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The effect of 30 Hz vs. 50 Hz passive vibration and duration of vibration on skin blood flow in the arm

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A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
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Summary

Background: Recently, researchers have demonstrated that Whole Body Vibration (WBV) results in significant increases in skin blood flow (SBF). No study has determined if a specific frequency or a specific duration is better at optimizing SBF.

Material/Methods: Two studies were conducted to determine, 1) if there is a difference in SBF due to passive vibration of the forearm at 30 Hz vs. 50 Hz, 2) if one frequency is superior, and 3) if there is an optimal duration. In the first study, 18 subjects (mean age 20.3±2.9 years) were randomly placed into a 30 Hz or 50 Hz vibration group, and in the second, seven subjects (mean age 23.3±3.8 years) participated in both 30 and 50 Hz vibration. Each subject's arm was passively vibrated for 10 minutes. SBF was examined during vibration and for 15 minutes of recovery.

Results: Both frequencies produced significant increases in SBF ($p<0.05$) within the first four minutes of vibration. Peak SBFs were obtained by the fifth minute. SBF remained high for minutes 4 through 10 of vibration in the second study. In the first study, SBF remained high for minutes 4 through 9. During recovery, 30 Hz vibration produced SBFs below baseline values while 50 Hz SBFs remained above baseline. Statistically one frequency was not superior to the other.

Conclusions: Five minutes of 30 Hz or 50 Hz vibration produced significant increases in SBF. Clinically, 50 Hz has additional benefits because SBF increased more rapidly and did not result in vasoconstriction during the recovery period. Future studies should be done to determine if these increases in SBF could be of benefit to populations with low circulation such as those with diabetes.

key words: **vibration • exercise • skin blood flow • cardiovascular**

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Background

A technique called Whole Body Vibration (WBV) is being used as an alternative to traditional exercise programs. WBV is a technique in which low frequency vibration is delivered to the entire body or, in some cases, just a specific part of the body. The idea is to engage in standard static or dynamic resistance exercise while being vibrated. An increasing number of studies have been published examining WBV since the initial idea of using vibration as a training mechanism came about decades ago. The majority of the studies have examined the effect of vibration on muscle [1,2], strength and power [3–5], jump height [6], sprint time [5], metabolism [7], hormonal release[8–11], and body composition[12]. Further, these studies have only examined WBV in healthy and athletic populations. There are handfuls of studies which have looked at the benefits of WBV on other populations, such as people with multiple sclerosis [13], Parkinson's [14] and in the elderly [15,16].

One of the areas regarding WBV that is lacking in research is the effect of the frequency of WBV on the peripheral vascular system. A few studies have examined blood pressure and heart rate [6,17,18]. Even fewer studies have examined the effect of WBV on skin blood flow (SBF) [19]. These studies revealed that there was an increase in SBF in the lower extremity, in response to vibration. The exact mechanism for the increased SBF due to WBV is unknown. The optimal dose (frequency and duration) for increased SBF is currently unknown as well. Both Rittweger et al. [6] and Kerschan-Schindl et al. [17] examined blood flow only at 26 Hz. In addition, both studies employed the use of exercise either with the weight of the body or the addition of weights. Rittweger et al. [6] had subject's complete weighted squats until exhaustion while the whole body was vibrated and Kerschan-Schindl et al. [17] had subjects complete a series from standing to squatting within a nine-minute time frame. To date, only one study has looked at blood flow changes due to passive WBV [19]. This study found a significant increase in SBF after 3 minutes of exposure to 30 Hz on the calf. The question arises whether or not greater blood flow increases can be achieved with a different frequency and in the upper body instead of the lower body. Additionally, would greater than 3 minutes of exposure to vibration cause greater increases in SBF? Discovering some parameters will aid in the future use of WBV as a clinical tool for populations with poor circulation. One population which may benefit would be those with diabetes. The improved circulation may help speed the healing of diabetic ulcers and prevent or slow peripheral neuropathy.

The purpose of this study was to examine the changes that occur in SBF due to 10 minutes of vibration in the upper body in young healthy subjects. Additionally, two frequencies, 30Hz and 50Hz, were examined to determine if there were any differences in SBF response.

Material and Methods

Subjects

The first study included 18 healthy volunteers, male (n=11) and female (n=7) (mean age, 20.3±2.9) and the second consisted of 7 healthy volunteers, male (n=3) and female (n=4) (mean age 23.3±3.8). (Tables 1,2) All subjects completed a questionnaire to assure they were free of cardiovascular and neurological disease, were not chronically exposed to vibration stimulus (e.g. Jackhammer, train conductor) and that the females were not pregnant. Subjects taking nitric oxide donors, calcium channel blockers, beta or alpha-blockers or antagonists were excluded from the study. All subjects had all procedures explained to them prior to participation and signed an informed consent document approved by the Loma Linda University, Institutional Review Board.

Table 1. General subject characteristics for Experiment 1 (n=18).

Age (yrs)	Height (cm)	Weight (kg)	Gender
20.3±2.9	168.9±12.2	88±15.7.6	F=7, M=11

Table 2. General subject characteristics for Experiment 2 (n=7).

Age (yrs)	Height (cm)	Weight (kg)	Gender
23.3±3.8	167.9±9.1	62.7±9.2	F=4, M=3

CR

Vibration

Vibration was delivered by commercial WBV equipment (Power Plate® Culver City, California, USA). The equipment is capable of delivering 30–50 Hz, at high (5–6 mm displacement) or low amplitude (2–3 mm displacement). For the purposes of this study, the machine was set on high amplitude (5–6 mm displacement) which provides a peak acceleration of 7 G. The highest (50 Hz) and lowest (30 Hz) available frequency on the machine were applied for a total of 10 minutes on the dominant arm. At the end of each minute, during the ten minutes of vibration, vibration was stopped for ten seconds to take a SBF measurement. These breaks were taken because the Doppler uses fiber optics which cannot accurately measure SBF during vibration. Movement in the X, Y and Z directions were verified with an accelerometer to make sure that weight location or quantity did not alter acceleration. Weights from 2.3 kg up to 91 kg were placed on the platform and acceleration was measured. The accelerometer was attached to the weights using athletic tape to secure it in place. Movement in the X, Y and Z direction remained stable for both 30 Hz (CV: X=1.7%, Y=1.1% Z=1.3%) and 50 Hz (CV: X=1.7%, Y=1.2% Z= 2.7%). To verify that location did not make a difference, weights were placed in various locations on the platform and acceleration was measured at 30 Hz (CV: X=1.8%, Y=1.5%, Z=0.6%), 50 Hz (CV: X=1.8%, Y=1.2%, Z=0.6%).

Blood flow

All blood flow measurements were taken with a laser Doppler flow meter (Biopac Systems, Golletta, CA). Before subjects arrived, the Doppler was allowed to warm for 30 minutes to insure reliable measurements. The sensor and amplifier were calibrated just before the series of experiments. Previous experiments in our lab indicated that skin blood flow was greatest at the points where the forearm made contact with the vibration platform (underside) and the areas directly opposed (top of arm). Since the amount of tissue in the arm varies from subject to subject, the underside of the forearm was chosen so that the true effect of direct vibration could be measured and not how well the vibration and its response traveled through the tissue. Measurements were taken from the underside of the forearm, about 2.54 cm distal to the elbow crease and 3.8 cm towards the ulnar from the center of the inner elbow. Marks were placed on the subjects' skin with a non-toxic marker to assure proper realignment.

Procedures

Two separate studies using different subjects were conducted. The first study utilized two different groups of subjects, one group received 30 Hz and the other group received 50 Hz. To determine if the findings from the first study were due to subject variability, a second study was conducted in which a group of new subjects received 30 or 50 Hz vibration on one day and returned on a second day to receive the other frequency.

For both studies subjects were instructed to not have eaten two hours prior to their arrival and to wear loose comfortable clothing. Subjects rested comfortably for 10 minutes to acclimatize to the temperature in the room (23–25°C). Subjects then sat in front of the vibration platform with their dominant forearm and hand placed palm down on the platform with the elbow bent at about 110°.

Experiment 1

Subjects were randomized into either the 30 Hz or 50 Hz group by the toss of a coin. The subjects were then instructed to place their arm onto the vibration platform. An initial one-minute laser Doppler flow meter measurement was taken on the underside of the forearm near the elbow. The vibration at either 30 Hz or 50 Hz lasted for 10 minutes. At the end of each minute, SBF was measured with the laser Doppler. Once vibration ended, additional SBF measurements were made continuously for 15 minutes.

Experiment 2

Subjects in this series participated in both 30 and 50 Hz vibration. Subjects came on two consecutive days at the same time of day. A coin was tossed to determine which frequency would be done on which day. The same protocol as in Experiment 1 was followed.

Data analysis

Mean baseline SBFs were determined as an average over a one-minute period. For the remaining SBF measurements, a four-second mean was taken to determine SBF at each collection point. To account for the variability in the subjects' baseline blood flows, all data was converted into a percent of baseline blood flow. An outlier was removed from the 50 Hz group for statistical analysis because the subject's SBF readings remained unusually high (550–730%) for all 15 minutes of recovery. Statistical analysis was then performed using SPSS 12.0. A Two-Way Repeated Measures ANOVA were used to determine differences in blood flow. An independent t-test was used to insure there was not a significance difference in SBFs between genders. The level of significance was $p \leq 0.05$.

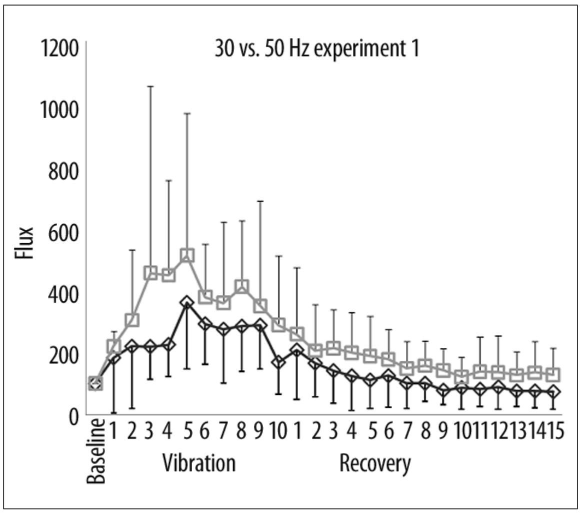

Figure 1. This figure illustrates the mean changes in skin blood flow as a percent of baseline skin blood flow, with standard deviations during baseline, 10 minutes of vibration and 15 minutes of recovery for both 30 Hz (◇)and 50 Hz (□) vibration in the first experiment.

RESULTS

Experiment 1

No significant difference was found between the SBF in the two groups (30 Hz or 50 Hz) before, during or after vibration ($p > 0.05$). Figure 1 shows that the SBF after 50 Hz was greater than that at 30 Hz; however, the variability was so great that there was no significant difference between 30 and 50 Hz. The 30 Hz and 50 Hz groups did differ in the rate at which SBF increased after the onset of vibration. At the second minute of vibration, the 50 Hz group had a mean SBF of 303%, whereas the 30 Hz group had a mean of 219%. By the third minute of vibration, the 50 Hz group blood flow was at a mean of 455% of baseline, while the 30 Hz group was at 219%.

There was a significant increase in SBF from baseline in both the 30 and 50 Hz groups by the fourth minute (30 Hz=225%, 50 Hz=447%, $p=0.03$) (See Figure 1). With the exception of the seventh minute ($p=0.06$), SBFs remained significantly high ($p < 0.05$) up until the ninth minute of vibration. The fifth minute of vibration yielded the greatest increases in flow with a mean of 360% in the 30 Hz group and a mean of 511% in the 50 Hz group. A second much smaller peak occurred around the eighth minute in the 50 Hz group and around the ninth minute in the 30 Hz group. Between minute 9 and 10 of vibration, there was a significant decrease in SBF (90%, $p=0.01$). By the seventh or eighth minute of recovery, SBF returned to baseline in the 30 Hz group. By the ninth minute of recovery in the 30 Hz group skin blood flow dropped below baseline (mean=78%) and reached its lowest point at 15 minutes after recovery (mean=74%). SBFs did not return to baseline within the fifteen minutes of recovery in the 50 Hz group. At minute 15 SBFs remained at a mean of 128%.

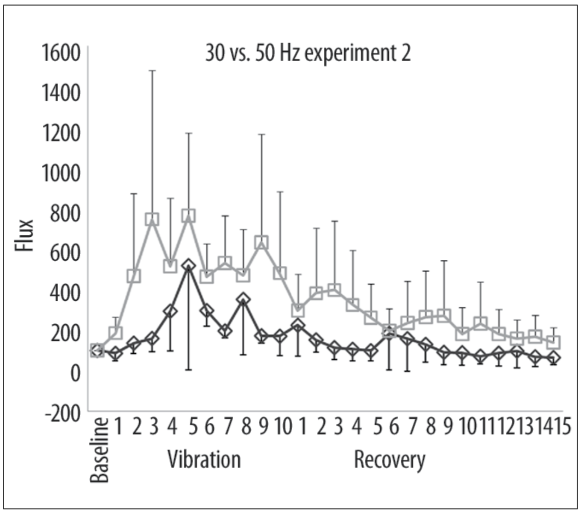

Figure 2. This figure illustrates the mean changes in skin blood flow as a percent of baseline skin blood flow, with standard deviations during baseline, 10 minutes of vibration and 15 minutes of recovery in the second experiment. Each subject was exposed to both 30 Hz (◇) and 50 Hz (□) vibration.

Experiment 2

There was a significant increase in SBF by the fourth minute of vibration in both treatment conditions (30 Hz=293%, 50 Hz=513%, p=0.002) (See Figure 2). Flows remained significantly higher throughout vibration treatment and for two minutes after. In the 50 Hz treatment, SBFs reached 746% at minute 3. SBFs reached their highest peaks after minute 5 of vibration with both the 30 Hz (517%) and 50 Hz (764%) treatments (p=0.001). With the 50 Hz treatment, there were two additional peaks at minute 3 (746%) and minute nine (634%). The 30 Hz treatment had one additional peak at minute 8 (351%). SBFs remained elevated with the 50 Hz treatment and never reached baseline (minute 15, 140%). With 30 Hz treatment, SBFs reached baseline shortly at minute 5 of recovery (99%), and then increased to 184% at minute 6. After minute 9, (91%), flows continued to drop throughout the remainder of the study. By minute 15 flows were at 65% of baseline.

Discussion

Both 30 and 50 Hz of passive vibration resulted in significant increases in SBF in the forearm. These results are similar to those found by Lohman and colleagues [19], who documented significant increases in SBF in the calf. In our study, the variability from subject to subject was so great, that statistically there was no significant difference between 30 and 50 Hz in the first or second experiment. Therefore, either frequency can be used to increase skin blood flow to the forearm. Clinically these increases would be beneficial to many populations especially those with diabetes. Over time, Type II diabetes can lead to autonomic nervous system damage which can lead to circulatory problems which can lead to ulcerations. [20]. Methods which may increase circulation may aid in wound healing in these populations.

Although the choice between 30 or 50 HZ frequency does not appear to make a difference, this study did reveal an optimal time frame for peak SBF. The greatest increases in SBF are obtained within the first 5 minutes of vibration. Significant increases in SBF were found by the fourth minute of vibration and mean peak SBFs were obtained by the fifth minute. On an individual basis, subjects' SBF peaked between minutes 3 and 5. Similarly, Lohman et al., [19] documented significant increases by the third minute. These results combined indicate that 5 minutes of vibration will produce the greatest increases in SBF for the majority of subjects. SBF remained elevated above baseline and peaked repeatedly during the 10 minutes of vibration however, SBFs never reached maximal again.

Immediately after vibration stopped there was a rapid decrease in SBF. In the 30 Hz group, SBFs were back to baseline between the seventh or ninth minute of recovery. Not only did SBFs reach baseline but they dropped below baseline indicating vasoconstriction. With 50 Hz, SBFs decreased rapidly but did not return to baseline within the monitored 15 minutes of recovery. It might take the body longer to bring flows down from a peak of 511% or 764% with 50 Hz than 360% or 517% with 30 Hz. Only one subject (First experiment, 50 Hz) did not follow this trend. Instead, his SBF remained extremely elevated for the entire duration of the study. This study cannot account for why this happened. It is possible that this was a very rare or situational occurrence, since it only happened in this one subject. It cannot be ruled out, however, that a small percentage of the population might respond to vibration in this manner.

Overall, the implications of this study are that in young healthy adults with either 30 or 50 Hz 1) SBF in the forearm increases significantly when exposed to passive vibration. 2) Significant increases in SBF are obtained within five minutes. 3) During vibration SBF can remain elevated for at least nine minutes. 4) Following exposure to vibration, blood flow remains elevated for at least seven minutes.

More studies are needed to determine the long-term effects of vibration on SBF. Vibration may end up being a much better method for increasing blood flow compared to current methods. Other methods used to increase SBF can lead to serious burns (hot packs), side effects (medications) or may be too difficult for some populations (exercise). Almost all the subjects reported enjoying the experience of vibration. Only a few found in a bit uncomfortable. The fact that SBFs can be increased within such a short time period and can remain elevated also makes vibration a very feasible, quick and cheap means of increasing SBF. Future studies should be done to determine if frequencies other than 30 or 50 Hz produce the same or better results. In this study, only one amplitude/G-Force (5–6 mm/7 G) was measured, future studies should also vary this parameter to see if greater increases in SBF can be obtained.

Conclusions

Both 30 Hz and 50 Hz vibration resulted in significant increases in SBF, which last for at least 9 minutes. 50 Hz has the advantage of increasing SBF more rapidly and remaining elevated during recovery, whereas 30 Hz results in SBF dropping below baseline levels during the recovery period.

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