looked at the possibility of using vibration independent of, not simultaneously with stretching to increase range of motion. Two studies have used vibration during stretching. A review of these studies follows.

In 1976, Atha and Wheatley (1976b) used locally applied cycloid vibration. They separated 42 healthy young adult males into three groups and gave each group one of three mobilizing treatments each day for three successive days. Each participant received the three treatments in a random order, but each possible combination of treatments included equal numbers of participants. The first treatment was 15 minutes of quiet seated rest. The second treatment was 15 minutes of sitting on a chair with vibrating cushions supporting the lower back and thighs with a frequency of 44 Hz and an amplitude of .1 mm. The third treatment was a classic stretching method which consisted of the following protocol:

1. Standing: continuous spot running followed by crouch jumping
2. Astride standing: head pressing to alternate knees
3. Tuck sitting, alternate heel support: single leg stretching
4. Rear lunge, with toe rest: calf and leg stretching

5. Crouch, ankles held: double knee stretching to pike standing

Subjects stretched to acute discomfort and held the stretch for 2-5 seconds, without bouncing, followed by several seconds of complete relaxation. Each exercise was done 10 times. Hip flexion was measured to the nearest centimeter using a modified sit-and-reach test (Atha and Wheatley 1976b) before and after each treatment session. Over the three days, the control group increased an average of 1.7 centimeters, the vibration group increased an average of 2.5 centimeters, and the exercise group increased an average of 2.9 centimeters. This research shows that, at this frequency and amplitude, 15 minutes of WBV is equally effective as a stretching protocol for short-term range of motion (ROM) increases in hip flexion, with results persisting for 24 hours.

Issurin et al. (1994b) looked at the influence of a specially made vibratory stimulation device on maximal isotonic force and flexibility. Twenty-eight healthy male physical education students from a university were separated into groups A, B, and C. Each group exercised 3 times per week for 3 weeks. Group A used conventional upper body exercises and vibratory stimulation (VS) exercises for leg flexibility (Issurin et al. 1994b). Group B did the reverse with VS for maximal arm strength exercises and traditional exercises for leg flexibility. Group C acted as the control group and did training unrelated to the measurements being taken, such as calisthenics running (Issurin et al. 1994b). The exercise was performed with a counter-weight pulley system. The upper-body exercise was six sets of sitting bench-pulls with each set being performed until exhaustion. The-lower body flexibility training consisted of standing on one leg and placing the other in a hanging ring. Six sets were used for flexibility training as well.

There were three parts to the stretching: static stretching, stretching together with body flexion, and ballistic stretching, stretching the right and left legs consecutively.

The VS device that was used was made specifically for this study and created eccentric oscillations of 3 mm amplitude and a frequency of 44 Hz. Each group warmed-up and the total workouts were each approximately 55 minutes. Group C performed calisthenics without arm strength exercises or leg flexibility exercises and then jogged or played basketball for the second half of the allotted exercise period. Two measures of flexibility, a side-split and a flex-and-reach test, were taken (Issurin et al. 1994b). For the side split test, group A, the VS flexibility group, showed a mean increase of 14.5 cm as compared to 4.1 cm and 2 cm increases for groups B and C, respectively. Similarly, for the flex-and-reach test the VS flexibility group showed a mean increase of 4.75 cm, as compared to 2.13 cm and 0.7 cm increases for groups B and C, respectively.

Cochrane and Stannard (2005b) performed a study with more acute interventions, yet found similar results as the previous study. Eighteen female field hockey players participated, and each randomly completed three interventions with 24 h recovery between each intervention. The three interventions, each lasting five minutes, were as follows: standing on the Galileo Sport machine with vibration, standing on the Galileo Sport machine without vibration, and seated cycling. Each participant was tested on three things within 15 seconds of completing each intervention in the same order that they were tested prior to the intervention, vertical jump, grip strength, and flexibility by a sit-and-reach test. The Galileo Sport was set to an amplitude of 6 mm and a frequency of

26 Hz. Subjects assumed 6 different positions while on the Galileo Sport. Positions 1-4 were held for 1 min and positions 5 and 6 were held for 30 s.

1. Standing upright with knees semi-locked
2. Isometric squat at a knee angle of approximately 120 degrees
3. Kneeling on the ground with arms straight and hands placed on the platform equating to a peak-to-peak amplitude of 6 mm of vertical vibration
4. Squatting at a tempo of 2 s up and 2 s down at a knee angle of approximately 120 degrees
5. Lunge position with left leg on platform and right leg on ground
6. Lunge position with right leg on platform and left leg on ground

Although no flexibility exercises were performed simultaneously with WBV, there was still an 8.2% increase in sit-and-reach flexibility, as compared to a 5.3% improvement after both the control and cycling interventions.

van den Tillaar (van den Tillaar 2006a) endeavored to find out if WBV would help increase the ROM of the hamstrings. Nineteen undergraduate physical education students were assigned to either the WBV group or the control group. Both groups warmed up on a treadmill, walking for 2 minutes at 4 km/h, then lay flat on their back on a table as ROM was measured using a goniometer as the angle, in degrees, between the femur and the pelvis, the greater trochanter acting as the rotation point. The average of three of these measurements was used in postintervention comparisons. Each group stretched 3 times per week for 4 weeks. Each session followed the same routine, with a 5-second isometric contraction immediately preceding 30 seconds of static stretch, repeated 3 times per leg (van den Tillaar 2006a). Those subjects in the WBV group underwent vibration treatment on a vibration platform for 30 seconds with a frequency of 28 Hz and amplitude of 10 mm. While on the platform, subjects stood in a squat position with knees flexed to 90 degrees. The average of the two legs was used for comparisons. For both groups, ROM of the hamstrings increased significantly. In the WBV group, significant increase was made after the first week, and each week thereafter except from Week 3 to 4. The control group, on the other hand, increased hamstring flexibility after Week 2, but did not significantly increase after Week 2. The WBV training, on average, showed greater increase than the control group, increasing 26.8 degrees and 12.4 degrees, respectively.

Another study by Fagnani et al. (2006a) investigated, among other parameters, the effects of an 8-week WBV training program on flexibility as measured by the sit-and-reach test. For the study, 26 female athletes (ages 21-27) were placed in either the vibration group or the control group. A frequency of 35 Hz was chosen along with an amplitude of 4 mm and an acceleration of 17g. This group trained on the platform 3 times per week for the 8 weeks doing two different types of exercises. Position one was both feet on the platform, and position two was only one leg on the platform with the other in the air. Training loading on the platform was as follows:

Weeks 1-2 3 sets of 20 s (with 1 min rest, position 1), 3 sets of 20 s (with 30 s rest, position 2)

Weeks 3-4 3 sets of 30 s (with 1 min rest, position 1), 3 sets of 20 s (with 30 s rest, position 2)

Weeks 5-6 3 sets of 45 s (with 45 s rest, position 1), 3 sets of 25 s (with 30 s rest, position 2)

Weeks 7-8 4 sets of 1min (with 1min rest, position 1), 4 sets of 30 s (with 30 s rest, position 2)

The vibration group showed significant improvements in the sit-and-reach test after 8 weeks, improving by 3 cm, while the control group's improvement of 1.19 cm was not significant.

Sands et al. (2006b) studied both the acute and long-term effects of VS on split flexibility. Ten young gymnasts who trained at the U.S. Olympic Training Center volunteered for the study. The 10 subjects were split into a control group and an experimental group. Subjects participated in regular warm-up activities, including calisthenic exercises, walking, jogging, light stretching, and some basic tumbling. The first measurement was taken as subjects were in a forward split position to a self-selected level of discomfort from the floor to the anterior superior iliac spine. Following this initial measurement, subjects performed forward split stretching on specially constructed vibration devices which were floor units that vibrated at a frequency of 30 Hz and an amplitude of 2 mm. They performed the forward split stretch in two different positions. "The first position has the athlete place his forward leg on the vibrating device such that the posterior calf area is supported by the device. The second position has the gymnast assume a lunge position with the rear thigh directly on top of the vibrating device. Subjects stretched to discomfort for 10 s, then rested for 5 s. Resting position was simply achieved by raising a few inches from the point of discomfort. By stretching each leg forward on the two devices for one minute each, there was a total of four minutes of stretching. This acute study showed impressive improvements in flexibility for both the right rear split and left rear split. A long-term experiment was conducted as the subjects performed the same stretch routine 5 days per week for 4 weeks. The long-term improvements in flexibility, after 4 weeks of intervention, were statistically significant for the right rear split, but not the left rear split.

In the flexibility studies just reviewed, one used seated vibration in place of stretching and found both to be equally effective in improving mobility of the hip flexors (Atha and Wheatley 1976b), two studies used sessions of standing on a WBV platform but no stretching to show improvements in flexibility (as measured by a sit-and-reach test) (Cochrane and Stannard 2005b; Fagnani et al. 2006a), one study used a session of standing on a WBV platform before stretching to show more improvement in hamstring flexibility than stretching alone (van den Tillaar 2006a), one used a vibrating cable during body flexion, static stretching and ballistic stretching to show improved flexibility (as measured by side splits) (Issurin et al. 1994b), and one study used a vibrating module placed under the leg being stretched to show improved flexibility (as measured by front splits) (Sands et al. 2006b). These studies show improved flexibility due to various means of vibration but fail to investigate the effects of performing a stretching protocol during WBV on a platform.

Conclusion

As shown here, there has been an abundance of research on different effects of WBV as well as locally applied vibration. Thirteen of the studies reviewed used some variation of a vibrating seat to produce WBV. For the most part, research has since moved toward the use of vibration platforms when studying WBV. Though all platforms used are similar, there are many different types of vibration platforms. Of the studies reviewed, 14 used a Galileo, 9 used a Power Plate, 6 used some model of Nemes, and each of the following were used in one reviewed study: Unidyne electrohydraulic vibrator (Oborne et al. 1981), Smith machine (Rønnestad 2004), Novotec (Rittweger et al. 2000b), Fitwave (Cardinale et al. 2007), and Zeptor-Med (Schuhfried et al., 2006).

Also, vibration studies which looked at WBV's effect on flexibility have not had the subjects perform a standard stretching protocol on the vibration platform. Studies to this point have either had subjects perform stretches off the platform and then stand, usually in a squatting position on the platform during WBV or locally applied vibration to the body part being stretched. Thus, more research is needed to determine the effects of stretching during vibration on a WBV platform and its effects on flexibility.

Chapter 3

Methods

Research Design

This study will be a 4x4 study with the number of post-intervention measurements varying for each subject depending on the number of post measurements needed to monitor retention. Subjects will be assigned to one of four groups: (C) a control group, (1) a group which does static stretching independent of, but immediately following WBV (26 Hz, 4mm), (2) a group which does a bout of WBV without stretching and then static stretching during WBV (26 Hz, 4mm), (3) and a group which does static stretching simultaneously with WBV (26 Hz, 4mm). The independent variables will be group and time. The dependent variable will be hamstring flexibility.

Subjects

At least 40-60 subjects (male and/or female) will complete this study. Subjects will be between the ages of 18-30 years of age. All subjects will be current students at the university. To qualify for the study subjects will have to exhibit "tight" hamstrings and not be currently involved in a flexibility program. For purposes of this study, "tight" hamstrings will be defined as the inability to touch the tops of their feet from a standing position with the legs straight and 70^0 or less on a straight-leg-raise test. This study will be approved by the human subjects review committee at Brigham Young University and all qualified subjects will sign an approved informed consent form.

Instruments

1. Galileo 2000 (Orthometrix, White Plains, NY). This is a whole body vibration device with a reciprocating/alternating vibration plate. The plate has a center fulcrum which, when vibrating, alternates which leg is going up and which leg is down.
2. MIE Inclinometer (Medical Research, UK) This device will be used for measuring passive knee extension ROM which, for purposes of this study will be representative of hamstring flexibility.

Procedures

All subjects who qualify for the study will report to the lab in the Human Performance Research Center in shorts and will be measured for baseline hamstring flexibility on both legs using a passive knee extension test (LPKE) as described below in the measurements section. Subjects will then report to another room and pick a number from a hat to be randomly assigned to a group. There will be 4 groups, as previously described.

All subjects will be required to report to the lab 5 days/wk for 3 weeks for the stretching protocol. Subjects in Groups 1, 2, and 3 will perform 5 repeated static stretches, 30 seconds each on the vibration platform (Galileo 2000, Orthometrix, White Plains, NY). Subjects in all treatment groups will stand on the vibration platform with feet at hip width apart.

Group 1 will do the following: stand on the WBV platform at approximately 10-20° knee flexion (semi-squat) with hands on the handrail. They will then do 5 30-second bouts of vibration at 26 Hz and 4 mm with 30 sec of rest between vibration bouts. After the 5th 30-second bout they will wait 3 minutes and then do 5 30-second bouts of static stretching on the WBV platform without the platform turned on. The static stretching will be done by the subjects slightly bending the knees (10-20 degrees) and then bending at the hip, keeping the back as straight as possible, until the stretch in the hamstrings become slightly uncomfortable; they will be instructed to maintain that level of slight discomfort throughout each repetition. Subjects will be instructed to grab the support bar with their hands to support upper body weight as much as possible and to minimize the stabilizing contraction of the hamstrings.

Group 2 will follow the same protocol as Group 1 except the WBV platform will be turned on at 26 Hz and 4 mm during the bouts of static stretching. Group 3 will perform the same routine in the beginning with the bouts of semi-squat and rest, but the WBV platform will not be vibrating. They will then perform the static stretch routine one the WBV platform while the platform is vibrating, the same as Group 2. Subjects will then be instructed to All subjects in the treatment groups will perform the stretches with the vibration platform running (26 Hz and 4 mm amplitude). Subjects in Group C will report to the lab and will stand in the same semi-squat position on the WBV platform for a similar amount of time as for those in the treatment groups to finish their protocol (approximately 8 minutes). However, the WBV platform will never be turned on for any subject in Group C. Any subject, in any group, who misses 3 days during the 3-week intervention period will be dropped from the study.

After each week of stretching all subjects will be measured again for hamstring flexibility (both legs). In order to determine if retention is similar, subjects will also be measured once per week following stretching intervention and instructed not to continue daily stretching. Subjects will continue to come in to be measured once per week until they return to their baseline flexibility measurement.

Subjects will also be asked to determine their dominant leg as determined by which leg they would use to kick a ball.

Measurements

All subjects will be measured for knee extension ROM (hamstring flexibility) using the lying passive knee extension test (LPKE). All flexibility measurements will be made by a second researcher who will be blinded to group assignment. The LPKE will be performed by having the subjects lie supine on an examination table. The body will be adjusted in position on the table so that the leg being measured can be placed in 90 degrees of hip flexion and have the thigh lightly contact a cross bar that is built into the table. A mark will then be made on the lateral thigh with a permanent marker, corresponding to the position on the table. The combination of table position and cross-bar contact will help to ensure consistent positioning on the table each time measurements were made. The leg not being measured will be held firmly to the table by an assistant. Once the hip is positioned at 90 degrees, the subject will be instructed to "relax" as much as possible. The inclinometer will be placed on the tibia at the base of the tibial tuberosity for measurement. The examiner will then passively move the tibia into terminal knee extension, which is operationally defined as the point at which the subject rated the stretch to be of "mild discomfort" in the hamstrings. At this point the knee extension value will be recorded.

Statistical Analysis

Statistical Analysis (Repeated measures ANOVA): The groups will be compared across time for hamstring flexibility. Multiple comparison type I error rate adjustment will be based on the Tukey's Honest Significant Difference (HSD) criterion. The experimentwise type I error rate for the set of hypotheses associated with each response variable will be ≤ 0.05. Confidence interval width will be similarly determined based on the Tukey's student range distribution. Goodness of model fit will be evaluated by residual diagnostics and data transformations will be performed when deemed necessary.

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