Effects of whole-body vibration on blood flow and muscle oxygenation: A meta-analysis

Objective: To quantitatively examine the effects of whole-body vibration (WBV) on muscle oxygenation and peripheral blood flow in healthy adults. **Data Sources:** Web of Science and PubMed databases, and reference lists from relevant articles. **Study Selection:** Key terms were searched using single word and combination searches. Eighteen potential articles were found. Further examination yielded ten studies meeting the inclusion criteria, requiring: 1) a commercially available WBV device; 2) a human research model; 3) a pre-WBV condition and at least one WBV experimental condition; and 4) unstandardized means and standard deviations of muscle oxygenation or peripheral blood flow in the publication. **Data Extraction:** Means, standard deviations, and sample sizes were extracted from the text, tables, and figures of included studies. A total of 35 and 90 data points were extracted for the muscle oxygenation and blood flow meta-analyses, respectively. **Data Synthesis:** Data for each meta-analysis were combined and analyzed using meta-analysis software. Weighted, random effects meta-analyses using the Hedges' g metric were completed for both muscle oxygenation and blood flow. Follow-up analyses using moderator variables were then completed. Moderator variables included: vibration type, vibration time, vibration frequency, measurement location, and sample type. **Conclusion:** Acute bouts of WBV increase peripheral blood flow, but do not alter skeletal muscle oxygenation. Vibration type appears to be the most important factor influencing both muscle oxygenation and peripheral blood flow. **Key Words:** Whole-body vibration, meta-analysis, peripheral blood flow, muscle oxygenation

Word Count: 234

Introduction

The incorporation of whole-body vibration (WBV) into fitness and injury treatment programs has expanded rapidly over the past decade.[1-2] Research demonstrates that WBV can improve aspects of physical performance such as strength[3-5] and flexibility;[6-7] while evidence regarding the physiological changes associated with therapeutic WBV remains unclear.[8-12] The influence of WBV on peripheral blood flow and muscle oxygen utilization is of special interest as these measures provide insight into the metabolic changes occurring in the skeletal muscle. Blood flow and muscle oxygenation are closely related. During exercise, blood flow is increased to the exercising muscle in response to increased demands for oxygen and fuel, as well as increased carbon dioxide and hydrogen ion concentration, among other factors.[13] Peripheral blood flow changes resulting from WBV sessions could provide a possible mechanism of action for WBV treatment. Increased circulation at the site of musculoskeletal injury is often a clinical goal in the application of therapeutic modalities during the fibroblastic-repair and maturation-remodeling phases of healing.[14] Understanding tissue oxygenation is important for athletic trainers in the prevention of secondary ischemic injury following musculoskeletal injury. A lack of oxygen (ischemia) results in decreased energy availability at the cellular level (because oxygen serves as the final electron acceptor in the electron transport chain) leading to cell death and eventually necrosis.[15] Alteration of peripheral blood flow and/or muscle oxygenation is often a goal during treatment and rehabilitation of a musculoskeletal injury. If WBV is found to increase blood flow or oxygenation it could be indicated as a therapeutic intervention in cases in which the clinical goal is to increase blood flow and/or muscle oxygenation.

WBV research on muscle oxygenation and peripheral blood flow has utilized different assessments producing mixed results due to the variation in the type of vibration used, time,

frequency, amplitude, and locations measured. Near-infrared spectroscopy (NIRS) is a common tool used to examine WBV's effect on muscle oxygen utilization.[8-9, 12, 16-18] NIRS non-invasively and indirectly measures changes in oxygen saturation levels by using near-infrared light which penetrates superficial structures (i.e., skin, etc.) and is either absorbed by hemoglobin or scattered into the tissue. The amount of near-infrared light scattered and absorbed indicates levels of oxygenated hemoglobin.[19]

WBV studies of peripheral blood flow also have used NIRS,[8-9, 16] and two other methods of assessment; laser Doppler,[10, 20] and Doppler ultrasound.[21-23] Laser Doppler uses light wavelength changes to calculate the number and velocity of blood cells in the region of interest.[24] Like laser Doppler, Doppler ultrasound calculates the number and velocity of moving blood cells based on a Doppler shift. With Doppler ultrasound the Doppler shift is measured using changes in frequency of ultrasonic waves delivered to the region of interest.[25] In addition to the range of methods used to collect data, a variety of vibration parameters have been used making comparison of peripheral blood flow studies difficult.

WBV is a relatively new tool for treatment and rehabilitation of musculoskeletal injuries. However, little is understood about the mechanism of action of WBV. Research to determine if WBV alters peripheral blood flow and muscle oxygenation is conflicting, making it difficult for clinicians to make an informed decision on whether or not to implement WBV into their clinical practice. A quantitative examination of the literature is needed to assist in our understanding of this potentially important treatment modality and to determine where gaps in the research exist. This study used meta-analyses to quantitatively assess the research literature to date on the acute effects of WBV on muscle oxygenation and peripheral blood flow in healthy adults. An

improved understanding of the physiological effects of WBV with regards to blood flow and muscle oxygenation has the potential to improve patient outcomes in clinical practice.

Methods

The methodology and presentation of results used in this meta-analysis conform to the PRISMA statement, with the exception that the review protocol is not registered.[26] Web of Science and PubMed databases were searched between January 2012 and March 2012 for relevant articles. Additionally, the reference lists of relevant articles were used to locate additional articles for review. No date range was specified and searches were conducted to include all possible years of publication in each respective database. Key terms for the searches were: whole body vibration, whole-body vibration, WBV, blood flow, peripheral blood flow, oxygenation, muscle oxygenation, circulation, circulatory, near infrared spectroscopy, NIRS, and power Doppler. Searches utilized single and combined keywords. The search yielded eighteen potential studies for inclusion in the meta-analyses. Upon closer examination, eight studies did not meet the criteria for inclusion, which included: 1) employment of a commercially available WBV device; 2) use of a human research model; 3) providing a pre-WBV condition and at least one WBV experimental condition; and 4) providing unstandardized means and standard deviations of muscle oxygenation or peripheral blood flow in the publication. These inclusion criteria were chosen based on the purpose of the present meta-analysis. A total of ten studies met the inclusion criteria and were included in the analyses.

Two separate meta-analyses were completed. Studies included in the muscle oxygenation meta-analysis examined the total oxygen index and the oxy-hemoglobin levels measured by NIRS at multiple locations in the lower extremity. Both vertical and side-alternating WBV

devices were included and ranged from 2 to 6 millimeters in amplitude. Total WBV application time ranged from 30 seconds (0.5 minutes) to 300 seconds (5.0 minutes). All WBV application times were recorded from a single session of WBV which may have included a single bout of WBV exposure or multiple bouts within a single session. WBV frequencies for the muscle oxygenation data ranged from 16 Hz to 50 Hz.

Studies analyzed in the peripheral blood flow meta-analysis examined total hemoglobin levels in the lower extremity measured by NIRS, common femoral artery blood velocity assessed by color Doppler ultrasound, popliteal artery blood velocity measured with power Doppler ultrasound, and skin blood flow assessed by laser Doppler in both the upper and lower extremities. The WBV parameters present in these data included both side-alternating and vertical vibration at frequencies between 5 Hz and 50 Hz. Total exposure times for WBV ranged from 30 seconds (0.5 minutes) to 900 seconds (15.0 minutes). Peripheral blood flow data included WBV application times from a single session which could include a single bout or multiple bouts of WBV exposure during a data collection session.

Of the ten studies included in the final analyses, muscle oxygenation was measured in five studies[8-9, 16-18] and peripheral blood flow was measured in eight studies.[8-10, 16, 20-23] Three studies examined both muscle oxygenation changes and peripheral blood flow changes.[8-9, 16] In the combined studies the data was separated and included in each of the respective analyses. All studies utilized repeated measures designs, exposed participants to multiple WBV parameters, and examined one or more anatomical locations. The study variables included: vibration type, vibration exposure time, vibration frequency, vibration amplitude, sample sex composition (e.g. males or females), measurement collection method, and measurement location. Data were extracted from the text, tables, and graphs of each study, and included the pre-WBV condition

and WBV experimental condition mean, standard deviation, and sample size for each condition. Data presented in graphs were extracted using Scion Image (Version 4.0.3.2, Scion Corp., Frederick, MD, USA). All means, standard deviations, and sample sizes were recorded and organized into a custom spreadsheet (Microsoft Excel 2010, Microsoft Corp., Redmond, WA, USA). Moderator variables were extracted from each study and included: vibration type, vibration time, vibration frequency, vibration amplitude, measurement method, measurement location, and sample type. The overall muscle oxygenation and peripheral blood flow meta-analyses consisted of 35 and 90 control-treatment comparisons, respectively.

To standardize comparisons across studies, an effect size was calculated using the Hedges' *g* for both muscle oxygenation and peripheral blood flow. The Hedges' *g* metric is based on a standardized (pooled variation) difference of paired means between pre- and during and/or immediately post-WBV for each data point. The measures used in the original studies were not on the same scale making the standardized mean difference metric (Hedges' *g*) appropriate. Ninety-five percent confidence intervals (CI) were then calculated around the mean effect sizes. If the mean effect size and 95% CI fall above zero it indicates that WBV significantly increases muscle oxygenation and peripheral blood flow above the pre-WBV conditions. If the mean effect and 95% CI fall below zero, WBV significantly decreases muscle oxygenation and peripheral blood flow. If the mean effect size and 95% CI cross zero, no significant effect of WBV occurred. The studies utilized a range of measures and WBV parameters making a weighted, random effects model appropriate for the muscle oxygenation analysis and peripheral blood flow analysis. Funnel plots were completed for both analyses to check for publication bias at the outcome level. A fail-safe N was calculated for both overall analyses to assess the number of unpublished works needed to nullify the statistical significance

of the analysis. Random effects meta-regressions were conducted after the overall analyses for both muscle oxygenation and blood flow with the continuous moderating variables of vibration application time and vibration frequency.

Several sub-group meta-analyses were conducted on both sets of data. Six muscle oxygenation sub-group analyses were conducted for the data collection location moderator variable (gastrocnemius lateralis,[18] gastrocnemius medialis,[8-9, 17] rectus femoris,[16] vastus lateralis,[8, 16] upper leg [rectus femoris and vastus lateralis, combined],[8, 16] and lower leg [gastrocnemius lateralis and medialis, combined][8-9, 17-18]) and five sub-analyses for the moderator of vibration frequency (50 Hz, 40 Hz, 30 Hz, 25 Hz, and 16 Hz). The peripheral blood flow sub-group meta-analyses included two analyses for the moderator of vibration type (side-alternating and vertical); nine analyses for the moderator of vibration frequency (50 Hz, 45 Hz, 40 Hz, 30 Hz, 25 Hz, 20 Hz, 15 Hz, 10 Hz, and 5 Hz); three analyses on the moderator of measurement location (vascular tissue [e.g., femoral artery], skeletal muscles [e.g., vastus lateralis], cutaneous blood flow [e.g., skin blood flow]); and three analyses on the moderator variable of data collection method (NIRS-Total Hemoglobin (Thb), ultrasound, laser Doppler). All statistical analyses were performed with Comprehensive Meta-Analysis Software (Version 2.0, Biostat Inc., Englewood, NJ, USA). Statistical significance was set *a priori* at $\alpha \leq 0.05$ for all analyses.

Results

The data points and source study information included in both the muscle oxygenation and blood flow meta-analyses, and a summary forest plot of each study's Hedges' *g* effect size metrics and 95% confidence interval are presented in Figures 1 and 2 respectively.

Muscle Oxygenation

160 The funnel plot analysis revealed a roughly symmetrical distribution about the mean
161 effect for muscle oxygenation indicating that publication bias did not influence our results. The
162 overall mean effect of therapeutic WBV on muscle oxygenation (Figure 3) did not indicate a
163 significant mean effect of WBV over that of control values [g = -0.005; n = 35; p = 0.979; 95%
164 CI (-0.272 – 0.261)] suggesting that WBV does not alter muscle oxygenation levels. Given the
165 lack of a significant effect of therapeutic WBV on muscle oxygenation, a fail-safe N was not
166 calculated. The I^2 value of 0.80 suggests that the variance observed in the peripheral blood flow
167 meta-analysis is true variance and sub-analyses are warranted.[27] The meta-regression for the
168 effects of vibration time on muscle oxygenation revealed no clear linear relationship (Q_{model} =
169 1.138, df = 1, p = 0.286) suggesting WBV application time during an acute bout does not alter
170 WBV's effect on muscle oxygenation. Meta-regression also showed no clear effect of vibration
171 frequency on muscle oxygenation Hedges' g (Q_{model} = 0.993, df = 1, p = 0.32).

172 The sub-analyses for the data collection location moderator variable are summarized in
173 Figure 4. Measurements of muscle oxygenation taken at the gastrocnemius lateralis muscle
174 show significantly increased muscle oxygenation levels compared to pre-WBV levels [g = 4.553;
175 n = 2; p = 0.002; 95% CI (1.647 – 7.459)]. Whereas measurements taken in the gastrocnemius
176 medialis muscle indicate significantly decreased muscle oxygenation levels compared to pre-
177 WBV levels [g = -0.302; n = 15; p = 0.046; 95% CI (-0.599 - -0.005)]. Measurements of muscle
178 oxygenation at the rectus femoris [g = 0.153; n = 3; p = 0.689; 95% CI (-0.593 – 0.898)], vastus
179 lateralis [g = -0.021; n = 15; p = 0.908; 95% CI (-0.374 – 0.332)], upper leg (rectus femoris and
180 vastus lateralis) [g = 0.003; n = 18; p = 0.984; 95% CI (-0.315 – 0.322)], and lower leg
181 (gastrocnemius lateralis and gastrocnemius medialis) [g = 0.024; n = 17; p = 0.914; 95% CI (-
182 0.410 – 0.458)] all yielded non-significant effects.

The mean effects, sample sizes, and 95% confidence intervals for the moderator of vibration frequency are presented in Table 1 and Figure 5. A vibration frequency of 30 Hz significantly decreased muscle oxygenation levels compared to pre-WBV levels; while a vibration frequency of 25 Hz significantly increased muscle oxygenation levels compared to pre-WBV levels. The 30 Hz data were comprised of studies utilizing vertical vibration, while the 25 Hz data were comprised of studies utilizing side alternating vibration. Vibration frequencies of 50 Hz, 40 Hz, and 16 Hz all utilized vertical vibration and had no significant mean effect on muscle oxygenation levels.

Peripheral Blood Flow

Funnel plot analysis also showed that no publication bias existed for the peripheral blood flow dataset. Peripheral blood flow (Figure 3) was shown to be positively influenced by WBV [$g = 1.179$; $n = 90$; $p < 0.001$; 95% CI (0.945 – 1.416)]. Calculation of a fail-safe N revealed that 9718 unpublished studies with non-significant results would be required to nullify the significant mean effects. This number is sufficiently high to conclude that these results are robust and not influenced by a possible publication preference for significant results.

The I^2 value of 0.84 suggests that the variance observed in the peripheral blood flow meta-analysis is true variance and sub-analyses are warranted.[27] The meta-regression for the effects of vibration frequency on peripheral blood flow revealed a significant direct, negative linear relationship ($Q_{model} = 28.66$, $df = 1$, $p < 0.001$) suggesting that lower frequencies may lead to greater changes in peripheral blood flow compared to higher frequencies (Figure 6). A non-significant linear relationship ($Q_{model} = 0.383$, $df = 1$, $p = 0.535$) was found for the effects of

vibration time on peripheral blood flow suggesting research to date does not indicate that short or long vibration times alter peripheral blood flow differently. Analyses of the moderator vibration type indicated that vertical WBV produced no mean effect on peripheral blood flow [$g = 0.182$; $n = 35$; $p = 0.152$; 95% CI (-0.067 – 0.431)], while side-alternating vibration significantly increased peripheral blood flow [$g = 1.906$; $n = 55$; $p < 0.001$; 95% CI (1.628 – 2.184)]. These results suggest that utilizing side-alternating vibration could significantly influence peripheral blood flow while vertical vibration may not affect peripheral blood flow.

Analyses of vibration frequency moderators included: 50 Hz, 45 Hz, 40 Hz, 30 Hz, 25 Hz, 20 Hz, 15 Hz, 10 Hz, and 5 Hz. The mean effects, sample sizes, and 95% confidence intervals are summarized in Table 2 and Figure 7. The mean effects indicate vibration frequencies of 50 Hz, 30 Hz, 25 Hz, 20 Hz, 15 Hz, 10 Hz, and 5 Hz all significantly increase peripheral blood flow, while 45 Hz and 40 Hz did not have a significant mean effect. The vibration frequency of 26 Hz was included in the overall peripheral blood flow analysis, but a sub-analysis was not completed since only one data point existed at this frequency.

Follow-up analyses were completed for measurement location. A significant mean effect was revealed for measures collected from vascular structures [$g = 2.641$; $n = 17$; $p < 0.001$; 95% CI (1.691 – 3.592)] as well as measures of skin blood flow [$g = 1.48$; $n = 40$; $p < 0.001$; 95% CI (1.27 – 1.69)]. No significant effect was revealed for measures collected from skeletal muscles [$g = 0.25$; $n = 33$; $p = 0.052$; 95% CI (-0.002 – 0.51)]. These results suggest that alterations in peripheral blood flow through the implementation of WBV can be quantified both in the vascular tissues and muscular tissues.

Examining the mean effect of peripheral blood flow by data collection method found that NIRS (Thb) did not detect a significant mean effect of WBV on peripheral blood flow [$g = 0.23$; $n = 31$; $p = 0.080$; 95% CI (-0.029 – 0.506)]. While assessment by ultrasound [$g = 2.641$; $n = 17$; $p < 0.001$; 95% CI (1.691 – 3.592)] and skin blood flow measured with laser Doppler [$g = 1.436$; $n = 42$; $p < 0.001$; 95% CI (1.214 – 1.659)] did detect a significant mean of effect of WBV on increased peripheral blood flow.

Discussion

The most important result of this analysis is that vibration type may influence blood flow response. The results suggest that peripheral blood flow increases during side-alternating vibration and not during vertical vibration. Thus, vibration type may be key in the use of therapeutic WBV to influence blood flow parameters. This is important for athletic trainers as currently no commercially available device is able to switch between vertical and side-alternating vibration modes. This may be an important factor in the decision on which type of device to purchase. Very little research has directly compared side-alternating vibration to vertical vibration using commercially available devices to examine changes in peripheral blood flow.[2] A study directly comparing vertical and side-alternating WBV found that a 20 minute WBV exercise protocol of side-alternating vibration significantly increased heart rate compared to the vertical WBV and no WBV conditions.[2] This supports our finding that side-alternating may create a different or greater response than vertical vibrations. No research is available that identifies the potential mechanism of how side-alternating vibration elicits different physiological responses from vertical vibration. Future studies directly comparing vertical

248 vibration to side-alternating vibration are needed to more clearly understand how vibration type
249 influences not only peripheral blood flow but also muscle oxygenation and to understand the
250 physiologic pathway by which each type of vibration may elicit physiological changes.

251 Vibration frequencies of 50 Hz, 30 Hz, 25 Hz, 20 Hz, 15 Hz, 10 Hz, and 5 Hz all resulted
252 in significant mean effects of therapeutic WBV on peripheral blood flow, ranging from $g = 0.94$
253 (50 Hz) to $g = 4.17$ (10 Hz). This agrees with the meta-regression analysis suggesting mean
254 effect of therapeutic WBV on peripheral blood flow would be greater at lower frequencies than
255 at higher vibration frequencies. It is important to note that meta-analysis cannot examine the
256 mechanisms by which the observed changes occurred. However, by objectively measuring the
257 reported effects of WBV, meta-analysis attempts uncover the effect of an acute bout of WBV.
258 The results from both the individual sub-analyses and the meta-regression demonstrate that
259 vibration frequency influences the amount of peripheral blood flow change produced. The
260 results of the present meta-analyses suggest that lower frequencies (5-25 Hz) produce a greater
261 observed effect than higher frequencies (30-50 Hz) of WBV. This evidence suggests that lower
262 frequencies should be utilized to increase peripheral blood flow.

263 One possible explanation is that the increased blood flow may be influenced by the rate
264 of muscle contraction. Lower frequencies may provide increased time between contractions
265 allowing for greater perfusion. Higher frequencies on the other hand may not allow for this
266 perfusion, resulting in lower blood flow during WBV application. This is simply a theory as to
267 our knowledge; no study has comprehensively examined the effects of vibration frequency on
268 peripheral blood flow at skeletal muscle or in the vascular tissues (e.g. arteries). Previous
269 work{Lythgo, 2009 #20} has examined the effects vibration frequency and amplitude of blood

velocity in the femoral artery and found that lower frequencies (10-30 Hz) increased blood velocity more than higher vibration frequencies (20-30 Hz) (33% vs 27%).

Another important parameter of WBV is the participants' position and if the position is loaded or unloaded with body weight. To explore this further, additional sub-analyses (not included in the original planned sub-analyses) were completed to examine the effect of loading as it relates to vibration frequency. The peripheral blood flow data included eight studies, seven of which applied WBV in a weight bearing position. One study (Maloney-Hinds et. al.) applied WBV to a body segment at two vibration frequencies (30 Hz and 50 Hz). The supplemental sub-analyses revealed that both weight bearing (loaded) [(g = 0.84; n = 14; p = 0.002; 95% CI (0.30 – 1.38)] and body segment (unloaded) [(g = 1.37; n = 20; p < 0.001; 95% CI (1.04 – 1.70)] WBV at 30 Hz increased peripheral blood flow. Conversely, at 50 Hz we found that WBV applied in a weight bearing (loaded) position did not alter peripheral blood flow [(g = -0.15; n = 11; p = 0.25; 95% CI (-0.41 – 0.11)], but when applied in an unloaded position (body segment vibration) we found that WBV again increased peripheral blood flow [(g = 1.56; n = 20; p < 0.001; 95% CI (1.35 – 1.84)]. This suggests that loading influences peripheral blood flow responses at higher frequencies. This also supports our meta-regression data suggesting lower frequencies result in a greater peripheral blood flow response than higher frequencies. These supplemental results must be interpreted carefully because all of the segmental vibration data were from one source study and one test location (forearm) and may not hold true for different WBV parameters or vibration application sites.

Measures taken at large vascular structures (e.g. femoral artery) revealed peripheral blood flow increased after WBV (g = 2.64) when compared to pre-WBV control measures. Measures examining cutaneous blood flow (i.e., skin blood flow) also found an increase in peripheral

blood flow following WBV (g = 1.48) compared to pre-WBV control measures. On the other hand, peripheral blood flow measured from skeletal muscle was not altered after WBV compared to controls. The data suggest that vascular tissues and cutaneous blood flow demonstrates larger responses to therapeutic WBV than skeletal muscle. It is important to note that all of the measures of peripheral blood flow are recorded superficially from the skin, but the location of the measurement of the vascular tissue of interest changes. For example, measures taken from skeletal muscles examine the capillary changes within the muscle. If one considers that the blood flow through the large vessels was altered the most, one can see that this may hold promise for therapeutic WBV's use as a non-pharmacological treatment for diseases of the peripheral vasculature. Comparing human WBV models to animal models and exercise hyperemia models of blood perfusion, we see potential mechanisms by which WBV could elicit changes in peripheral blood flow. Recent WBV work[29] in a mouse model of hind limb ischemia supports our findings of increases in peripheral blood flow in the vascular tissue through vasodilation, stimulated by the endothelial nitric oxide synthase (eNOS) mechanism.[29] However, this study did not examine mice without hind limb ischemia and the mechanism by which nitric oxide creates vasodilation may be altered. Further, examination of the exercise hyperemia literature suggests that there may be a large number of potential vasodilatory agents that are released with muscle contractions including potassium,[30] adenosine,[31] and nitric oxide.[32] Contraction induced hyperemia has been shown to occur following as little as one muscle contraction.[33] While the exercise hyperemia studies support that muscle contractions increase blood flow, the frequency at which the contractions take place may not be comparable to that of what occurs during a bout of WBV. Clearly more work is needed in this area specifically examining WBV. There are likely many mechanisms (metabolic, humoral, and neuronal factors) which potentially play a role

316 in the increased blood flow observed following WBV exposure. Additional work is needed to
317 determine the mechanism of by which increased blood flow occurs during therapeutic WBV
318 exposure.

319 Vibration frequency was revealed to selectively influence muscle oxygenation levels. A
320 vibration frequency of 30 Hz decreased muscle oxygenation levels (g = -0.53) compared to
321 control levels. This finding suggests the physiologic oxygen demand is greater than the oxygen
322 supply during WBV at 30 Hz in the skeletal muscles tested. It may be that 30Hz preferentially
323 activates concentric and eccentric muscle contraction cycles compared to higher vibration
324 frequencies. Preferential stimulation of skeletal muscle by WBV is supported in recent work[34]
325 that found that vibration frequencies of 25-35 Hz preferentially activated the lateral
326 gastrocnemius muscle when measured with electromyography (EMG). In contrast, the present
327 study found that a WBV frequency of 25 Hz greatly increased muscle oxygenation levels (g =
328 4.55) compared to baseline, suggesting that the oxygen supply far exceeded demand during the
329 WBV exposure. These results are difficult to explain given the large range of scores (g = -0.53
330 to g = 4.55) after only a five Hertz frequency change. A closer investigation of the data showed
331 that the 25 Hz data consisted of only 2 data points and were from the same study. Caution is
332 needed in the interpretation of this data since it comes from a single source with a small sample
333 (N = 10). Further examination of the original source data revealed that the 30 Hz treatments
334 utilized vertical vibration, while the 25 Hz treatments utilized side-alternating vibration. This
335 may suggest that vertical vibration and side-alternating vibration affect oxygen demand and
336 delivery differently. All of the data points utilized in the muscle oxygenation meta-analysis use
337 vertical vibration with the exception of the data point using a vibration frequency of 25 Hz;
338 which used side-alternating vibration. Further examination into the role of vibration type on

muscle oxygenation is not possible at this point given the limited data available. The ability of oxygen supply to meet oxygen demand under WBV conditions could be attributed to two hypotheses: 1) therapeutic WBV does not elicit a metabolic demand in the muscle greater than what is required during rest; or 2) therapeutic WBV does elicit a metabolic demand in muscle greater than at rest, but this demand is met with increased peripheral blood flow. The second theory is supported by previous research suggesting that WBV elicits reflexive muscle contractions.[35] The muscle oxygenation data indicates that this increased demand is matched by increased supply during therapeutic WBV. Additionally, the hypothesis that WBV elicits increased metabolic demand which is adequately met is supported by our results from the peripheral blood meta-analysis. These data indicate an overall increase in peripheral blood flow during and immediately following an acute bout of therapeutic WBV.

The results from these meta-analyses suggest additional research is warranted to determine if WBV is safe and effective in pathological or injured populations. All of the studies examined in these meta-analyses utilized young, healthy participants. Populations with injury, illness, or disease may produce very different results. Recent research has examined therapeutic WBV in populations with osteoporosis[36-37] and obesity;[38-39] but little work[40] has examined WBV's effect on blood flow and oxygenation measures in special populations. It is important that research be completed on the dose response of WBV following repeated treatments and the training effects of WBV on measures of blood flow and muscle oxygenation. There is also a need for common reporting standards. Recent recommendations (e.g., common terminology, proper intervention descriptions) for the reporting of WBV intervention studies by the International Society of Musculoskeletal and Neuronal Interactions (ISMNI) begin to address

this issue;[41] however, not all studies have implemented these reporting recommendations. Comparison among studies is difficult without common reporting standards.

There are several limitations which must be considered when interpreting our results. Care must be taken in generalizing these results as we assessed studies with a large variation in the measurement tools and vibration parameters. There is also always a risk of bias at both the study and outcome level. Although we attempted to retrieve as much of the WBV literature as possible, there is a risk that we did not completely retrieve the data we identified for inclusion including studies that were not published in English and studies published in journals which were not indexed in the search engines. Finally, the meta-analysis technique is designed to uncover the true effect of a treatment by quantitatively examining the effects of individual data points. This aids in our understanding of the effects of WBV on blood flow and muscle oxygenation, but it does not aid in uncovering the mechanism by which the observed effects are occurring. Mechanistic studies need to be completed in order to understand the pathway by which WBV influences blood flow and muscle oxygenation.

Conclusions

Analysis of the literature suggests that an acute bout of therapeutic WBV increases peripheral blood flow, but does not alter muscle oxygenation levels. The vibration type and frequency influences the effects of both peripheral blood flow and muscle oxygenation during an acute bout of WBV.

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Legends to Figures

Figure 1: Forest plot and source study information for the muscle oxygenation meta-analysis.

Mean ± 95% confidence intervals.

Figure 2: Forest plot and source study information for the peripheral blood flow meta-analysis. Mean ± 95% confidence intervals.

Figure 3: Overall meta-analyses for the mean effect of therapeutic whole-body vibration on muscle oxygenation levels and peripheral blood flow. Mean ± 95% confidence intervals.

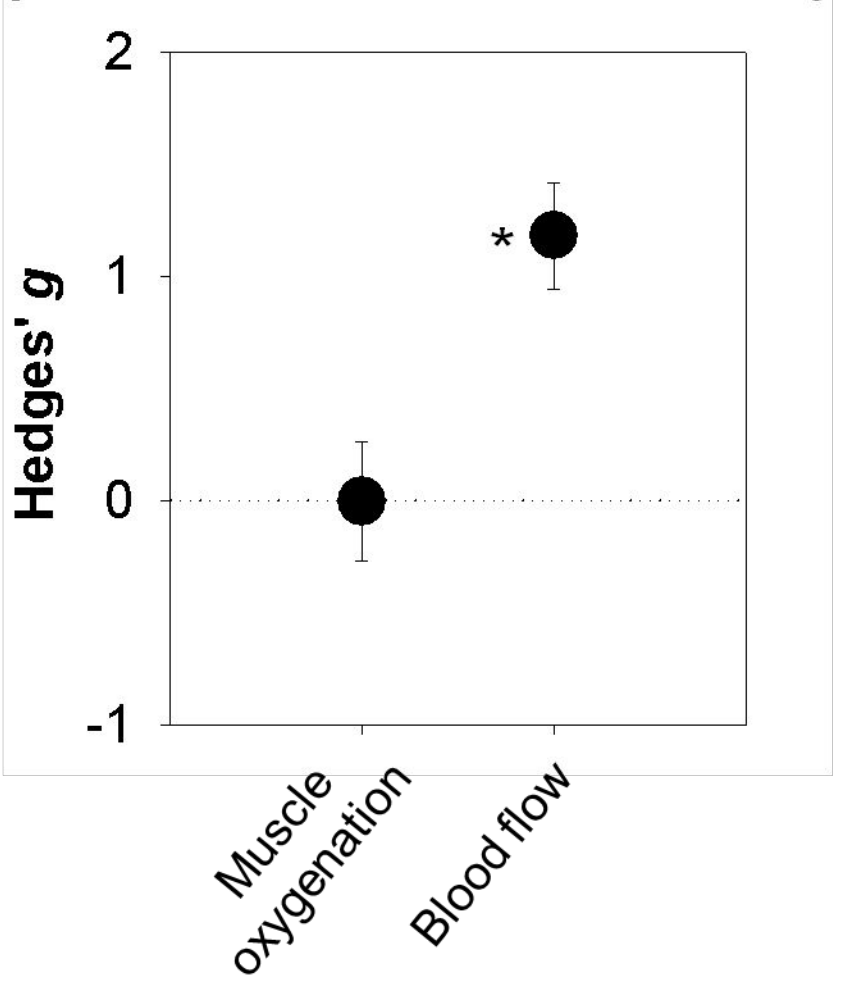
Figure 4: Summary of the mean effect of therapeutic whole-body vibration on muscle oxygenation levels based on measurement location. Mean ± 95% confidence intervals.

Figure 5: Summary of the mean effect of therapeutic whole-body vibration on muscle oxygenation levels based on vibration frequency. Hz: Hertz. Mean ± 95% confidence intervals.

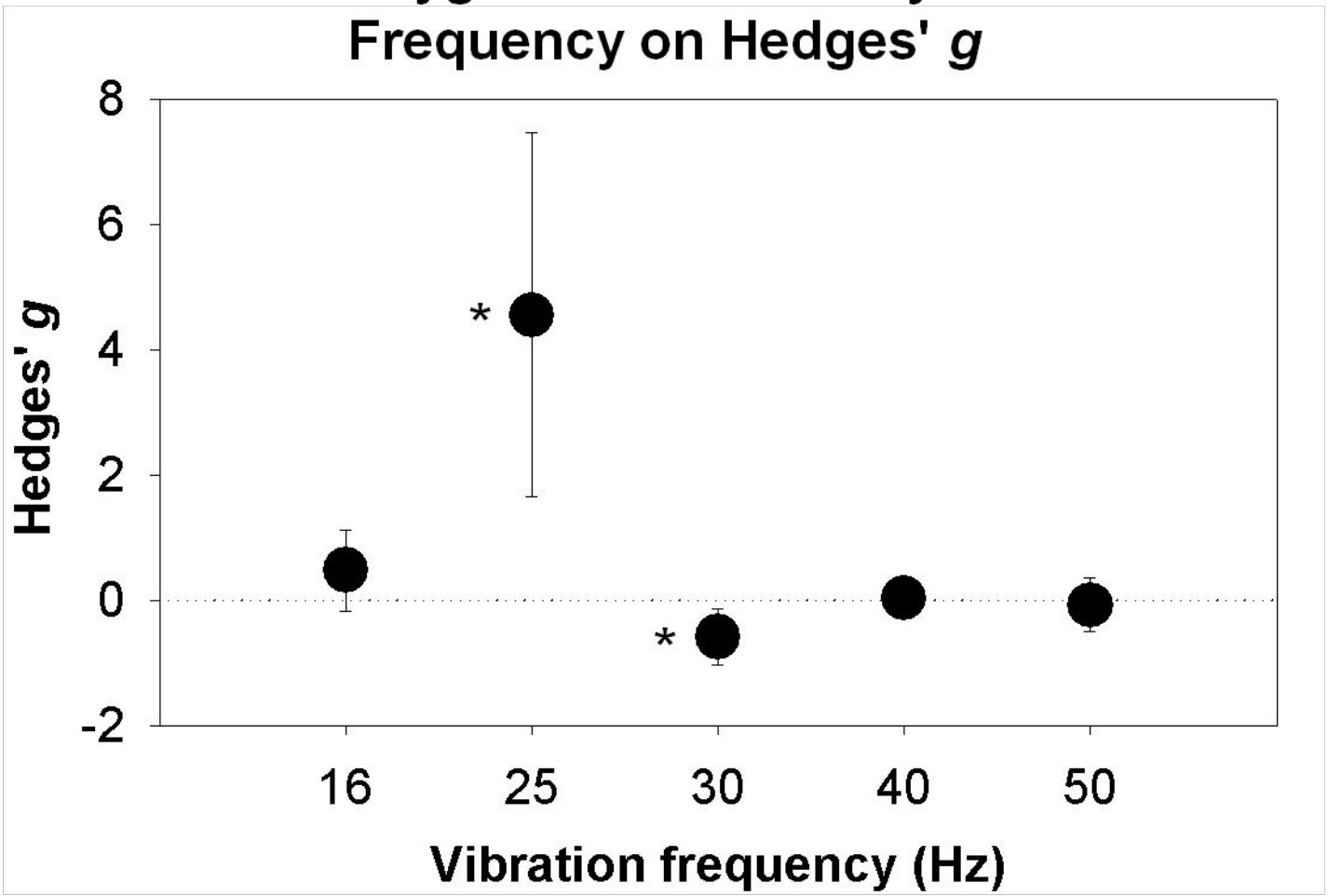
Figure 6: Meta-regression of the moderator of vibration frequency (Hertz) on the mean effect of therapeutic whole body vibration on peripheral blood flow.

Figure 7: Summary of the mean effect of therapeutic whole-body vibration on muscle oxygenation levels based on vibration frequency. Hz: Hertz. Mean ± 95% confidence intervals.

Mean Effects of Overall Muscle Oxygenation & Peripheral Blood Flow Meta-Analyses



Muscle Oxygenation Levels by Location on Hedges' *g*


Muscle Oxygenation Levels by Vibration Frequency on Hedges' g
Hedges' g
8
6
4
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16
25
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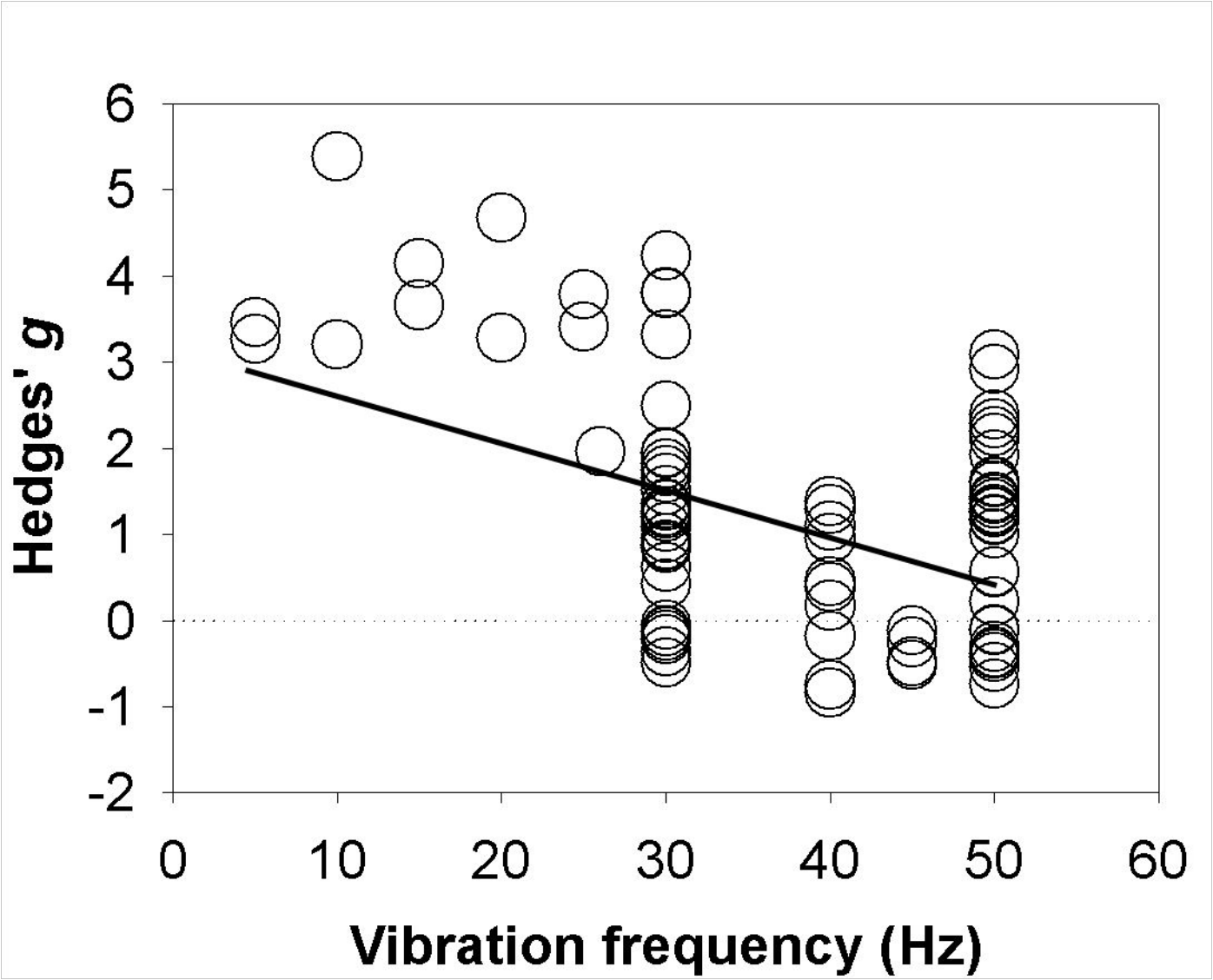
50
Vibration frequency (Hz)


Hedges' g
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3
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Vibration frequency (Hz)

Peripheral Blood Flow by Vibration Frequency on Hedges' *g*

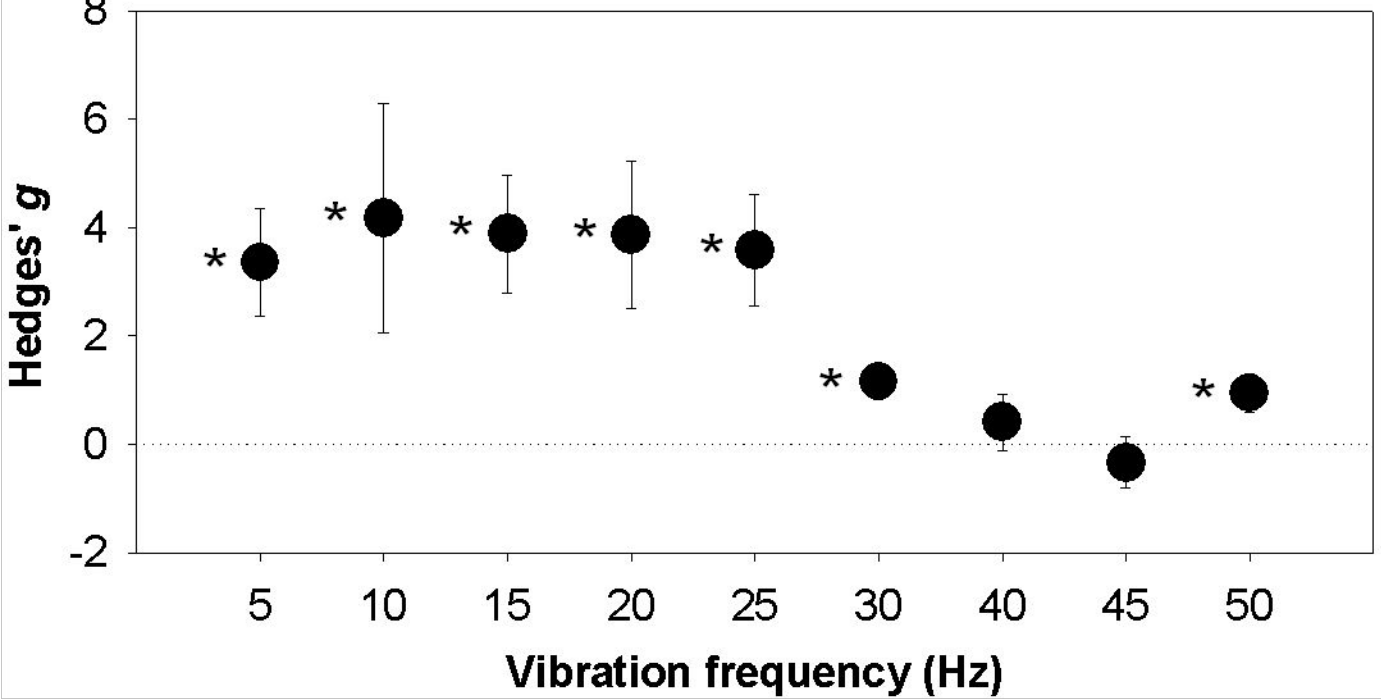

Table 1: Study information, study effect, and 95% confidence intervals for data points utilized in the muscle oxygenation meta-analysis.

Study (Numbers Represent Multiple Data Points from One Study)	Vibration Type	Vib. Time (s)	Vib. Freq. (Hz)	Vib. Mag. (mm)	Sample Type	Sample Size	Measure Utilized	Measure Location	Hedge's *g*	95% CI	
										Lower Limit	Upper Limit
Calvisi Et. Al. (1)	Vertical	110	30	N/A	Males & Females	7	NIRS (TOI)	RF	-0.595	-1.600	0.411
Calvisi Et. Al. (2)	Vertical	110	40	N/A	Males & Females	7	NIRS (TOI)	RF	0.663	-0.348	1.674
Calvisi Et. Al. (3)	Vertical	110	50	N/A	Males & Females	7	NIRS (TOI)	RF	0.389	-0.603	1.380
Calvisi Et. Al. (4)	Vertical	110	30	N/A	Males & Females	7	NIRS (TOI)	VL	-0.389	-1.380	0.603
Calvisi Et. Al. (5)	Vertical	110	40	N/A	Males & Females	7	NIRS (TOI)	VL	0.000	-0.981	0.981
Calvisi Et. Al. (6)	Vertical	110	50	N/A	Males & Females	7	NIRS (TOI)	VL	-0.889	-1.924	0.145
Cardinale, Ferrari, Quaresima (1)	Vertical	30	30	4	Males	20	NIRS (TOI)	GM	-0.353	-0.965	0.259
Cardinale, Ferrari, Quaresima (2)	Vertical	60	30	4	Males	20	NIRS (TOI)	GM	-0.502	-1.119	0.115
Cardinale, Ferrari, Quaresima (3)	Vertical	90	30	4	Males	20	NIRS (TOI)	GM	-1.010	-1.657	-0.364
Cardinale, Ferrari, Quaresima (4)	Vertical	110	30	4	Males	20	NIRS (TOI)	GM	-1.515	-2.207	-0.823
Cardinale, Ferrari, Quaresima (5)	Vertical	30	40	4	Males	20	NIRS (TOI)	GM	0.022	-0.585	0.630

Cardinale, Ferrari, Quaresima (6)	Vertical	60	40	4	Males	20	NIRS (TOI)	GM	0.374	-0.239	0.987
Cardinale, Ferrari, Quaresima (7)	Vertical	90	40	4	Males	20	NIRS (TOI)	GM	-0.162	-0.771	0.446
Cardinale, Ferrari, Quaresima (8)	Vertical	110	40	4	Males	20	NIRS (TOI)	GM	-0.359	-0.972	0.253
Cardinale, Ferrari, Quaresima (9)	Vertical	30	50	4	Males	20	NIRS (TOI)	GM	0.116	-0.492	0.724
Cardinale, Ferrari, Quaresima (10)	Vertical	60	50	4	Males	20	NIRS (TOI)	GM	-0.142	-0.750	0.466
Cardinale, Ferrari, Quaresima (11)	Vertical	90	50	4	Males	20	NIRS (TOI)	GM	-0.768	-1.399	-0.138
Cardinale, Ferrari, Quaresima (12)	Vertical	110	50	4	Males	20	NIRS (TOI)	GM	-1.154	-1.812	-0.496
Cardinale, Ferrari, Quaresima (13)	Vertical	30	30	4	Males	20	NIRS (TOI)	VL	0.650	0.026	1.274
Cardinale, Ferrari, Quaresima (14)	Vertical	60	30	4	Males	20	NIRS (TOI)	VL	0.034	-0.574	0.642
Cardinale, Ferrari, Quaresima (15)	Vertical	90	30	4	Males	20	NIRS (TOI)	VL	-0.575	-1.195	0.046
Cardinale, Ferrari, Quaresima (16)	Vertical	110	30	4	Males	20	NIRS (TOI)	VL	-1.191	-1.852	-0.530
Cardinale, Ferrari, Quaresima (17)	Vertical	30	40	4	Males	20	NIRS (TOI)	VL	0.950	0.307	1.592
Cardinale, Ferrari, Quaresima (18)	Vertical	60	40	4	Males	20	NIRS (TOI)	VL	-0.342	-0.954	0.270
Cardinale, Ferrari, Quaresima (19)	Vertical	90	40	4	Males	20	NIRS (TOI)	VL	0.000	-0.607	0.607

Cardinale, Ferrari, Quaresima (20)	Vertical	110	40	4	Males	20	NIRS (TOI)	VL	-0.475	-1.091	0.142
Cardinale, Ferrari, Quaresima (21)	Vertical	30	50	4	Males	20	NIRS (TOI)	VL	1.295	0.625	1.966
Cardinale, Ferrari, Quaresima (22)	Vertical	60	50	4	Males	20	NIRS (TOI)	VL	0.808	0.175	1.441
Cardinale, Ferrari, Quaresima (23)	Vertical	90	50	4	Males	20	NIRS (TOI)	VL	-0.327	-0.938	0.285
Cardinale, Ferrari, Quaresima (24)	Vertical	110	50	4	Males	20	NIRS (TOI)	VL	-0.149	-0.758	0.459
Coza, Nigg, Dunn (1)	Vertical	100	16	4	Males	16	NIRS (TOI-AO)	GM	0.821	0.116	1.526
Coza, Nigg, Dunn (2)	Vertical	100	16	4	Males	16	NIRS (TOI-NO)	GM	0.160	-0.516	0.837
Games, Sefton	Vertical	300	50	2	Males & Females	14	NIRS (O2Hb)	GM	-0.079	-0.799	0.640
Rittweger et. Al. (1)	Side-Alternating	30	25	6	Males	10	NIRS (TOI)	GL	6.157	4.073	8.242
Rittweger et. Al. (2)	Side-Alternating	180	25	6	Males	10	NIRS (TOI)	GL	3.183	1.888	4.478

Information provided includes: vibration type, vibration time, vibration frequency, vibration magnitude, sample type, sample size, measure utilized for data collection, measure location, Hedge's *g*, and 95% confidence interval. Vib. = vibration, Freq. = frequency, Mag. = magnitude, s = seconds, Hz = Hertz, N/A = not available, mm = millimeters, NIRS = near infrared spectroscopy, TOI = total oxygen index, AO = arterial occulusion, NO = no occlusion, O2Hb = oxy-hemoglobin, RF = rectus femoris, VL = vastus lateralis, GM = gastrocnemius medialis, GL = gastrocnemius lateralis.

Table 2: Study information, study effect, and 95% confidence intervals for data points utilized in the blood flow meta-analysis.

Study (Numbers Represent Multiple Data Points from One Study)	Vibration Type	Vib. Time (s)	Vib. Freq. (Hz)	Vib. Mag. (mm)	Sample Type	Sample Size	Measure Utilized	Measure Location	Hedge's *g*	95% CI	
										Lower Limit	Upper Limit
Calvisi Et. Al. (1)	Vertical	110	30	N/A	Males & Females	7	NIRS (Thb)	Rectus Femoris	-0.494	-1.492	0.503
Calvisi Et. Al. (2)	Vertical	110	40	N/A	Males & Females	7	NIRS (Thb)	Rectus Femoris	0.172	-0.810	1.155
Calvisi Et. Al. (3)	Vertical	110	50	N/A	Males & Females	7	NIRS (Thb)	Rectus Femoris	-0.369	-1.359	0.621
Calvisi Et. Al. (4)	Vertical	110	30	N/A	Males & Females	7	NIRS (Thb)	Vastus Lateralis	-0.359	-1.348	0.631
Calvisi Et. Al. (5)	Vertical	110	40	N/A	Males & Females	7	NIRS (Thb)	Vastus Lateralis	-0.184	-1.167	0.799
Calvisi Et. Al. (6)	Vertical	110	50	N/A	Males & Females	7	NIRS (Thb)	Vastus Lateralis	-0.114	-1.096	0.868
Cardinale, Ferrari, Quaresima (1)	Vertical	30	30	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	-0.049	-0.657	0.559
Cardinale, Ferrari, Quaresima (2)	Vertical	60	30	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	1.262	0.594	1.929
Cardinale, Ferrari, Quaresima (3)	Vertical	90	30	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	1.818	1.091	2.544
Cardinale, Ferrari, Quaresima (4)	Vertical	110	30	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	1.934	1.193	2.674
Cardinale, Ferrari, Quaresima (5)	Vertical	30	40	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	-0.751	-1.380	-0.122
Cardinale, Ferrari, Quaresima (6)	Vertical	60	40	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	-0.838	-1.473	-0.203
Cardinale, Ferrari, Quaresima (7)	Vertical	90	40	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	0.454	-0.161	1.070
Cardinale, Ferrari, Quaresima (8)	Vertical	110	40	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	0.391	-0.223	1.004
Cardinale, Ferrari, Quaresima (9)	Vertical	30	50	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	-0.426	-1.040	0.189

Cardinale, Ferrari, Quaresima (10)	Vertical	60	50	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	-0.539	-1.158	0.080
Cardinale, Ferrari, Quaresima (11)	Vertical	90	50	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	0.220	-0.390	0.829
Cardinale, Ferrari, Quaresima (12)	Vertical	110	50	4	Males	20	NIRS (Thb)	Gastrocnemius Medialis	0.562	-0.058	1.181
Cardinale, Ferrari, Quaresima (13)	Vertical	30	30	4	Males	20	NIRS (Thb)	Vastus Lateralis	-0.218	-0.827	0.391
Cardinale, Ferrari, Quaresima (14)	Vertical	60	30	4	Males	20	NIRS (Thb)	Vastus Lateralis	-0.125	-0.734	0.483
Cardinale, Ferrari, Quaresima (15)	Vertical	90	30	4	Males	20	NIRS (Thb)	Vastus Lateralis	0.428	-0.187	1.043
Cardinale, Ferrari, Quaresima (16)	Vertical	110	30	4	Males	20	NIRS (Thb)	Vastus Lateralis	0.619	-0.003	1.242
Cardinale, Ferrari, Quaresima (17)	Vertical	30	40	4	Males	20	NIRS (Thb)	Vastus Lateralis	0.958	0.315	1.600
Cardinale, Ferrari, Quaresima (18)	Vertical	60	40	4	Males	20	NIRS (Thb)	Vastus Lateralis	1.386	0.707	2.065
Cardinale, Ferrari, Quaresima (19)	Vertical	90	40	4	Males	20	NIRS (Thb)	Vastus Lateralis	1.094	0.441	1.747
Cardinale, Ferrari, Quaresima (20)	Vertical	110	40	4	Males	20	NIRS (Thb)	Vastus Lateralis	1.292	0.622	1.962
Cardinale, Ferrari, Quaresima (21)	Vertical	30	50	4	Males	20	NIRS (Thb)	Vastus Lateralis	-0.737	-1.365	-0.108
Cardinale, Ferrari, Quaresima (22)	Vertical	60	50	4	Males	20	NIRS (Thb)	Vastus Lateralis	-0.389	-1.003	0.224
Cardinale, Ferrari, Quaresima (23)	Vertical	90	50	4	Males	20	NIRS (Thb)	Vastus Lateralis	-0.306	-0.917	0.305
Cardinale, Ferrari, Quaresima (24)	Vertical	110	50	4	Males	20	NIRS (Thb)	Vastus Lateralis	-0.099	-0.707	0.508
Games, Sefton	Vertical	300	50	2	Males & Females	14	NIRS (Thb)	Gastrocnemius Medialis	0.569	-0.166	1.303
Hazell et. Al. (1)	Vertical	240	45	2	Males	8	Ultrasound (Blood Flow)	Femoral Artery	-0.116	-1.043	0.812

Hazell et. Al. (2)	Vertical	480	45	2	Males	8	Ultrasound (Blood Flow)	Femoral Artery	-0.516	-1.460	0.428
Hazell et. Al. (3)	Vertical	720	45	2	Males	8	Ultrasound (Blood Flow)	Femoral Artery	-0.477	-1.418	0.464
Hazell et. Al. (4)	Vertical	900	45	2	Males	8	Ultrasound (Blood Flow)	Femoral Artery	-0.253	-1.184	0.678
Kerschan-Schindl et. Al.	Side-Alternating	540	26	3	Males & Females	20	Doppler Ultrasound (Blood Flow)	Popiliteal Artery	1.960	1.216	2.704
Lohman et. Al. (1)	Side-Alternating	180	30	5-6	Males & Females	15	Laser Doppler (SBF)	Gastrocnemius	-0.134	-0.831	0.564
Lohman et. Al. (2)	Side-Alternating	180	30	5-6	Males & Females	15	Laser Doppler (SBF)	Gastrocnemius	1.240	0.476	2.004
Lythgo et. Al. (1)	Side-Alternating	60	5	2.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.271	1.887	4.655
Lythgo et. Al. (2)	Side-Alternating	60	10	2.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.203	1.836	4.570
Lythgo et. Al. (3)	Side-Alternating	60	15	2.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	4.148	2.532	5.763
Lythgo et. Al. (4)	Side-Alternating	60	20	2.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	4.675	2.912	6.437

Lythgo et. Al. (5)	Side-Alternating	60	25	2.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.779	2.263	5.295
Lythgo et. Al. (6)	Side-Alternating	60	30	2.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.797	2.276	5.317
Lythgo et. Al. (7)	Side-Alternating	60	5	4.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.456	2.025	4.888
Lythgo et. Al. (8)	Side-Alternating	60	10	4.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	5.380	3.415	7.346
Lythgo et. Al. (9)	Side-Alternating	60	15	4.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.661	2.176	5.145
Lythgo et. Al. (10)	Side-Alternating	60	20	4.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.279	1.893	4.665
Lythgo et. Al. (11)	Side-Alternating	60	25	4.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.408	1.989	4.827
Lythgo et. Al. (12)	Side-Alternating	60	30	4.5	Males	9	Color Doppler (Blood Velocity)	Femoral Artery	3.809	2.285	5.333
Maloney-Hinds et. Al. (1)	Side-Alternating	60	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	0.621	-0.282	1.524

Maloney-Hinds et. Al. (2)	Side-Alternating	120	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	0.835	-0.086	1.757
Maloney-Hinds et. Al. (3)	Side-Alternating	180	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.514	0.505	2.524
Maloney-Hinds et. Al. (4)	Side-Alternating	240	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.514	0.505	2.524
Maloney-Hinds et. Al. (5)	Side-Alternating	300	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.647	0.615	2.678
Maloney-Hinds et. Al. (6)	Side-Alternating	360	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.944	0.859	3.030
Maloney-Hinds et. Al. (7)	Side-Alternating	420	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.335	0.353	2.317
Maloney-Hinds et. Al. (8)	Side-Alternating	480	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.735	0.688	2.781
Maloney-Hinds et. Al. (9)	Side-Alternating	540	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.745	0.696	2.793
Maloney-Hinds et. Al. (10)	Side-Alternating	600	30	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	0.877	-0.049	1.802
Maloney-Hinds et. Al. (11)	Side-Alternating	60	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	2.917	1.620	4.215
Maloney-Hinds et. Al. (12)	Side-Alternating	120	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.267	0.295	2.240

Maloney-Hinds et. Al. (13)	Side-Alternating	180	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.606	0.581	2.630
Maloney-Hinds et. Al. (14)	Side-Alternating	240	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.555	0.539	2.571
Maloney-Hinds et. Al. (15)	Side-Alternating	300	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.250	0.280	2.220
Maloney-Hinds et. Al. (16)	Side-Alternating	360	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	2.286	1.132	3.440
Maloney-Hinds et. Al. (17)	Side-Alternating	420	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.403	0.411	2.395
Maloney-Hinds et. Al. (18)	Side-Alternating	480	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.923	0.842	3.004
Maloney-Hinds et. Al. (19)	Side-Alternating	540	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.012	0.072	1.952
Maloney-Hinds et. Al. (20)	Side-Alternating	600	50	5-6	Males & Females	9	Laser Doppler (SBF)	Forearm	1.169	0.210	2.128
Maloney-Hinds et. Al. (21)	Side-Alternating	60	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	-0.174	-1.157	0.809
Maloney-Hinds et. Al. (22)	Side-Alternating	120	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	0.869	-0.163	1.902
Maloney-Hinds et. Al. (23)	Side-Alternating	180	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.268	0.181	2.356

Maloney-Hinds et. Al. (24)	Side-Alternating	240	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.360	0.257	2.462
Maloney-Hinds et. Al. (25)	Side-Alternating	300	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.084	0.024	2.144
Maloney-Hinds et. Al. (26)	Side-Alternating	360	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	3.318	1.746	4.890
Maloney-Hinds et. Al. (27)	Side-Alternating	420	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	4.237	2.386	6.087
Maloney-Hinds et. Al. (28)	Side-Alternating	480	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.201	0.124	2.278
Maloney-Hinds et. Al. (29)	Side-Alternating	540	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	2.498	1.149	3.846
Maloney-Hinds et. Al. (30)	Side-Alternating	600	30	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	0.952	-0.090	1.994
Maloney-Hinds et. Al. (31)	Side-Alternating	60	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.357	0.255	2.459
Maloney-Hinds et. Al. (32)	Side-Alternating	120	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.161	0.090	2.232
Maloney-Hinds et. Al. (33)	Side-Alternating	180	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.167	0.096	2.239
Maloney-Hinds et. Al. (34)	Side-Alternating	240	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.613	0.465	2.762

Maloney-Hinds et. Al. (35)	Side-Alternating	300	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	2.110	0.856	3.365
Maloney-Hinds et. Al. (36)	Side-Alternating	360	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	3.083	1.578	4.588
Maloney-Hinds et. Al. (37)	Side-Alternating	420	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	2.390	1.069	3.711
Maloney-Hinds et. Al. (38)	Side-Alternating	480	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	2.192	0.919	3.466
Maloney-Hinds et. Al. (39)	Side-Alternating	540	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.292	0.201	2.383
Maloney-Hinds et. Al. (40)	Side-Alternating	600	50	5-6	Males & Females	7	Laser Doppler (SBF)	Forearm	1.434	0.319	2.550

Information provided includes: vibration type, vibration time, vibration frequency, vibration magnitude, sample type, sample size, measure utilized for data collection, measure location, Hedge's *g*, and 95% confidence interval. Vib. = vibration, Freq. = frequency, Mag. = magnitude, s = seconds, Hz = Hertz, N/A = not available, mm = millimeters, NIRS = near infrared spectroscopy, THb = total hemoglobin, SBF = skin blood flow.

Table 3: Mean effects, 95% confidence intervals, and sample sizes for the sub-analyses of the vibration frequency moderator on muscle oxygenation. Hz = Hertz, CI = confidence interval.

Vibration Frequency (Hz)	Number of Data Points Included	Hedge's *g*	95% CI	
			Lower Limit	Upper Limit
50	11	-0.074	-0.501	0.352
40	10	0.035	-0.251	0.321
30	10	-0.538	-0.941	-0.134
25	2	4.553	1.647	7.459
16	2	0.483	-0.165	1.131

Table 4: Mean effects, 95% confidence intervals, and sample sizes for the sub-analyses of the vibration frequency moderator on blood flow. Hz = Hertz, CI = confidence interval.

Vibration Frequency (Hz)	Number of Data Point Included	Hedge's *g*	95% CI	
			Lower Limit	Upper Limit
50	31	0.943	0.584	1.303
45	4	-0.338	-0.806	0.13
40	10	0.407	-0.112	0.927
30	34	1.157	0.823	1.489
25	2	3.581	2.545	4.617
20	2	3.866	2.516	5.217
15	2	3.884	2.791	4.977
10	2	4.172	2.051	6.293
5	2	3.36	2.365	4.356