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Acute effects of whole body vibration combined with blood restriction on electromyography amplitude and hormonal responses

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ABSTRACT: The purpose of this study was to investigate the effects of whole body vibration (WBV) exercise with and without blood flow restriction (BFR) on electromyography (EMG) amplitude and hormonal responses. Eight healthy male adults who lacked physical activity participated in this study and completed 10 sets of WBV and WBV + BFR sessions in a repeated measures crossover design. In the WBV + BFR session, the participants wore a BFR device inflated to 140 mmHg around the proximal region of the thigh muscles. The results indicated that the EMG values from the rectus femoris and vastus lateralis during the WBV + BFR session were significantly higher than those during the WBV session ($p < 0.05$). Two-way analysis of variance with repeated measures showed that the WBV + BFR and WBV exercise sessions induced a significant (simple main effect for time) increase in lactate (LA) (0.61–4.68 vs. 0.46–3.44 mmol/L) and growth hormone (GH) (0.48–3.85 vs. 0.47–0.82 ng/mL) responses after some of the post-exercise time points ($p < 0.05$). WBV + BFR elicited significantly higher LA and GH (simple main effect for trial) responses than did WBV after exercise ($p < 0.05$). Although no significant time × trial interactions were observed for testosterone (T) (604.5–677.75 vs. 545.75–593.88 ng/dL), main effects for trial ($p < 0.05$) and for time ($p < 0.05$) were observed. In conclusion, WBV + BFR produced an additive effect of exercise on EMG amplitude and LA and GH responses, but it did not further induce T responses compared to those with WBV alone.

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INTRUDUCTION

The importance of performing regular resistance exercise has been emphasized by sports-related associations [1]. However, engaging in regular resistance exercise can be difficult for some populations. Therefore, commercially available passive exercise equipment has been designed for contracting muscles. For example, whole body vibration (WBV) training devices have been commonly used as alternative resistance exercise modalities [2]. WBV training devices are specially designed machines that can be easily operated and can contract the users' muscles passively (termed the tonic vibration reflex, TVR). During TVR, the muscle spindles work through the stretch reflex, which facilitates the activation of Ia-motoneurons, leading to involuntary muscle contraction [2]. Acting as an alternative resistance exercise modality, WBV exercise has the potential to elicit similar metabolic and hormonal responses as those with resistance, which is often accompanied by elevation of lactate (LA) [3, 4], growth hormone (GH) [3, 4, 5, 6], and testosterone (T) [5, 6, 7] levels after either resistance exercise or WBV exercise. During WBV exercise, a higher frequency often results in a greater muscle contraction and thus increased exercise intensity [8], which may induce a greater exercise response. However, once the vibration frequency reaches a certain level, the participant may feel uncomfortable due to excessive head vibration that raises safety concerns. Hence, strategies aimed at increasing the effects of WBV exercise often employ various types of external resistance, which can magnify the response of acute WBV exercise [9]. In this context, exploring portable equipment for amplifying the WBV exercise response effectively might be of great significance for individuals.

Studies conducted in the past few decades have indicated that low-intensity resistance exercise performed under blood flow restriction (BFR) conditions appears to induce greater metabolic [10, 11]

and hormonal responses [11, 12] compared to those induced by low-intensity resistance exercise without BFR. Furthermore, GH responses to 20% of a one-repetition maximum (1-RM) low-intensity resistance exercise with BFR are slightly higher than those to 80% of 1-RM high-intensity resistance exercise without BFR [13], and low-intensity resistance training with BFR engenders muscle hypertrophy and strength gain and results in adaptations similar to those with high-intensity resistance training [14]. This emerging strength training method using low-intensity resistance exercise combined with BFR, which typically involves wrapping a pressure cuff or wraps around the proximal portion of the exercising muscles, is known as occlusion training or BFR resistance exercise [15].

During BFR resistance exercise, the venous return of blood flow from the muscles is reduced, and even the arterial inflow into the muscle is reduced depending on the cuff pressure applied [16], which might result in an ischemic/hypoxic environment, subsequently leading to increased metabolic accumulation [17, 18]. Although the mechanisms underlying BFR resistance exercise conferring its training effect are not completely understood, the exaggerated LA response has been speculated to occupy the central role [15]. The magnified metabolic accumulation can increase the muscle activity, showing a greater electromyography (EMG) amplitude [14, 19]. In addition, increased LA concentration has been suggested as a primary stimulus for the BFR resistance exercise-induced GH response [10]. This is because GH could be stimulated by an acidic intramuscular environment [14, 20]. With regard to the T response, there are limited studies on BFR resistance exercise, with inconsistent results. Madarame et al. [21] determined that 30% 1-RM resistance exercise with BFR resulted in significant increases in the concentration of T when compared with the pre-exercise values, whereas Fujita et al. [11] reported that the increase in the concentration of T was not significant. These inconsistent results might be attributable to the low-exertion type of exercise mode, insufficient exercise volume, or limited total muscle mass involvement during an exercise session.

Taken together, given that the magnification of the BFR resistance exercise response is often observed under low-intensity resistance exercise, it is hypothesized that even passive muscle contractions by WBV lead to intensities comparable to those during low-intensity resistance exercise and can induce an additive exercise effect when combined with BFR. However, limited data utilizing WBV + BFR regimens are available. Therefore, the aims of this study were to investigate the effect of WBV + BFR on EMG amplitude and metabolic and hormonal responses and to investigate whether WBV + BFR could produce an additive exercise response compared to that with WBV alone.

MATERIALS AND METHODS

Participants

A total of eight healthy males (aged: 21.63 ± 1.19 years, height: 177.16 ± 4.69 cm, body mass: 68.66 ± 9.25 kg) participated in this study. All of them were determined to be physically inactive through screening with the International Physical Activity Questionnaire-Short Form [22]. No participants reported that they were smokers or alcohol and coffee drinkers. The Institutional Review Board of Kaohsiung Medical University Chung-Ho Memorial Hospital approved all the methods and procedures employed in this study, and all the participants provided written informed consent. The sample size was calculated according to a previous study, which compared the effect of resistance exercise with or without BFR on the LA response using a repeated measures design [23]. That study had reported a mean difference of 0.6 mmol (standard deviation; SD, 0.3 mmol) in the LA response between low-intensity resistance exercise + BFR and low-intensity resistance exercise alone. On this basis, sample size calculations in the present study indicated that eight participants would be required to show an expected difference in the LA response of this magnitude, using a power of 0.8 and an alpha level of 0.05.

Experimental design

A week before the experiment, the participants were familiarized with the experimental procedures and devices. Subsequently, they completed two exercise sessions, i.e., 10 sets of WBV + BFR (intervention: WBV plus BFR) or 10 sets of WBV (intervention: WBV alone), using a repeated measures crossover design, with the sessions separated by a 1-week interval. The WBV protocol was adapted from Bosco et al. [5], who reported that both GH and T levels were successfully induced by their WBV treatment, suggesting that the intensity might be sufficient to induce an LA response due to the GH response being partly regulated by LA [10, 14, 21]. In the WBV + BFR session, BFR is achieved via the application of external pressure using inflatable cuffs over the proximal portion of the thigh muscles. To determine the participants' rating of perceived exertion (RPE) and the EMG amplitude during each exercise session, the RPE and the thigh EMG activity were measured to document and compare any significant changes between the exercise sessions. Briefly, these values were collected following each set for a total of 10 measurements per session, and then each of the 10 sets of values were averaged to create a composite value for statistical analysis. In addition, fasting blood samples before and after exercise were collected to assess the LA levels and the hormonal responses. For the experiments, the participants were instructed to refrain from consuming alcohol, caffeine, or nutritional supplements for 24 h before the exercise sessions and to avoid strenuous exercise for 48 h before the sessions. To minimize diurnal variance, all measurements were obtained at the same time in the morning of the experiment day (between 9:00 and 11:00 AM).

Procedure

The study lasted for 1 month and was performed during the summer. On each assessment day, the participants arrived at the laboratory and rested for 10–15 min. A registered nurse then collected fasting blood samples from the participants in the sitting position as a baseline measurement. Subsequently, the participants completed a 5-min

warm-up on a cycle ergometer at a self-selected pace. Then, Ag/AgCl circular bipolar surface electrodes (2-cm interelectrode distance) were attached to the participants' thigh muscles of the dominant leg to collect EMG signals during each exercise session. The dominant leg was defined based on the individuals' self-reported better performance of the final foot before a jump takeoff on one side of the body in comparison with the other side. The participants then completed a given WBV exercise with or without BFR, and they were instructed to stand on the vibration platform in a squat position with 100° of knee flexion with their hands placed on the rigid lever arms of the exercise platform during the exercise. At the end of each set, the participants were asked to rate their perceived exertion. Immediately, post-exercise blood samples and 15- and 30-min post-exercise blood samples were collected again from each participant in the sitting position for subsequent analysis.

WBV protocol

The WBV protocol was adapted from Bosco et al. [5]. In the current study, the participants were exposed to WBV exercise on a commercially available platform (BH YT18, Taipei, Taiwan). The vibration frequency was set at 26 Hz (amplitude = 4 mm). The participants were exposed to a series of 10 sets of WBV, each with a 1-min duration and 1-min rest between sets, except for 2 min of rest allowed after the fifth treatment. During the rest intervals, the participants were instructed to stand on the vibration platform. During all the vibration treatments, the participants were instructed to wear thin socks without shoes.

BFR device and pressure applied

In the WBV + BFR session, all participants wore a custom-made BFR device around the proximal portion of the thigh muscles. The device is composed of two inflatable cuffs (made of nylon; width = 9 cm, length = 70 cm), a hand bulb pump with a check valve, a pressure gauge, and rubber tubes, similar to those of a sphygmomanometer. The two cuffs are connected to the hand bulb by the rubber tubes, through which air passes during pumping. Another tube from the bulb connects the pressure gauge, which measures the pressure of the cuffs.

The BFR resistance exercise is often performed using low-intensity resistance exercise combined with BFR. However, the appropriate cuff pressure to be combined with WBV for a beginner to perform WBV + BFR exercise is not well known. In our pilot study, the cuff pressure was initially set at 140–160 mmHg, which has been considered as suitable for most individuals [24]. After testing the protocol several times, we concluded that participants would not tolerate 10 sets of WBV + BFR once the cuff pressure is above approximately 150 mmHg. For safety reasons and to ensure that all participants would complete the protocol, the cuff pressure used in the current study was set at 140 mmHg, which was consistent with the pressure used in the majority of previous studies on frail individuals (elderly and untrained subjects) and BFR exercise beginners, which have often used a cuff pressure of 140 mmHg for lower body exercise [25, 26, 27]. Before the WBV + BFR session, the cuff was inflated to a pressure of 140 mmHg with the participants standing (P_{stand}). Then, the participants postured themselves in a squat position with 100° of knee flexion with their hands placed on the rigid lever arms of the vibration device. In this squat position, the pressure of the cuff increased to 180–190 mmHg (P_{squat}). Once the cuffs were inflated, they remained so for the entire experimental session, including during the rest intervals between sets. During the session, the pressure of the cuff was adjusted to each participant's P_{stand} or P_{squat} within the range of ±3 mmHg.

Rating of perceived exertion

RPE was measured using the Borg CR-10 scale immediately at the end of each set of exercise sessions. For assessing the RPE, standard instructions and anchoring procedures were explained during the familiarization session. A rating of 0 was associated with no effort, and a rating of 10 was associated with the maximal effort of exercise ever performed. During the WBV or WBV + BFR exercise sessions, RPE was immediately assessed after each set of exercise based on the participants' response to the question "How would you rate your effort?" The participants were asked to rate their perceived exertion by choosing any number on the scale to rate their effort. These measurements of each set were also used to monitor exercise safety. The average value for the 10 sets was calculated for statistical analysis to represent a more accurate assessment of the entire exercise session.

Electromyography

The surface electrodes were attached on the belly of three thigh muscles of the dominant leg, namely the rectus femoris (RF), biceps femoris (BF), and vastus lateralis (VL), after each participant's skin was shaved, abraded, and cleaned with alcohol to minimize impedance. The EMG signals were collected using the Noraxon TELEmyo DTS EMG system (Noraxon Inc, USA). Electrodes and electrode wires were secured with tape to minimize disruption during exercise. The EMG signals were recorded telemetrically with an offline sampling frequency of 1000 Hz and were bandpass-filtered (10–500 Hz). The recorded EMG signals were analysed during each set. To evaluate the EMG amplitude, root mean square (RMS) values were processed as the raw EMG signals and were full-wave-rectified and low-pass-filtered (12 Hz) over the given periods using Noraxon Myoresearch XP Master software (Noraxon Inc, USA). The RMS values of each muscle were then averaged over the 10 sets of each exercise session.

Blood sample collection and analysis

The blood samples were collected from the antecubital vein both before and after each exercise session. The blood samples were stored at 4°C and centrifuged at 1500 rpm for 30 min within 2 h of sampling. Subsequently, the serum samples were stored at 2°C for additional serum marker assays. The serum samples were sent to the

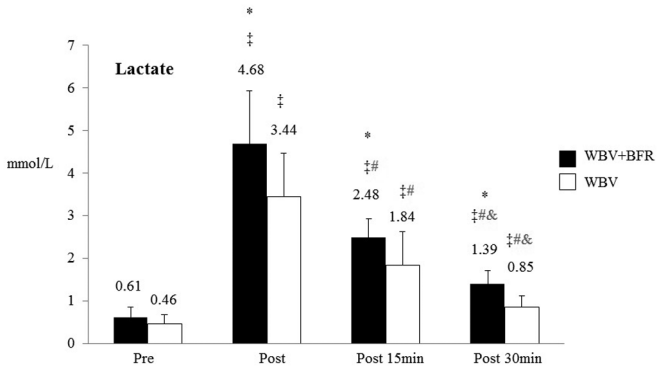

FIG. 1. Comparison of blood lactate concentrations (mean ±SE) between WBV + BFR and WBV for various time points. *Significant difference between WBV + BFR and WBV; ‡Significant difference compared with the pre time point measurements. #Significant difference compared with the post time point measurements. &Significant difference compared with the post 15min time point measurements. WBV + BFR = whole body vibration plus blood flow restriction; WBV = whole body vibration.

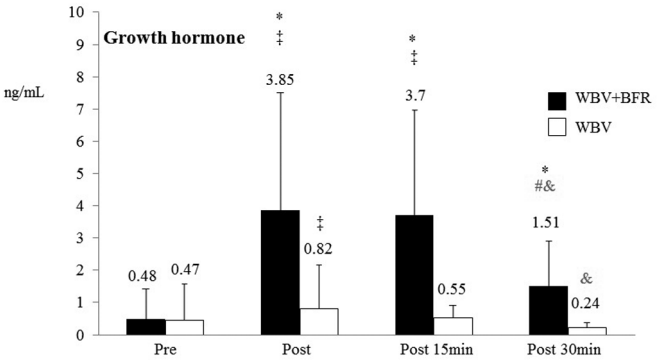

FIG. 2. Comparison of growth hormone concentrations (mean ±SE) between WBV + BFR and WBV for various time points. *Significant difference between WBV + BFR and WBV; ‡Significant difference compared with the pre time point measurements. #Significant difference compared with the post time point measurements. &Significant difference compared with the post 15min time point measurements. WBV + BFR = whole body vibration plus blood flow restriction; WBV = whole body vibration.

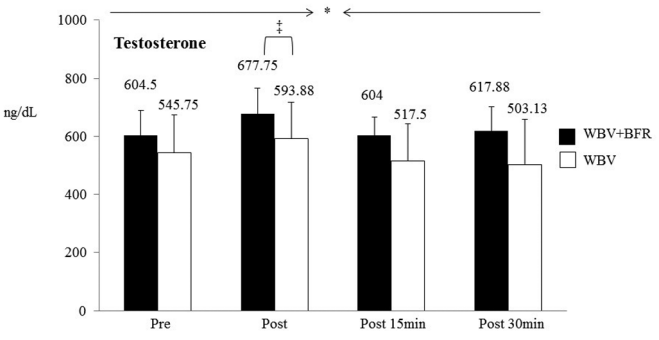

FIG. 3. Comparison of testosterone concentrations (mean ±SE) between WBV + BFR and WBV for various time points. *Significant main effect of trial (WBV + BFR versus WBV session). ‡Significantly different from other time points as tested by post-hoc comparison for main effect of time.

clinical laboratory for analysis. All the assays were performed according to the manufacturer's instructions.

LA levels were estimated using an automated analyser: the Dimension RxL Max Integrated Chemistry System (Siemens Healthcare Diagnostics Inc, Deerfield, IL, USA). GH levels were measured by a chemiluminometric assay (Beckman Coulter Inc, USA). The GH level sensitivity and the inter-assay and intra-assay coefficients of variance were 0.002 μg/l, 2.1%–11.3%, and 1.9%–14.4%, respectively. The T levels were measured by a chemiluminometric assay (Advia Centaur; Siemens Healthcare Diagnostics Inc., Tarrytown, NY, USA). The T level sensitivity and the inter-assay and intra-assay coefficients of variance were 10 ng/dl, 2.3%–6.2%, and 1.4%–4.7%, respectively.

Statistical analyses

Continuous data are expressed as the mean ± standard error (SE). A paired *t*-test was used to compare the EMG amplitude between the WBV + BFR and WBV sessions. Blood biochemistry values were analysed using a two-way analysis of variance with repeated measures (trial vs. time). A post hoc test was performed using the least significant difference technique. For the categorical variable (RPE), the Wilcoxon signed-ranks test was used as the data were not measured on a continuous scale. RPE scores are presented as medians and 25th and 75th percentiles. Statistical significance was set at $p < 0.05$ for all tests.

RESULTS

The RPE values were obtained by averaging the results of 10 sets of each exercise session. The Wilcoxon signed-ranks test revealed that the RPE was higher for the WBV + BFR sessions than that for the WBV sessions [median: 5.85 vs. 4 (25th and 75th percentiles: 5.02, 6.85 vs. 2.75, 4.62); $Z = 2.52$, $p < 0.05$]. The EMG amplitude in specific muscles is shown in Table 1. The paired *t*-test indicated that the RMS values of the RF and VL during WBV + BFR were significantly higher than those during WBV alone ($p < 0.05$). However, the difference in RMS values of the BF between WBV + BFR and WBV was not significant ($p > 0.05$).

Two-way ANOVA with repeated measures showed that LA values indicated a time × trial interaction ($F = 3.08$, $p < 0.05$). A significant simple main effect of time was observed for WBV + BFR ($p < 0.05$) and WBV ($p < 0.05$) sessions. Pairwise comparisons for the time factor further revealed that for both WBV + BFR and WBV sessions, the LA values were significantly increased at the post-exercise time point ($p < 0.05$) and then gradually decreased at 30 min after exercise ($p < 0.05$), but the values remained higher than the pre-exercise measurements ($p < 0.05$). In addition, a simple main effect analysis revealed that while the pre-exercise LA values did not differ between the sessions ($p > 0.05$), the LA values for the WBV + BFR session were significantly higher ($p < 0.05$) at all the post-exercise time points than those for the WBV session (Fig. 1).

Two-way ANOVA with repeated measures showed that GH values exhibited a significant time × trial interaction ($F = 7.10$, $p < 0.05$).

TABLE 1. Root mean square (RMS) electromyography (EMG) values (μV, mean ± SEM) between WBV+BFR and WBV.

	WBV+BFR	WBV	t	p
Rectus femoris	55.96±5.31*	42.41±6.68	2.59	.036
Vastus lateralis	87.65±5.28*	67.86±4.72	2.54	.039
Biceps femoris	16.06±2.81	12.00±1.04	1.49	.179

* Significant difference between WBV+BFR and WBV ($p < 0.05$). WBV + BFR = whole body vibration plus blood flow restriction; WBV = whole body vibration.

A simple main effect analysis revealed a significant effect of time for the WBV + BFR ($p < 0.05$) and WBV ($p < 0.05$) sessions. Pairwise comparisons for the time factor further revealed that for the WBV session, the GH values were significantly higher at the post-exercise time point than the pre-exercise measurement, and the GH values were significantly lower at 30 min after exercise than the 15-min post-exercise measurement ($p < 0.05$); for the WBV + BFR session, the GH values were significantly higher immediately after exercise and 15 min after exercise ($p < 0.05$) than the pre-exercise and 30-min post-exercise measurements. In addition, the results of the significant simple main effect analysis for the trials revealed that the pre-exercise GH values did not differ between the sessions ($p > 0.05$). The GH values were significantly higher ($p < 0.05$) for WBV + BFR at all the post-exercise time points than those for WBV (Fig. 2).

While two-way ANOVA with repeated measures showed that the T values exhibited a significant main effect for time ($F = 13.62$, $p < 0.05$) and a main effect for trial ($F = 10.93$, $p < 0.05$), no evidence was found for a time × trial interaction ($F = 1.70$, $p > 0.05$). An LSD post hoc comparison among the time points revealed that post-exercise T values were greater than those at other time points ($p < 0.05$) (Fig. 3). Since no significant time × trial interaction was observed for T values, the effect of the exercise sessions was thus equal.

DISCUSSION

The principal finding of this study is that the primary EMG amplitude is greater during WBV + BFR than that during WBV. Both WBV exercise and WBV + BFR induced an increase in LA and GH responses. In addition, WBV + BFR induced greater LA and GH responses compared to those with WBV alone. However, the T response induced by WBV was not further increased by BFR.

In the present study, the participants stood on the WBV platform with their knees at 100° flexion for the WBV + BFR and WBV sessions. It has been documented that this posture during WBV exercise leads to a greater increase of EMG amplitude of the quadriceps femoris than that of the hamstrings, suggesting that the quadriceps femoris is the primary muscle among the thigh muscles used in WBV exercise in the partial squat position [28]. Our findings indicate that the participants perceived the WBV + BFR session as being significantly more difficult than the WBV session. The EMG analysis showed that the EMG amplitude of the RF and VL (but not the BF) was greater during WBV + BFR than that during WBV alone. It is reasonable to assume that when BFR is applied with WBV, the primary muscles would have a greater EMG amplitude to accommodate the greater effort, as the blood flow is restricted. The results of this study are similar to those of previous BFR resistance exercise studies, in which the working muscles showed a greater EMG amplitude following the application of BFR during resistance exercise [19, 29].

Muscle contraction through WBV manipulation may produce metabolic responses [30]. Our results are in accordance with previously reported results that acute WBV exercise led to an increase in LA concentration [3]. In addition, in the current study, the concentrations of LA after the WBV + BFR exercise session were higher than those after the WBV exercise session. Our findings are comparable to those reported from BFR resistance exercise studies [10, 11]. It is speculated that during WBV + BFR exercise, the reduced venous outflow (even arterial inflow) may produce a low oxygen level state in the target muscle, leading to magnified metabolic stress.

Exercise that produces greater demands on anaerobic glycolysis, such as intermittent exercise with a short rest period between multiple sets, could easily stimulate the hypophyseal secretion of GH [31]. In the present study, the participants were exposed to 10 sets of exercise each for a duration of 1 min and 1 min of rest between each WBV treatment (2 min of rest was allowed after the fifth treatment). As expected, our results indicate an increase in GH levels after acute WBV, which is similar to the results of previous studies [3, 5, 6]. In addition, the blood concentration of GH was increased to a greater extent by WBV + BFR. This finding is similar to those from previous studies that have shown that BFR resistance exercise with increased LA accumulation enhances GH responses [10, 14, 21]. As already mentioned, an acidic intramuscular environment or LA accumulation has been suggested to be a primary stimulus for the BFR resistance exercise-induced GH response [14, 20]. In the present study, the GH response induced by the two sessions with a concomitant LA response immediately after exercise possibly indicates that the increase in LA concentration plays a role in WBV + BFR-induced GH secretion, although other factors could partly account for this.

Acute resistance exercise significantly improves T responses in men [7], but the T response to WBV has been examined only by a few studies, with no effects [32] or elevations [5, 6] being reported. Our study protocol was adapted from Bosco et al. [5] and supports the finding that the WBV-induced TVR may in turn trigger a T re-

sponse [5]. However, no further response occurred when BFR was applied with WBV since the effects of WBV + BFR and WBV exercise on the T response were equal (Fig. 3). It was difficult for us to compare these results with previous studies because data regarding the comparison of acute T responses between resistance exercise and BFR resistance exercise are lacking. Although metabolic stressors may act as a potent stimulus for increasing the T levels [7, 33], in the present study, a further increase in LA levels by BFR was not paralleled by changes in T response. Despite no additive response by BFR, the increase in T response following the WBV + BFR regimen support the findings of Madarame et al. [21], who demonstrated an increase in T levels immediately after BFR resistance exercise.

The transient increase in GH and T levels after acute resistance exercise has been considered to facilitate the synthesis of muscle protein pervasively [34]. However, this is somewhat controversial, because the intramuscular signalling process is not influenced by transient increases in systemic GH and T levels [35, 36]. Recent studies have indicated that the elevations of these hormones might act by mobilizing fuel stores [36, 37], enhancing connective tissue remodelling [38, 39], and participating in the repair and recovery process [40]. Although the precise mechanism remains to be elucidated, the findings of this study provide evidence showing that adding BFR to WBV exercise can magnify (GH) or maintain (T) acute hormonal responses.

Limitations regarding the interpretation of this study need to be mentioned. First, it might only be appropriate to extrapolate the findings to populations who seldom engage in regular exercise. Whether physically active people have a similar response to this exercise compared with untrained people must be clarified in the future. Second, our participants were male adults. It is uncertain whether females would have a similar response following these treatments, because research has shown that gender differences affect muscular fatigue resistance and hormonal responses to exercise [41, 42]. Third, the use of a uniform pressure should be noted. Although the cuff pressure was adjusted based on an individual's limb circumference as recommended by Fahs et al. [24], the majority of previous studies on frail individuals (elderly and untrained subjects) and BFR exercise beginners have often used a cuff pressure of 140 mmHg for lower limb exercise [25, 26, 27]. For safety reasons, the uniform cuff pressure of 140 mmHg was applied in all participants. In the present study, although all participants were physically inactive, a uniform pressure was applied for each participant, and a WBV-magnified exercise response was observed, individual differences in exercise tolerance were observed. This might lead to a disproportionate increase in blood parameter values. Finally, drawing definite conclusions regarding the benefits of a short-term training programme for muscle performance is beyond the scope of the research design, and we are only left to speculate that WBV + BFR following periods of training might have potential effects for facilitating skeletal muscle adaptations among people who engage in low levels of physical activity.

CONCLUSIONS

WBV exercise with superimposition of external pressure using inflatable cuffs proximal to the working muscle produced greater effort, increased primary muscle EMG amplitude, and magnified the LA and GH responses, but it did not further induce T responses in untrained healthy male adults. It is possible that WBV + BFR provides a basis for additive training potential. If the untrained participants wish to enhance the WBV exercise response, they can simply apply a suitable cuff proximal to the working muscle.

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Conflict of interest declaration

The authors declare no conflict of interest.

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