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Intramuscular Temperature Responses of the Vastus Lateralis and Semitendinosus
During Squatting and Stretching With Whole Body Vibration

Joshua Allen

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Master of Science

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ABSTRACT

Intramuscular Temperature Responses of the Vastus Lateralis and Semitendinosus During Squatting and Stretching With Whole Body Vibration

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Master of Science

This study was a randomized control trial. The purpose of this study was threefold: 1) to determine if intramuscular temperature (IMt) increases in the semitendinosus (ST) are similar to the vastus lateralis (VL) during standard WBV static squatting; 2) to determine if changes in intramuscular temperature of the hamstrings is different from a standard static semi-squat when undergoing WBV in a static stretching position; and 3) to determine if shorter overall durations as is typically used for stretching protocols (i.e. 5 repetitions of 30s each), will result in IMt increases. Twelve subjects (all males), with tight hamstrings completed this study (age 23.5 ± 1.5 years; body mass 76.3 ± 17.7 kg; height 177.8 ± 15.2 cm). Subjects were randomly assigned to treatment order of three groups: semi squat vibration (SQ), vibration with static stretch (VS), and static stretch only (SS). Subjects reported to the lab 3x, each visit separated by one week to receive all treatments. Each treatment day consisted of baseline temperature measurements in the VL and ST and following each of 2 sets (5x60-second for SQ, 5x30-second for VS and SS, with 30 seconds rest in between reps). Post-hoc comparisons revealed that VL temperature increases were significantly greater from baseline than the hamstrings at all three time periods ($p < .0001$). There were no significant differences found in ST IMt when comparing 5-minutes of total WBV in the VS condition (both sets of 2.5 minute bouts) to 5-minutes of vibration in the SQ condition ($p = 1.000$), or between VS and SS after 5 minutes ($p = .9827$). Post-hoc comparisons between SS and VS conditions revealed no significant differences after 2.5 minutes ($p = 1.000$), 5 minutes ($p = .8812$), and 10-minutes post vibration ($p = .9844$) in ST or VL ($p = 1.000$, $p = .0540$, and $p = .1815$ respectively) temperature. The results of our study show that the ST does not exhibit similar increases in IMt as the VL when performing standard semi-squat WBV training. The IMts seen in the static stretch both with and without vibration seem to suggest that factors other than IMt most likely contribute to flexibility changes seen in prior WBV flexibility studies.

Keywords: [vibration, intramuscular temperature, quadriceps, hamstring]

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Introduction

In the past eight years, the effect of WBV training has been looked at extensively on numerous variables and different populations. In studies using older subjects, WBV is reported to have decreased the duration of the timed up-and-go test [1-3], decreased the overall number of falls [4], improved gait and body balance [2], increased walking velocity and stand-walk-sit time [5], and improved overall posture [6]. Positive effects of WBV training have also been reported in stroke patients [7]. On a broader scale, WBV training has been studied for various physiological and performance effects. It has been reported to increase hormone levels [8], improve jump height [9], increase flexibility [10], and is widely being utilized as an adjunctive exercise modality to normal strength training routines [11-14]. A large number of WBV training studies have been centered on the effect of vibration on muscle strength [15, 16] and performance [17-19], particularly in the lower extremities.

While there is an abundance of research on the effect of WBV on strength and performance, research on its effects on flexibility is limited. Currently, only 12 articles have been published reporting the response to vibration on flexibility [10, 18, 20-29]. All of these studies, except for one [28], reported positive changes in flexibility. Only one published study to date has looked at static stretching concurrently with WBV on a WBV platform [29]. One other study used a WBV platform, but performed stretches in between vibration bouts [21]. Four studies used a WBV platform without any stretching protocol [10, 18, 20, 25]. Other studies used locally applied vibration [24, 26, 28], or a specially constructed vibration module [23, 27, 28], or vibration through a cable [22]. Only three performed stretching while simultaneously using vibration [22, 23, 27], but not on a WBV platform. In the Feland et al [29] study, stretching with vibration was found to produce greater gains in hamstring flexibility than static

stretching alone and it was suggested that increasing muscle temperature could possibly contribute to the results observed. Increased muscle temperature as a result of increased blood flow was also theorized to be a plausible reason for increases in flexibility according to Cronin et al.[26]

Currently a few studies exist that have shown that skin and muscle blood flow increase in the vibrated appendage [30-33]. Immediately after a WBV intervention, skin blood flow was recorded to have a mean increase of 250%, and ten minutes after the intervention the increase of skin blood flow was at 200% [31]. In the popliteal artery, mean blood flow velocity increased from 6.5 to 13 cm/s as a result of vibration [30]. If blood flow rates are increasing, it is plausible to assume that intramuscular temperature is increasing. However, research on intramuscular temperature responses to WBV training is limited at the current time to two studies by Cochrane et al. [34, 35].

Cochrane et al. reported the rate of muscle temperature increase in the vastus lateralis (40mm depth) was two times greater ($0.30^{\circ}\text{C}/\text{min}$, 1.5°C increase/5min) doing dynamic squats (DS) superimposed with WBV than that achieved by cycle ergometer ($0.15^{\circ}\text{C}/\text{min}$, 0.75°C increase/5min) and hot water immersion ($0.09^{\circ}\text{C}/\text{min}$, 0.45°C increase/5min) interventions [34]. Their second study looked at the effect of dynamic squatting (DS) with and without vibration, along with static squatting (SS) both with and without vibration [35]. Over the course of the 10-minute intervention, results demonstrated that vibration induced the greatest change in temperature both in DS and SS (1.6°C DS+, 1.1°C DS-, 1.4°C SS+, 0.7°C SS-). The DS+ did not increase VL temperature significantly more than DS- and SS+. They concluded that for those doing repeated dynamic squats, muscle temperature increased by about the same amount and rate with or without WBV. However, combining static squatting with WBV "...may increase soft

tissue temperature rapidly for exercise-associated rehabilitative purposes where dynamic exercise could not be performed.”[35]

While previous studies clearly show enhancement of flexibility due to vibration [23, 27, 29], it is unknown if these changes can be attributed to intramuscular temperature increases. No studies to date have reported the measurement of muscle temperature in the hamstrings either from a standard static semi-squat training position, or as a result of stretching, both with and without vibration.

Therefore, the purpose of our study was threefold; first, to determine if intramuscular temperature increases in the hamstrings (semitendinosus) is similar to the vastus lateralis during standard static squatting with WBV; second, to determine if changes in intramuscular temperature of the hamstrings is different from a standard static semi-squat when undergoing WBV in a static stretching position; and third, to determine if intramuscular temperature increases are seen in static stretching and static stretching with vibration when using shorter time intervals (5 x 30-seconds).

Methods

Subjects

Twelve subjects (all males) completed this study (age 23.5 ± 1.5 years; body mass 76.3 ± 17.7 kg; height 177.8 ± 15.2 cm). All subjects were students at Brigham Young University. To qualify for the study, subjects had to exhibit “tight” hamstrings, be “recreationally active,” and have <1 cm subcutaneous fat superficial to the vastus lateralis (VL) and semitendinosus (ST). For purposes of this study, “tight” hamstrings were defined as the inability to touch the tops of their toes from a standing position with the legs extended. “Recreationally active” was defined

as either participating in at least one physical activity class concurrently or participating in some form of physical exercise for at least 30-min two or more times per week. Subjects who were not participating in any physical activity or participating in intercollegiate athletics were not allowed to participate. This study was approved by the human subjects review committee at Brigham Young University, and all subjects signed an institutionally approved informed consent form.

Procedures

All subjects were randomly assigned to one of six treatment orders (Latin Square design) by drawing out of a hat: Semi-squat vibration (SQ), Vibration stretch (VS), and static stretch only (SS). All subjects were required to report to the lab one day/wk for 3-weeks to receive all treatments. Treatment days were separated by one week. On the initial visit to the lab, subjects were measured for subcutaneous fat depth using Doppler ultrasound (12 MHz linear probe, GE Logiq P5, GE Healthcare) at the two test sites. Evaluation of the subcutaneous fat above the VL muscle was measured at a point in the middle of the palpable muscle belly (approximately 3-4 inches above the distal demarcation of the muscle and its insertion into the quadriceps tendon). The ST was measured on the dorsomedial aspect of the middle 1/3 of the palpable muscle belly. The site on the skin was then marked for consistent thermistor placement.

Each day subjects reported to the lab, the two insertion sites were prepped and the 26-gauge/2cm thermistors (Type MT-26/2, Physitemp Instruments Inc., New Jersey, USA) inserted. Subjects rested lying prone on the testing table, with the right leg externally rotated and slightly flexed (See Figure 1). Once thermistors were inserted in the VL and ST, baseline temperature was monitored and reached when the temperature was steady within .2°C for a 2-minute period.

Once baseline temperature was steady, it was recorded for one minute. Thermistor probes were then removed and interventions were initiated.

For the SQ intervention, subjects performed two sets of 5x60-second semi squats (40° knee flexion) during vibration on the vibration platform, with 30s of rest between bouts. To achieve consistent squatting depth, an adjustable strap, behind the subject, was set to contact the posterior thigh when the knee was flexed to 40° (See Figure 2). After the first set of 5x60-second vibrations, the subject immediately returned to the treatment table, two different thermistors were inserted into the same sites, and temperature was monitored for another 60-seconds (recordings taken every 5 seconds and the 12 measurements were averaged as “time 1”). Subjects then returned to the vibration platform to complete the second set. Following the 2nd set of 5x60-second vibrations, subjects again returned to the treatment table and thermistors were again inserted and temperature was measured for 10-minutes (analyzing and averaging the first 12 measurements as “time 2”, and the final 6 measurements as “time 3”). The thermistors were then removed and the portal sites were treated with antibiotic ointment and covered. After each use, the thermistors were immersed for 24 hours in Cidex solution to perform high level disinfection.

The WBV platform used in this study was a Gallileo 2000 (Orthometrix, White Plains, NY), which is an alternating vibration platform. Subjects in all groups stood on the vibration platform, aligning both heels on a marked position that provided a 4mm amplitude vibration.

In the VS and SS interventions, subjects performed 5 repeated 30-s static stretches on the vibration platform (2.5 min of total vibration per set), with 30s of rest between stretches. Two sets were performed (for a total of 5 min vibration for the 2 sets) and temperature measurements were done in the same manner. The stretching position used for this study was the same used in

a previous study by Feland et al.[29] The position was adapted to be able to allow for bilateral hamstring stretching and also allow the slight knee bend necessary to reduce vibration transmission and discomfort to the upper half of the body. Subjects were instructed to slightly flex the knees and flex at the hip, keeping the back as straight as possible, until the stretch in the hamstrings became slightly uncomfortable. Subjects were also instructed to hold a support bar with their hands to reduce low back stress, help with balance and to minimize stabilizing contraction of the hamstrings (See Figure 3).

All subjects in the VS group performed the stretches with the vibration platform running (26Hz and 4mm amplitude). This frequency was chosen because it had been used previously in the literature [36] and in our lab [29, 37, 38]. The vibration platform was not turned on for those in the SS group. Subjects served as their own control. All subjects reported to the lab on their scheduled dates and all were able to complete the study.

Analysis

Data were analyzed using SAS Version 9.2 (SAS Institute, Inc, Cary, NC). The model run was a mixed models analysis of covariance using the baseline temperature as a covariate blocking on subjects. The dependent variable was the change in muscle temperature. The independent variables were muscle (VL, ST), treatment (SS, SQ, VS), and time (Time 1, Time 2, and Time 3). All main effect interactions were fit and were significant. Differences between individual means were compared using Tukey post-hoc comparisons with the level of significance at .05.

Results

We found all main effects and two-way interactions to be significant ($p \leq .0001$). The three-way interaction (muscle*treat*time) was also significant ($p \leq .0001$), indicating that each treatment resulted in different temperature changes at each time period for each person. A description of the results as it relates to our three research questions follows.

- 1) Determine if intramuscular temperature increases in the ST is similar to the VL during standard static squatting with WBV.

There was a significant increase from baseline in VL temperature after the first set of 5x60-second bouts of WBV ($LSM = 1.5^{\circ}C \pm .1$, $p \leq .0001$), after the second set ($LSM = 2.3^{\circ}C \pm .1$, $p \leq .0001$), and the increase was still significant after 10 minutes post vibration ($LSM = 1.8^{\circ}C \pm .1$, $p \leq .0001$). There was also a statistically significant increase in ST temperature from baseline after the first set of 5x60-second bouts of WBV ($LSM = .59^{\circ}C \pm .1$, $p \leq .0001$), after 10 minutes ($LSM = .77^{\circ}C \pm .1$, $p \leq .0001$), and the increase was still significant after 10 minutes post vibration ($LSM = .5^{\circ}C \pm .1$, $p \leq .0001$). Post-hoc comparisons revealed that VL temperature increases were significantly greater from baseline than the ST at all three time periods (See Table 1). A significant difference was also found in VL across time (See Table 3), and only at time 2 for the ST.

- 2) Determine if changes in intramuscular temperature of the ST is different between SQ and VS, and between SQ and SS.
- 3) Determine if intramuscular temperature increases are seen in static stretching and static stretching with vibration when using shorter time intervals (5 x 30-seconds).

Squat vs. vibration in the hamstring stretching position

There were no significant differences found in ST intramuscular temperature when comparing 5-minutes of total WBV in the VS condition (completion of both sets of 2.5 minute bouts) to 5-minutes of vibration in the SQ condition ($p=1.000$), or at 10-minutes post vibration ($p=1.000$). Thus, no significant difference in hamstring temperature occurred when undergoing WBV in a standard semi-squat position compared to a static stretching position.

For the VL, a significantly greater temperature response was found in the SQ condition than the VS when comparing 5-minutes of total vibration ($p=.0041$), and at 10-minutes post vibration ($p\leq.0001$). The intramuscular temperature response of the VL was significantly less when vibrating in the hamstring stretching positions compared to the SQ condition.

Static stretching vs. vibration with static stretching

Post-hoc comparisons between SS and VS conditions for each time period revealed no significant differences after 2.5 minutes ($p=1.000$), 5 minutes ($p=.8812$), and 10-minutes post vibration ($p=.9844$) in ST temperature. Likewise, for VL, no differences existed between SS and VS conditions after 2.5 minutes ($p=1.000$), 5 minutes ($p=.0540$), and 10-minutes post vibration ($p=.1815$).

For the SS group, post-hoc comparisons of ST intramuscular temperature between 2.5 minutes and 5 minutes of static stretching ($p=.9827$) and between 5 minutes and 10 minutes post static stretching ($p=.1877$) were all insignificant.

For the VS group, post-hoc comparisons also showed no significant difference in VL intramuscular temperature between 2.5 minutes and 5 minutes of static stretching ($p=.9995$) or between 5 minutes and 10 minutes post static stretching ($p=.1046$).

Discussion

Our study is unique in that it is the first to report on intramuscular temperature of the hamstrings (ST) in both a traditional semi-squat training position and from a hamstring stretching position on a WBV platform with simultaneous vibration. Our study looked at temperature measurements in the VL and ST after 2 separate sets of vibration were performed and for 10 minutes after the cessation of treatment.

Recent studies have shown that vibration can increase blood flow and volume [30, 33, 39], and it has been suggested that this increase in blood flow would produce a concomitant increase in muscle temperature, and hence, muscle extensibility [22, 23]. Prior research has shown WBV training to improve flexibility and theorized that intramuscular temperature changes may account for the results reported [26, 29]. It was also proposed in previous research [29] that stretching during vibration may have a cumulative intensity effect, meaning that stretching with imposed vibration may result in a greater than normal level of intensity to the stretch. The addition of vibration to static stretch has been reported to increase the firing rates of both primary and secondary endings with localized vibration application [40, 41]. Since WBV appears to facilitate involuntary contraction of muscles in the lower leg, it may further increase contraction for a muscle group on stretch. If vibration facilitates more contraction to a muscle on stretch and increases blood flow, then intramuscular temperature should also increase.

In previous pilot study work in our lab, we measured intramuscular temperature of the VL after performing 2 separate 5x60-second bouts of WBV (26Hz and 4mm amplitude) in a standard semi-squat position. Based on this pilot data, we expected an average increase of approximately 1.3°C after 5 minutes of WBV and 2.0°C after 10 minutes of WBV, which was

slightly higher than those reported by Cochrane et al.[35] No prior work was found regarding hamstring intramuscular response.

Prior work from Cochrane [35], reported VL intramuscular temperature increases of 1.4°C after 10 minutes of WBV in a semi-squat position and 1.6°C after dynamic squatting with WBV at 26 Hz and 6mm amplitude. For our study we had subjects perform 2 separate 5x60-second bouts of WBV in a 40° flexed semi-squat position. Interestingly our VL temperature changes in the SQ group were significantly greater than in the VS and SS groups (See Table 5). The times and duration were chosen because they mimic similar WBV training protocols in other studies [36, 38, 42, 43]. Results from the standard semi-squat position in our study showed that VL temperature increased 1.5°C after the first set of 5x60-second vibration bouts and a total of 2.3°C after the second set of WBV bouts. Our difference in VL temperature compared to Cochrane et al. could be due to a different measurement technique and depth (we used thermistors that were 2cm in length to measure in between bouts of WBV while Cochrane used indwelling thermocouples that were reportedly 4.5cm in length), and/or time, since the SQ intervention performed 2 sets of 5x60-second bouts of vibration with 30-second rest periods rather than 10-minutes continuously.

It appears that the quadriceps attempt to dampen the majority of the vibration in the SQ condition due to the greater intramuscular temperature responses recorded. The ST did increase .6°C and .8°C respectively. However, the ST increases were not similar to those of the VL for the SQ condition (See Table 1). Another purpose of our study was to see if flexibility increases of prior WBV studies could be partially explained by hamstring intramuscular temperature increases. To do this we created two interventions similar to those by Feland et al.[29]. Interestingly, we found no differences between VL and ST temperature after performing either of

the 2 separate 5x30-second bouts of a standard static stretch (SS) without vibration (See Table 2).

The greatest temperature change in the ST from baseline after 5-minutes of total WBV was observed in the VS condition (0.7°C) at time 2 (See Table 2). However, while this was significantly different from baseline, it was not significantly different from any other time period within that condition (See Table 3). We hypothesized that WBV applied to a muscle on stretch would increase muscle activation, possibly due to an increased sensitivity of the muscle spindles during the stretch [44, 45]. We suspected that the VS condition would consequently result in the greatest temperature change in the ST, although we expected it to be similar to the increase in the VL of the SQ condition. So, even though the ST intramuscular temperature increased in the VS condition, it was not significantly different from the VL in the same condition (See Table 2), or to the same ST temperature at the same time period in the SS condition (See Table 2). Further research should evaluate electromyography (EMG) to determine if hamstring activation is affected when stretching with concurrent WBV.

The position used for the hamstring stretch in our study may have allowed for a large portion of the vibration to be transmitted up to the hips. During vibration in the VS condition and the stretch in the SS condition, subjects would slightly flex their knees (5-10°) and flex at the hip to cause a stretch in the hamstrings. In this position, the vibrations would not be dampened in the lower extremities, but would be transmitted up to the hip. By relieving the load on the quadriceps in the stretching position, the temperature increase in the VL was also much less than that found in the semi-squat position.

However, it also appears that too much knee flexion can also involve dampening through muscles higher up in the chain. In previous research by Abercromby et al [46], it was

demonstrated that during WBV, head acceleration increased when dynamic squats were performed from 31-35° of knee flexion, suggesting that the ability of the legs to dampen mechanical vibration energy was suppressed when the knee angle was greater than 30°. Damping of vibration results in mechanical energy and muscle activation [47], which is partly dependent on joint angle. By using a 40° knee flexion angle for our semi-squat group, it is possible that the ability of the quadriceps to dampen the vibrations was compromised so that more of the vibration was felt in the hip and hamstrings.

Cochrane et al. reported that when comparing the effects of 10 minutes of static squats (40°) to that of dynamic squats (55°, cadence of 50 bpm) both with and without vibration, static squats with vibration produced similar increases in VL temperature to dynamic squats with vibration [35]. Thus, eliciting a larger knee angle may not increase muscle activation of the quads as other researchers have reported [48]. In studies without use of WBV, Caterisano et al. demonstrated that there was no significant differences on EMG activity between the biceps femoris, vastus lateralis, and vastus medialis at different squatting depths [49]. Their major finding was that there was no significant change in hamstring activity according to squat depth and that the gluteus maximus was the primary muscle that became more active as squat depth increased from a partial squat (16.9%) to parallel squat (28%) to a full-depth squat (35.4%). Another study recorded only 27% MVIC from the hamstrings and 73% from the quads, concluding that the squat exercise is not optimal for training the hamstrings [50]. However, increased hamstring activity during squats has been shown to be found when performing modified single leg squats rather than a traditional (two-legged) squat [51]. Roelants et al. reported a significantly higher WBV effect on the knee extensors during single leg squats and no

difference in knee extensor activation between high and low squats [44]. They did not look at the hamstring muscles.

It appears that there is an optimal angle (30-40°) to elicit changes in intramuscular temperature of the quadriceps during a semi-squat, while also minimizing transmission to the head and other parts of the body. Future research should establish whether activation and/or intramuscular temperature of the hamstrings is different in single leg WBV training. A comparison of muscle activation at different knee joint angles while undergoing WBV would also be beneficial to establish the best static training position.

Overall, the minimal changes in ST temperature from the VS condition (0.69°C) were not significantly different than the SS condition (0.44°C). As expected, the SQ condition produced greatest temperature gains in the VL (1.53°C after 5 minutes WBV and 2.3°C after 10 minutes) when compared to the VS (0.93°C) and SS (0.47°C) after 5 minutes of WBV. The overall temperature change was significantly less in the VL in the VS and SS conditions, and was not significantly different from the ST within each group when comparing similar time periods.

Based on the results from our current study temperature increase does not appear to explain why hamstring flexibility increases were greater in the WBV stretching group in the study by Feland et al.[29]. It was initially proposed that a temperature increase (caused by vasodilation of the vibrating muscle) would result in increased cutaneous and deep vessel blood flow and muscle temperature, causing a reduction tissue viscosity and increase muscle elasticity [52], but our findings do not support this.

It is possible that other mechanisms were responsible for the flexibility changes observed with WBV. Other possible mechanisms of increasing flexibility could be a reduction of pain sensation, changes in stretch reflex sensitivity of the muscle, or possibly alterations in the

muscle-tendon unit (MTU). It was proposed that increased range of motion results mainly from reductions in the passive stiffness of the MTU and tonic reflex activity [53], which may be limiting factors in increasing muscular flexibility. Also, the reduction of pain sensation after vibration may increase the pain threshold, which could facilitate flexibility by increasing the range of motion where the pain is sensed [54]. It has also been suggested that neurophysiological adaptations to WBV might indicate a reduction in the efficacy of transmission between the Ia fibers and the alpha motor neuron [55]. Further research is needed to determine the mechanisms for the flexibility effects seen from repetitive WBV flexibility training.

Conclusion

The results of our study show that the ST does not exhibit similar increases in intramuscular temperature as the VL when performing standard semi-squat WBV training. We also cannot assume that the result of the ST would be similar to the semimembranosus. The semimembranosus is deeper, may function as more of a postural muscle, and as such may also be more slow twitch and perhaps have better blood flow, but this has yet to be investigated. Minimal increases in intramuscular temperatures in both the VL and the ST occur with standing toe-touch type static stretching with or without vibration. The intramuscular temperatures seen in the static stretch both with and without vibration seem to suggest that factors other than intramuscular temperature most likely contribute to flexibility changes seen in prior WBV flexibility studies.

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Table 1. Mean intramuscular temperature differences (\pm SE) from baseline of the vastus lateralis (VL) and semitendinosus (ST) for the SQ condition

	SQ Time 1	SQ Time 2	SQ Time 3
ST($^{\circ}$C)	$0.6 \pm 0.1^*$	$0.8 \pm 0.1^*$	$0.5 \pm 0.1^*$
VL($^{\circ}$C)	1.5 ± 0.1	2.3 ± 0.1	1.8 ± 0.1

Time 1 = after 1 set of 5x60-second WBV

Time 2= after 2 sets of 5x60-second WBV

Time 3= 10 minutes post WBV

* $p < .0001$ compared to VL at same time period

Table 2. Mean intramuscular temperature differences (\pm SE) from baseline of the vastus lateralis (VL) and semitendinosus (ST) for the Static Stretch (SS) and vibration with static stretch (VS) condition

	SS Time 1	SS Time 2	SS Time 3	VS Time 1	VS Time 2	VS Time 3
ST ($^{\circ}$ C)	0.3 \pm 0.1	0.4 \pm 0.1	0.2 \pm 0.1	0.5 \pm 0.1	0.7 \pm 0.1	0.4 \pm 0.1
VL ($^{\circ}$ C)	0.4 \pm 0.1	0.5 \pm 0.1	0.2 \pm 0.1	0.5 \pm 0.1	0.9 \pm 0.1	0.6 \pm 0.1

Time 1 = after 1 set of 5x30-second WBV

Time 2= after 2 sets of 5x30-second WBV

Time 3= 10 minutes post WBV

Table 3. Within group/between time comparisons of differences of least squares means for the (ST) and vastus lateralis (VL)

Muscle	Treat	Time	Adjusted P	Muscle	Treat	Time	Adjusted P
ST	SS	1 vs 2	0.9827	VL	SS	1 vs 2	0.9995
	SS	2 vs 3	0.1877		SS	2 vs 3	0.1046
	SS	1 vs 3	0.9741		SS	1 vs 3	0.6822
	VS	1 vs 2	0.2294		VS	1 vs 2	0.0001
	VS	2 vs 3	0.0502		VS	2 vs 3	0.0103
	VS	1 vs 3	1.0000		VS	1 vs 3	0.9897
	SQ	1 vs 2	0.6067		SQ	1 vs 2	<.0001
	SQ	2 vs 3	0.0226		SQ	2 vs 3	<.0001
	SQ	1 vs 3	0.9741		SQ	1 vs 3	0.2661

Table 4. Comparison between ST temperatures between groups after five minutes

ST Temperature at 5 Minutes							
SQ	vs	VS	p value	SQ	vs	SS	p value
0.59°C		0.69°C	1.0000	0.59°C		0.44°C	0.0041

Table 5. Comparison between VL temperatures between groups after five minutes

VL Temperature at 5 Minutes							
SQ	vs	VS	p value	SQ	vs	SS	p value
1.53°C		0.93°C	0.0041	1.53°C		0.47°C	<.0001

Figure 1. Lying position for insertion of thermistors into ST and VL.



Figure 2. Position of standard semi-squat in SQ group.



Figure 3. Position of hamstring stretch in VS and SS groups.



Intramuscular Temperature Responses of the Vastus Lateralis and Semitendinosus
During Squatting and Stretching With Whole Body Vibration

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A thesis submitted to the faculty of
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INTRODUCTION

Whole body vibration (WBV) training is a rapidly growing area of research. WBV platforms are designed such that an individual can stand with both feet on the platform, through which mechanical vibrations are transmitted. The intensity of the vibration is primarily a result of the combination of frequency (Hz) and amplitude (mm) of the vibration platform. There are three common types of WBV platforms; primarily those that produce vertical, oscillatory, and multiplanar vibrations. Studies have varied greatly in the types of platforms used and manipulation of the different variables of treatment (frequency, amplitude, duration and sets).

In the past eight years, the effect of WBV training has been looked at extensively on numerous variables and different populations. In studies using older subjects, WBV is reported to have decreased the duration of the timed up-and-go test ^{1,2}, decreased the overall number of falls ³, improved gait and body balance ², increased walking velocity and stand-walk-sit time ⁴, and improved overall posture ⁵. Positive effects of WBV training have also been reported in stroke patients ⁶. On a broader scale, WBV training has been studied for various physiological and performance effects. It has been reported to increase hormone levels ⁷, improve jump height ⁸, increase flexibility ⁹, and is widely being utilized as an adjunctive exercise modality to normal strength training routines ¹⁰⁻¹³.

A large number of WBV training studies have centered on the effect of vibration on muscle strength ^{14,15} and performance ¹⁶⁻¹⁸, particularly in the lower extremities. Four studies that have looked at squats with WBV found enhanced neuromuscular excitability due to WBV ¹⁹, increased specific VO₂ with squatting ²⁰, and an increased activation of leg muscles with WBV

While there is an abundance of research on the effect of WBV on strength and performance, research on its effects on flexibility is limited. To date only 12 articles have been published reporting flexibility measurement in response to vibration^{9,17,22-31}. All of these studies, except for one³⁰, reported positive changes in flexibility as a result of applied vibration, however, their methodologies have been very different. These prior studies used locally applied vibration^{26,28,30}, a specially constructed vibration module^{25,29,30}, vibration through a cable²⁴, or used a WBV platform without any stretching protocol^{9,17,22,27}, or applied the vibration stimulus in between stretching repetitions^{23,30}. Only three performed stretching while simultaneously using vibration^{24,25,29}, but not on a WBV platform. Only one published study to date has looked at static stretching concurrently with WBV on a WBV platform³¹. In the Feland et al³¹ study, stretching with vibration was found to produce greater gains in hamstring flexibility than static stretching alone and it was suggested that increasing muscle temperature could possibly contribute to the results observed. Increased muscle temperature as a result of increased blood flow was also theorized to be a plausible reason for increases in flexibility according to Cronin et al.²⁸

To date, a few studies have shown that skin and muscle blood flow increase in the vibrated appendage³²⁻³⁵. Immediately after a WBV intervention, skin blood flow was recorded (using a laser Doppler imager, Moor Instruments) to have a mean increase of 250%, and ten minutes after the intervention the increase of skin blood flow was at 200%³³. Immediately after exercise, mean blood flow velocity in the popliteal artery increased from 6.5 to 13 cm/s as a result of vibration³².

If blood flow rates are increasing, it is a plausible assumption that muscles are also warming in the process. However, studies observing intramuscular temperature increases due to

WBV are lacking, and at the time of writing this article, only two could be found^{36,37}. Cochrane et al. measured the rate of intramuscular temperature increase during acute WBV exercises. They found that due to vibration, the rate of muscle temperature increase in the vastus lateralis (40mm depth, 2mm of tip exposed) was two times greater (0.30°C/min, 1.5°C increase/5min) than that achieved by cycle ergometer (0.15°C/min, 0.75°C increase/5min) and hot water immersion (0.09°C/min, 0.45°C increase/5min) interventions. However, the effect of WBV on intramuscular temperature change was confounded because during the whole 5 minutes of vibration the subjects were performing squats. Thus, it remains unclear whether or not the faster increase in intramuscular temperature was due to vibration independently or due to the active exercise of repeated squatting. Cochrane et al. approached this weakness in a follow-up study in which they compared repeated dynamic squats to static squat position with and without vibration.³⁷ They concluded that for those doing repeated dynamic squats for 10 minutes, muscle temperature increased by about the same amount and rate with (DS+ 1.6°) or without (DS- 1.1°) WBV. The groups performing static squats (SS) demonstrated that SS+ (w/vib) caused a greater change in temperature than SS- (1.4° vs 0.7°). Combining static squatting with WBV could be advantageous to rapidly increasing soft tissue temperature prior to performing rehabilitation exercises when dynamic exercise cannot be performed.³⁷

Due to the Cochrane et al. studies, it appears that WBV does promote a quicker increase in vastus lateralis temperature with a static squat after both 5 minutes and 10 minutes of vibration. Pilot studies in our lab have also shown increases in vastus lateralis temperature following repeated 60-second bouts for a total of 5 minutes and 10 minutes. Our pilot studies have also shown that gastrocnemius muscle temperature increases, although not as much as the vastus lateralis. Thus far, no WBV studies have observed intramuscular temperature increases in

other muscle groups, including the hamstrings. As mentioned previously, it is possible that increased muscle temperature may contribute to the effectiveness of combined WBV and static stretching on hamstring flexibility. However, it is unknown if the hamstrings would exhibit similar temperature increases to the vastus lateralis in a static standing position, and whether or not a static stretch position for the hamstrings would alter the temperature response, especially considering the shorter duration of 5 repetitions for 30-seconds each (2.5 minutes of total vibration).

Therefore, the purpose of this study is threefold: 1) determine if intramuscular temperature increases in the hamstrings (semitendinosus) is similar to the vastus lateralis during standard static squatting with WBV; 2) determine if changes in intramuscular temperature of the hamstrings is different when undergoing WBV in a static stretching position; and 3) to determine if intramuscular temperature increases are seen using shorter overall durations as is typically used for stretching protocols (i.e. 5 repetitions of 30-seconds each).

Hypothesis

Null: There will be no difference in hamstring muscle temperature between static stretch only and static stretch with vibration.

Null: There will be no difference in intramuscular temperature between the vastus lateralis and the semitendinosus following WBV in a static squat position.

Null: There will be no difference in intramuscular temperature in the semitendinosus between subjects undergoing 2.5 vs 5 minutes of WBV.

Delimitations

1. The study will be performed on a college-aged population (18-30 years old).
2. The only WBV settings that will be used will be at a frequency of 26 Hz and amplitude of 4 mm on a reciprocating oscillatory platform.

Limitations

1. Subjects do not represent a random sample of the population.
2. Results may not be attributable to different age groups.
3. Potential temperature changes of the semitendinosus may be dependent on the positioning used for the hamstring stretch during WBV.

Chapter 2

Review of Literature

Introduction

In 1996, a whole body vibration device was made commercially available for use in the standing position. Whole body vibration (WBV) platforms transmit a vibratory stimulus through vertical, multidirectional or oscillatory vibrations. Since their introduction, they have been heavily marketed as an exercise and adjunctive training device for everything from home use to sports teams. The mechanical vibrations increase the gravitational load on the neuromuscular system and facilitate muscle contraction. Since whole body vibration became more available, there have been many studies looking at its effect on the body and body systems.

The following major headings will be addressed in this review of literature: whole body vibration platforms and procedure, strength and power, balance and posture, flexibility, blood flow, and temperature. Articles for this literature review date back to 1976, with an increase of WBV studies up to the present day. These articles were found via EBSCO, searching databases of SPORTDiscuss, CINAHL, and MEDLINE. Search terms used included the following: whole-body vibration, strength, flexibility, range of motion, balance, posture, vibration, blood flow, temperature, and warm-up. Only recently have there been studies that investigate the effects of whole body vibration upon intramuscular temperature. The purpose of this research is to investigate the effects of whole body vibration on intramuscular temperature of the vastus lateralis and semitendinosus muscles among healthy college-aged individuals.

Whole Body Vibration Platforms and Procedure

The positioning on a vibration platform, along with its settings, are key components to producing positive results. Abercromby et al used two different vibratory platforms (PowerPlate and Galileo 2000) to observe the variation in biodynamic responses (knee flexion angle, mechanical impedance, head acceleration) and neuromuscular responses through EMG^{38,39}. The PowerPlate (vertical vibration, VV) vibrates in a predominantly vertical direction with 4 mm amplitude, while the Galileo 2000 (rotational vibration, RV) works by tilting on a central axis to produce an oscillating vibratory stimulus.

Both platforms significantly increased neuromuscular activity of the muscles of the leg, while the extensors response (vastus lateralis) was greater during RV than VV, and the tibialis anterior was greater during VV than RV. The neuromuscular responses of the vastus lateralis, gastrocnemius, and tibialis anterior were all affected by the knee angle during the vibration stimulus, with the greatest responses seen at small knee angles³⁹.

The negative effects of whole body vibration were measured by head acceleration and an estimated vibration dose value. Head acceleration varied with knee angle, and is greater during VV than during RV at all given knee angles³⁸, with 71-189% greater transmission of mechanical energy to the upper body and head. The International Organization for Standardization (ISO) standards indicate that 10 minutes/day of WBV training is potentially harmful to the human body³⁸.

The gold standard for optimal frequency, displacement, and duration for maximizing power output (Watts) with whole body vibration is still debatable. It was found that while performing counter-movement jumps pre- and post-vibration treatment at different stimuli that

high frequencies were more effective in producing peak power when combined with high displacements, and low frequencies worked best with low displacements⁴⁰. Adams et al also concluded that 30 seconds of vibration was ideal for optimal power results⁴⁰.

After comparing the effects of different frequencies and amplitudes of whole body vibration on the WAVE (vertical vibration) platform, the results were that vertical oscillating frequencies of 35+ Hz with an amplitude of 4 mm seems to have the greatest ability to increase lower-body muscle activity (through surface EMG electrodes) during both dynamic and static contractions⁴¹. Di Giminiani and colleagues stated that an optimal vibration frequency is still undiscovered, and whole body vibration at various frequencies produce different results⁴². It is thus suggested that vibration should be individualized to the participant, in terms of frequency, duration, and intensity.

Long durations of vibration can cause negative effects upon health. When 2, 4, and 6 minutes of continuous vibration were tested upon knee extensor strength and peak torque, Stewart et al found that whole body vibration for 4 and 6 minutes decreased peak torque significantly, while 2 minutes provided positive results⁴³. Some vibration may be good, but that doesn't mean that more is better.

Strength and Power

The general idea of vibration is that it generates acceleration forces in the working muscles and causes them to lengthen, and that signal is received by the muscle spindles. Subconscious contractions of other muscle fibers will follow and therefore elicit greater muscle recruitment when using whole body vibration, causing greater force of contraction and increased

muscular performance. The effect of vibration on strength, power output, and muscle activity has been perhaps, the most commonly studied and reported area of WBV.

There have been numerous studies that have reported an increase in the strength characteristics of muscles in the leg^{11,18,44-50}. Whole body vibration training may improve muscle strength by facilitating neural control following tonic vibration reflex muscle activation⁵¹. The increase in motor unit synchronization, co-contraction of the synergist muscle, increased inhibition of the antagonist muscles, and increased ability of motor units to fire briefly at very high rates are proposed mechanisms. Issurin et al reported that an increase in explosive strength exertion attributed to vibratory stimulation was 10.4% and 10.2% for maximal and mean power in the elite group (Israeli national judo, wrestling, weightlifting, gymnastics and track and field teams), and 7.9% and 10.7% in the amateur group (participants in club and college sports)⁴⁷. Explosive strength was measured during rapid bilateral bicep curls, and mean power was computed as a product of force and velocity.

Typical benefits are less commonly seen amongst a trained population. The adaptations that occur in an older, sedentary focus group are more noticeable with WBV. Rees et al demonstrated that vibration among older individuals caused a 12.4% improvement in sit-to-stand, 3.0% faster in the 5-minute fast walk, and 8.1% stronger in knee-extension strength¹⁸. Those improvements in the elderly were also observed from participation in a normal exercise group without vibration (static squats, dynamic squats, and calf raises). Vibration training has produced similar strength gains to other fitness and resistance training programs among the youth and other untrained individuals^{46,48,52}.

In comparison, few studies have shown vibration training to be ineffective on strength gains^{53,54}. Delecluse used subjects who were sprint-trained athletes, and reported no significant changes in their start velocity, start acceleration, and sprint running velocity⁵³. Lamont also reported minimal changes when testing previously resistance trained men⁵⁴. The relative ineffectiveness demonstrated could be more a factor of the population tested (a more fit/trained population will demonstrate fewer strength gains than an untrained population).

Research does not appear to be in agreement with regard to the effect of WBV training on counter-movement jump height. Vertical jump or counter-movement jump height has been reported to improve due to whole body vibration training^{16,46,55,56}. While other studies^{8,42} state that counter-movement jump height was not affected by whole body vibration. Most studies however do report an increase in jump height following varied durations, repetitions and frequency of WBV training.

Balance and Posture

The effects of whole body vibration upon balance and postural improvements are most commonly seen among the elderly or diseased individuals. Older populations have benefited from whole body vibration by improving their timed up-and-go test, Tinetti test, gait score, body balance score, walking speed, step length, maximum standing time, and overall posture and steadiness^{1-3,5,57}.

The Tinetti test is a commonly used measurement for balance and gait. The balance portion of the test assesses 9 different maneuvers (sitting balance, arises, attempts to arise, immediate standing balance, nudged, eyes closed at max position, turning 360°, sitting down) and scores them accordingly. The gait assessment tool has the subject walk down a hallway at

first in a usual pace, then back in a rapid/safe pace while monitoring 7 different criteria (initiation of gait, step length and height, step symmetry, step continuity, path, trunk, walking stance) and scoring them based on steadiness and normal gait patterns.

In a one year study of postural control in older individuals, Bogaerts et al demonstrated that whole body vibration training was associated with a reduction of fall frequency on a moving platform when vision was disturbed³, much similar to a fitness group. Among Parkinson's patients, whole body vibration of 25 Hz with an amplitude of 7-14 mm amp (2-15 min sessions/day, 5 days/week) for three weeks resulted in an improved Tinetti balance score from 9.3 to 12.9⁴. Secondary measures of the stand-walk-sit test and walking velocity also improved among these patients.

Whole body vibration has also been used to improve the postural stability of athletes after ACL reconstruction. The improvements in postural stability in the whole body vibration training group were significantly greater than the conventional training group⁵⁸, as was the somatosensory effect on balance

In contrast, Torvinen et al found that in a younger age population (19-38 yrs), whole body vibration was safe to use in producing significant increases in jump height, there was no effect on dynamic and static body balance during the training^{16,55}. The jump height benefit diminished by the end of the 4-month intervention, and there was no change in shuttle run or balance tests from the vibration⁵⁵. In the 8-month study, when measuring for bone turnover as well as strength and balance, jump height increases were once again found, but there was no effect upon performance and balance tests as have been reported by previous experiments¹⁶.

Flexibility

Very few researchers have looked at whole body vibration specifically for flexibility. Most of the studies using whole body sinusoidal vibrations use frequencies ranging from 26 to 50 Hz, 1.25 to 10.5 mm amplitude, and accelerations of 0.5 to 17.0 m/s². While studies reporting on vibration's effect on flexibility exist, vibration parameters have varied greatly. Vibration training appears to significantly affect flexibility since it is theorized to also influence the neurophysiological mechanisms because of the high accelerations⁵¹.

To date only 12 articles have been published reporting flexibility measurement in response to vibration^{9,17,22-31}. All of these studies, except for one³⁰, reported positive changes in flexibility as a result of applied vibration, however, their methodologies have been very different. These prior studies used locally applied vibration^{26,28,30}, a specially constructed vibration module^{25,29,30}, vibration through a cable²⁴, or used a WBV platform without any stretching protocol^{9,17,22,27}, or applied the vibration stimulus in between stretching repetitions^{23,30}. Only three performed stretching while simultaneously using vibration^{24,25,29}, but not on a WBV platform.

When compared to the gold standard of static stretching, 15 minutes of low-frequency locally applied vibration (44 Hz, 0.1 mm amplitude) conducted on the thighs and lower back was found by Atha and Wheatley to have the same impact on increasing hip range of motion²⁶. Whole body vibration was also discovered to increase the range of motion in individuals who perform the training more frequently than just for 15 minutes on one day (as tested above). Van den Tillaar et al²³ reported greater increases in flexibility when a combination of contract-release and static stretch was preceded by 6x30 second bouts of static squat vibration (28 Hz and

10mm). After four weeks the average increase per group in range of motion of the hamstrings were 26.8° for whole body vibration (six repetitions of 30 second vibrations in a 90 degree squat position, at 28 Hz and 10 mm) and 12.4° for the static stretch group (three repetitions of 5 second isometric contractions on each leg, followed by 30 seconds static stretch).

Cronin et al have done numerous studies using whole body vibration in attempts to determine the proper settings for the vibration stimulus. What they deemed a proper range to elicit positive results in range of motion of the hamstrings was a frequency of 14-44 Hz, amplitude of 3-5 mm, and an acceleration of 19.3 – 49.4 m/s²²⁸. The greatest range of motion gains were attributed to a setting with a frequency of 44 Hz and amplitude of 5 mm.

Only one published study to date has looked at static stretching concurrently with WBV on a WBV platform³¹. In the Feland et al study, subjects in a static stretch group and stretch w/WBV group stretched 5 days/week for 4 weeks (5x30 stretches with 30 seconds rest). Results showed that stretching with vibration was found to produce greater gains in hamstring flexibility than static stretching alone (71.1° to 68.7°, with control at 60.7°), and that at 3 weeks post-intervention the gains from stretching with vibration were still evident (65.1°/60°/60.2°). It was suggested that increasing muscle temperature could possibly contribute to the results observed. Increased muscle temperature as a result of increased blood flow was also theorized to be a plausible reason for increases in flexibility according to Cronin et al.²⁸

Blood Flow

The use of a Doppler ultrasound to measure the changes in blood flow due to whole body vibration has recently been studied^{32,33,35}. A Doppler ultrasound uses reflected sound waves to evaluate blood as it flows through a blood vessel. During the ultrasound, a handheld transducer

is passed lightly over the skin above a blood vessel. The transducer sends and receives sound waves that bounce off solid objects, including blood cells. The movement of blood cells causes a change in pitch of the reflected sound waves (Doppler Effect). Whole body vibration exercises have been shown to increase skin and muscle blood flow in individuals³²⁻³⁵.

Kerschman-Schindl et al. reported that a nine-minute standing test on a Galileo whole body vibration platform led to alterations in the muscle blood volume of the calf and thigh³². The mean blood flow velocity in the popliteal artery (measured by a diagnostic ultrasound machine with color/power Doppler) increased from 6.5 to 13 cm/s as a result of whole body vibration³². Similar findings were demonstrated by Lythgo et al, stating that whole body vibration bouts produced a four-fold increase in mean blood cell velocity and a two-fold increase in peak blood cell velocity³⁵. Although changes in velocity do not necessarily indicate increases in blood volume, the systolic and diastolic blood pressures after exercise did not show a significant change when compared to baseline.

When measuring skin blood flow with a laser Doppler immediately after a whole body vibration intervention, it was recorded that there was a mean increase of 250%, and 10-minutes after the intervention the increase of skin blood flow was at 200%³³. Maloney-Hinds and colleagues measured skin blood flow in the dominant arm at two different frequencies (30 vs 50 Hz). During the ten minutes of vibration, it was determined that there were increases in skin blood flow within the first four minutes, and that peak skin blood flow was obtained by the fifth minute³⁴. The skin blood flow of the individuals tested remained elevated for minutes 4 through 10. The blood flow requirements of active muscles superseded the increased cutaneous vascular changes as a result of vibration.

Temperature

Only within the past two years have the effects of whole body vibration on skin and intramuscular temperature been evaluated. Much of the research has incorporated a wide spectrum of variables measured with different protocols and durations.

Skin temperature has been proven to increase from WBV. Hazell and colleagues had subjects perform 15 one minute bouts of whole body vibration, separated by one minute of rest (30 minutes total) using a WAVE platform (45 Hz, 2mm). The two conditions examined were, first a seated (passive, unloaded) condition where the subjects feet were strapped onto the vibration platform, and second was a semi-squat (static, loaded) position, both with and without whole body vibration. The leg skin temperature was assessed with a skin temperature probe at a site 2.5 cm superior to the lateral malleolus of the left ankle. They concluded that the non-whole body vibration group had no increases in leg skin temperature, but the whole body vibration group increased temperature over baseline at several points during and following exercise. Likewise, the static semi-squat position resulted in no change in temperature, while adding whole body vibration to that same exercise led to a sustained significant increase in temperature at 16 minutes (1 min on 1 min off) continuing through 30 minutes (end of exercise) up to 40 minutes (10 min post exercise)⁵⁹.

Cochrane et al compared the rate of muscle temperature increase during acute whole body vibration to that of stationary cycling and passive warm-up³⁶. The premise behind this research was that an increase in tissue temperature will lead to the enhancement of muscular performance, as proven in previous studies⁶⁰⁻⁶². After the protocol of visiting the lab on three separate occasions, and taking basal measurements, performance tests were conducted (three

vertical counter-movement jumps and five-second maximal isokinetic cycle test). After 40 minutes of rest, two groups were randomly assigned (41°C hot water bath for 17 min, or whole body vibration for 5 min) following a controlled warm-up of stationary cycling (10 minutes at 70 W). Vastus lateralis muscle temperature was measured using an 18-gauge cannula, inserted to a depth of 40 mm (leaving an exposed tip of approximately 2 mm). The mean rate of muscle temperature increase during acute whole body vibration (Galileo: 26 Hz, 6mm) was around twice that achieved by cycle ergometer (.30°C to .15°C) and three times hot water immersion interventions (.30°C to .09°C)³⁶. This study demonstrated that it is plausible that the eccentric component of acute whole body vibration is more effective in warming the muscle compared to cycling or hot water immersion.

It is unclear from this first study by Cochrane et al.³⁶ as to whether or not the faster increase in intramuscular temperature was due to vibration independently or due to the active exercise of repeated squatting. Cochrane et al. approached this weakness in a follow-up study in which they compared repeated dynamic squats to static squat position with and without vibration.³⁷ They concluded that for those doing repeated dynamic squats, muscle temperature increased by about the same amount and rate with or without WBV (1.6° to 1.1°). However, combining static squatting with WBV for 10 minutes caused a temperature increase of 1.4°, when static squatting without WBV only caused a temperature increase of 0.7°. WBV is proposed to be advantageous in rapidly increasing soft tissue temperature prior to performing rehabilitation exercises when dynamic exercise cannot be performed.³⁷

Conclusion

The use of whole body vibration as a method for training adaptations and improved body function has been on the rise in the past decade. Many studies have varied in their focus and differing effects have been observed among athletes, the elderly, and a normal population. Whole body vibration has proven to have a positive impact on muscle strength/performance, EMG activity, postural stability/balance, flexibility, increased blood flow, and most recently on increasing tissue temperatures.

According to the literature, there are many different types of whole body vibration platforms, all of which have produced significant and beneficial findings. Most research is conscious about eliminating the dangerous effects of vibration, and therefore use settings that safe for the participant while still bringing about positive results. It is assumed that a vibration platform oscillating at a frequency of 26 Hz, with an amplitude of 4-6mm is safe and capable of producing positive changes within the body.

Research is lacking in regards to the actual benefits of whole body vibration and its effect upon intramuscular temperature. It appears that the intramuscular temperature of the vastus lateralis significantly increases in a static semi-squat position³⁷. It is probable that the effects of vibration would be seen in greater magnitude among muscles closer to the platform (tibialis anterior, gastrocnemius, and other muscles of the lower leg). However, based on pilot studies performed in our lab, the gastrocnemius temperature also increases during a static semi-squat, although not as much as the vastus lateralis. It remains unknown whether or not this increasing temperature also occurs in other muscles groups (i.e. the hamstrings). Studies clearly show that

vibration can enhance the flexibility of the hamstrings, but it is also unknown as to whether or not any of these changes can be attributed to intramuscular temperature increases.

METHODS

Participants.

At least 10 qualified college-age (18-30 yrs) male subjects will complete this study. Subjects will be recruited from university classes and by word of mouth. To qualify, subjects must be 18-30 years of age, have no recent history of any lower extremity or back injury and have no known circulatory disorders or diabetes. Subjects cannot be athletes or engaged in organized or intercollegiate sports. Subjects need to be classified as “recreationally active,” which is defined as exercising 3x/week for 20-30 minutes. Additional qualifying criteria include: subjects must have tight hamstrings (defined as inability to reach toes when bending over while standing), subjects must have a subcutaneous fat thickness of 1 cm or less (as confirmed by ultrasound) over the mid portion of the medial hamstrings and vastus lateralis. This study will be approved by the University IRB and all subjects will sign an approved informed consent form before engaging in the study.

Design and Variables.

This study will be a randomized crossover design in which recruited subjects will serve as their own control. Treatment order will be blocked to minimize the order effect. This study will have the following three groups: 1; a semi-squat vibration (SSV), 2; stretch with vibration treatment (VS), and 3; a control condition in which the same stretching protocol will occur without vibration (C). All subjects in the VS group will perform stretches on the Galileo vibration platform set at a frequency of 26 Hz and an amplitude of 4 mm. This frequency was chosen because it has been used in previous research both in our laboratory³¹ and elsewhere^{63,64}.

Independent variables are treatment (vibration and control), and time (baseline, after 2.5 minutes vibration and after 5 minutes of vibration). The dependent variable is temperature as measured at three different time periods.

Instruments.

Doppler Ultrasound

To ensure qualification into the study, subcutaneous fat above the probe insertion sites in the vastus lateralis and semitendinosus will need to be less than 1 cm. Doppler ultrasound will be used to quickly measure the thickness of subcutaneous fat at these two sites on day one in the lab. Evaluation of the subcutaneous fat around the vastus lateralis muscle will be measured at a point in the middle of the palpable muscle belly of the vastus lateralis (approximately 3-4 inches above the distal demarcation of the muscle and its insertion into the quadriceps tendon). For the semitendinosus, a point on the dorsolateral aspect of the middle 1/3 of the semitendinosus will be marked (with verification of the semitendinosus via ultrasound). The transducer will be placed parallel to the muscle belly to determine the thickness of the subcutaneous fat. Once the location for the insertion of the thermistor is found, each of the two areas will be marked by a black dot with a sharpie marker. This will ensure that we test the exact same area of the muscle on ensuing test days.

Iso-Thermex/Thermistors

Intramuscular temperature will be measured by using a 2 cm long 26-gauge thermistor needle (Physitemp model TM 26/2) at a depth of 1-2cm below the skin surface. Reliability/accuracy of the thermistors will be assessed in our lab through measurement of a known temperature beaker of water.

Procedures.

Qualified subjects will be asked to report to the Human Performance Research Center lab for treatment wearing shorts on three separate days. Treatment days will be separated by one week. The first day of reporting to the lab, subjects will draw a number from a hat, which will correlate to the randomized blocking of order of treatments (SSV, VS and C). Latin square blocks will be created to ensure an equal chance of picking a given treatment order (2 sets of each of the 6 possible orders will be in the hat).

Baseline Temperature

SSV Intervention. Intramuscular baseline temperature will first be measured with subject in a side lying position on the treatment table. Under sterile conditions a 2 cm long 26-gauge thermistor needle will be inserted into the two marked insertion sites (vastus lateralis and medial hamstrings) on the right leg of each subject. The thermistors will be sterilized using clinically employed techniques at the Human Performance Research Center (gas sterilization or Cidex solution). Baseline temperature will be considered to be reached when the temperature stops decreasing and does not change more than $.2^{\circ}$ C in a 2-minute period.

Once baseline temperature is reached, the thermistors will be withdrawn and subjects will perform two sets of 5x60 second semi squats (using a manual goniometer set to approximately 40° of knee flexion with an adjustable hurdle placed under the gluteal fold) with 30-second rest periods between repetitions. Vibration will be set at 26 Hz with the foot placement on the platform set to a position in which the amplitude is 4mm. Immediately following the first five bouts of vibration, intramuscular temperature will be reassessed for 1 minute in the side lying position using two different 26-gauge 2cm thermistors. The thermistors will be withdrawn again

and the subjects will perform the second set of vibration bouts. Following the second set of vibration bouts, intramuscular temperature will again be reassessed again as before, but temperature will be followed for 10 minutes to track the rate of temperature decline.

Intramuscular thermistors will be removed and portal sites within the tissue will be treated with an alcohol swab and covered with a band-aid. Subjects will then be given a basic wound care guide with contact information should any questions arise. For each subject, a total of 6 thermistors will be used (3 measurements at each of the 2 sites).

VS Intervention. Subjects in the VS intervention will undergo a process similar to the SSV intervention except for the following changes. Subjects will perform two sets of 5x30 second hamstring stretches on a Galileo 2000 vibration platform (Orthometrix, White Plains, NY) in a hamstring stretching position with 30-second rest periods between repetitions (see figure 1).

Control intervention (C). Subjects in the control intervention will adhere to the same protocol as instituted in the VS intervention, except the vibration unit will not be turned on.

Stretching Procedure.

The stretching position used for this study has been used in previous studies in our lab³¹. It is adapted to be able to allow for bilateral hamstring stretching and also allow the slight knee flexion necessary to reduce vibration transmission and discomfort to the upper half of the body. Subjects will be instructed to slightly flex the knees and flex at the hip, keeping the back as straight as possible, until the stretch in the hamstrings became slightly uncomfortable (as indicated in figure 1). Subjects will also be instructed to grasp an adjustable support bar with their hands to support their upper body weight as much as possible and to minimize stabilizing contraction of the hamstrings. All subjects in the VS group will perform the stretches with the

vibration platform running (26 Hz and 4 mm amplitude). The vibration platform will not be turned on for those in the C group.

Data Analysis.

Statistical Analysis. The level of significance will be set at $p \leq 0.05$ for all statistical analyses.

Data will be analyzed using a repeated measure ANOVA with post-hoc tests as necessary to determine where the differences exist.

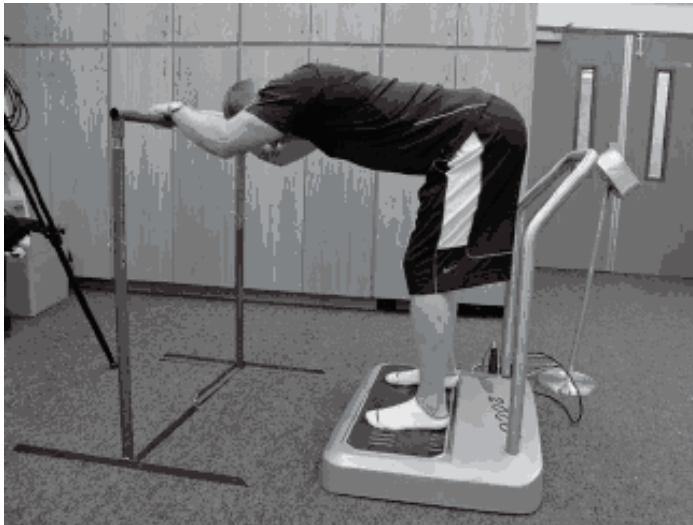


Fig. 1 Stretching position on WBV platform.

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APPENDIX A: Raw Data

Temperature Measurements in SQ Position

Subject	room	base VL	post 1 VL	post 2 VL	post 3 VL	base ST	post 1 ST	post 2 ST	post 3 ST
1 Gary	24.80	35.02	37.26	38.28	37.48	35.17	35.99	36.07	35.88
2 Michael	24.92	35.10	36.85	37.34	36.77	35.39	35.80	36.15	35.95
3 Jordan	25.35	36.15	37.21	37.66	36.78	36.14	37.12	36.96	36.21
4 Robert	24.91	35.48	37.28	38.10	37.46	36.05	36.81	36.79	36.29
5 Jacob	24.58	36.05	36.71	37.31	37.01	35.47	35.73	36.19	36.15
6 Jarom	24.03	35.30	36.68	37.58	37.04	36.25	36.47	36.90	36.71
7 Cameron	25.89	35.25	37.20	37.80	37.04	35.41	35.95	36.26	35.75
8 Matt	24.57	34.69	37.10	38.42	37.57	35.66	35.96	36.20	36.13
9 Michael	24.69	33.60	35.84	36.76	36.30	35.04	35.05	35.15	34.99
10 Jason	24.40	34.65	36.68	37.64	37.18	35.91	35.91	36.19	36.22
11 Nicholas	23.47	35.63	36.66	37.14	36.87	34.94	36.18	36.29	35.83
12 David	23.84	34.85	36.77	37.89	37.38	35.83	36.84	36.81	36.27

Temperature Measurements in VS Position

Subject	room	base VL	post 1 VL	post 2 VL	post 3 VL	base ST	post 1 ST	post 2 ST	post 3 ST
1 Gary	24.70	35.00	35.36	35.55	35.41	35.62	35.96	35.83	35.76
2 Michael	24.77	35.06	36.09	36.78	36.19	35.43	35.51	36.06	35.67
3 Jordan	24.99	35.11	35.40	36.03	35.75	36.02	36.49	36.59	36.01
4 Robert	24.71	34.82	35.83	36.17	35.68	35.60	36.03	36.10	35.97
5 Jacob	25.19	35.54	36.24	36.55	36.53	35.54	35.84	36.20	36.33
6 Jarom	24.48	36.09	36.31	36.38	36.23	36.63	36.68	36.85	36.69
7 Cameron	24.72	35.34	35.62	36.10	35.82	35.24	36.25	36.47	35.89
8 Matt	24.44	34.87	36.21	36.81	36.55	36.29	36.39	36.63	36.57
9 Michael	24.22	35.54	36.11	36.28	35.97	35.35	35.02	35.43	35.27
10 Jason	23.16	35.86	36.20	36.75	36.18	36.37	36.48	36.78	36.73
11 Nicholas	24.26	35.36	36.21	36.51	35.94	35.38	36.37	36.51	35.89
12 David	22.97	34.86	35.20	36.00	35.83	35.18	35.91	36.19	35.55

Temperature Measurements in SS Position

Subject	room	base VL	post 1 VL	post 2 VL	post 3 VL	base ST	post 1 ST	post 2 ST	post 3 ST
1 Gary	25.10	35.12	35.45	35.42	35.33	35.69	35.77	35.73	35.81
2 Michael	24.68	35.11	35.51	35.87	35.50	34.90	35.39	35.45	35.14
3 Jordan	25.09	35.47	35.99	35.91	35.67	35.96	35.84	36.10	35.59
4 Robert	26.12	35.50	36.04	35.93	35.67	35.89	36.09	35.95	35.95
5 Jacob	24.93	35.64	36.33	36.09	35.90	35.48	35.96	35.90	35.69
6 Jarom	25.27	36.33	36.58	36.80	36.66	36.35	36.13	36.60	36.50
7 Cameron	23.56	35.00	35.42	35.80	35.55	35.27	35.29	35.80	35.72
8 Matt	22.29	35.27	35.63	36.17	35.70	36.27	36.48	36.53	36.15
9 Michael	24.65	36.14	36.34	35.95	35.91	36.78	36.81	36.49	36.09
10 Jason	22.81	35.05	35.47	35.72	35.51	35.88	35.76	35.93	35.92
11 Nicholas	23.32	35.75	36.01	35.91	35.66	35.93	36.25	36.47	35.97
12 David	25.13	34.60	35.42	35.61	35.08	35.95	36.47	36.66	36.28

APPENDIX B: Pilot Data

Temperature Measures in SQ Position (2.5 min vibration bouts, 10 min total)

Subject	room	base VL	post 1 VL	post 2 VL	post 3 VL	post 4 VL	base ST	post 1 ST	post 2 ST	post 3 ST	post 4 ST
1 Gary	24.26	35.62	36.68	37.15	37.36	37.69	35.60	35.62	35.60	35.54	35.47
2 Cameron	23.85	34.90	36.27	36.75	36.96	36.91	35.23	36.05	36.40	36.71	36.79