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Low-frequency vibration therapy enhances recovery in college football athletes after fatigue-induced exercise

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ABSTRACT

Vibration therapy is known to help with muscle fatigue from daily activities. Research is ongoing, but early signs suggest it might be a promising tool for health promotion via faster recovery after streneous exercise. This randomized controlled trial examined the effects of low-frequency vibration therapy (LFVT) on recovery of lower back muscles after induced fatigue. Recovery-related parameters, including pressure pain threshold (PPT), visual analog scales (VAS) of perceived fatigue, sit-and-reach (SAR), and heart rate variability (HRV) were measured before the session of induced fatigue, immediately after receiving either the LFVT or the rest, and 24-hour follow-up period. Seventy participants were allocated to either LFVT group (received a 10-minute session of LFVT) or control group (rested under the same environment). Results showed that participants in LFVT group significantly improved VAS and PPT after intervention. The between-group comparison revealed that the improvement in the average heartbeat (AHB), VAS, SAR, and PPT were greater in LFVT group than in control group immediately after the treatment. Moreover, improvements in SAR and PPT were also greater in the LFVT group than in the control at 24-hour follow-up. The findings revealed that LFVT can be used as a recovery-health care method for football athletes.

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1. INTRODUCTION

In sports training or competition, performance has to be sustained constantly, fatigue is inevitable during and after sports activity. Fatigue is represented by the capacity to maintain the required work rate [1]. One of the critical obstructions is strenuous usage, resulting in decreased physical function from the induced exercise [2]. Exercise-induced muscle fatigue on lower back muscles is common for athletes, they must perform technical and tactical skills, changing direction, decelerations, accelerations, and jumps to adapt successfully to rapidly changing situations and achieve the best performance [3]. Reaching a good balance between the induced fatigue and recovery is crucial for maintaining the athlete's performance; otherwise, it could bring potential tissue damage to reduce abilities of the athletes [4] and affect their daily health [5]. Exercised-induced fatigue of the lower back muscle usually lasts for hours to some days. Therefore, rapid recovery from fatigue is crucial for football players to resume their athletic performance and health.

Many therapies (such as massage, stretching, electrical stimulation, ultrasonic wave, hyperbaric oxygen therapy, and vibration therapy) have been employed to repair the damaged muscles to achieve the balance between fatigue and recovery on lower back muscles. Vibration therapy is one of the most popular ways to transfer energy to the target muscles from the vibration device [6]. Nowadays, many instruments that apply vibrations are easy accessible. Vibration instruments can generate mechanical oscillations, which may affect the muscle spindle, causing transformations in the extent of the extrafusal muscle fibers [7]-[12].

Previous studies using local vibration mode mainly focus on the lower limbs and knee joint injury of football players. However, the effects of low-frequency vibration therapy (LFVT) on the recovery of lower back muscles have not been explored, especially among college football athletes. This study aims to examine the short-term effects of LFVT on college football athletes in treating their lower back muscle fatigue. It is expected that LFVT could have a role as a health care method to enhance recovery from back muscle fatigue after a streneous exercise.

2. METHOD

2.1. Participants and sample size

This single-blinded randomized controlled trial was conducted during September to Octorber 2023 in the Physical Therapy Department, Physical Education School, Shaoguan University, China. Seventy participants were recruited through advertisement boards. Before the data collection, participants were instucted to refrain from a big meal for four hours. The inclusion criteria of the participants consisted of male football athlete (except the goalkeeper), aged eighteen to twenty-seven years old, had football training experience of more than one year, received football training at least 90 minutes/time, three times a week. Each of them was excluded if he had one of the following conditions: a habit of drinking or smoking, took any medicine one week ago, had a history of chronic pain in the lower back, and had a history of surgery one year before the data collection. Eighty one people volunteered but seventy participants met the inclusion criteria and participated in this study. Each of the participants signed an informed consent, it provided information on the objectives, risks, and benefits of the study, and the issue of withdrawing from this study without giving any reason at any time during experimental procedures. The research protocol had been approved by the Ethics Committee of the Center for Ethics in Human Research, Khon Kaen University (HE642185). This study was performed in accordance with the Declaration of Helsinki. The sample size calculation of this study was based on a formula below [13]. According to the data from a previuos similar study [14], it had two groups: the experiment and the control group, to examine the therapy effects on the pressure pain threshold (PPT).

Calculation formula:

$$N/group = \frac{(Z_{1-\alpha/2} + Z_{1-\beta})^2(\alpha_{tre}{}^2 + \alpha_{con}{}^2)}{\Delta^2}$$
$$= \frac{(1.96 + 0.84)^2(22.4^2 + 26.2^2)}{(56.3 - 38.9)^2}$$
$$= \frac{7.84 * (501.76 + 686.44)}{302.76}$$
$$\approx 30.769$$
$$\approx 31$$

The minimum sample size of this study was 31, and account for 10% of drop-out rate was assumed (d=0.1).

$$n_1 = \frac{n}{(1-d)^2}$$
$$= \frac{31}{(1 - 0.1)^2}$$
$$\approx 34.444$$
$$\approx 35$$

The total sample size of this study was 70 participants.

Notes: α_{tre}= tandard deviation post-test in the treatment group; α_{con}=standard deviation post-test in the control group; $\Delta=\mu_{tre}-\mu_{con}$; μ_{tre}=post-test mean value in the treatment group; μ_{con}=post-test mean value in the control group; alpha(α)= 0.05, Z(0.975), Z1-α/2=01.96; Beta(β)=0.2, Z(0.800), Z1-β=0.84

2.2. Procedure

Seventy participants were randomly assigned to the experimental or control groups as shwon in Figure 1. The randomization process was based on the following: numbered the participants from 1 to 70 through the Random Permutations generator, the smallest integer selected 1, the largest integer selected 70, and the integers per line selected 35 (according to the website: *http://www.randomization.com*). The first visit of the participants was arranged for getting familiar with the surroundings and how to measure with the veteran assessors who were blinded for group allocation. On the next day it was arranged for measurement of baseline and recording the demographic data, including age, weight, height, sit-and-reach (SAR), PPT, heart rate variability (HRV), and visual analog scales (VAS). In order to control the confounding variables, all data collection started at 4 pm because the HRV was affected by time. What's more, we checked the PPT value (primary outcome) immediately after the induced fatigue, the two groups had no significant difference.

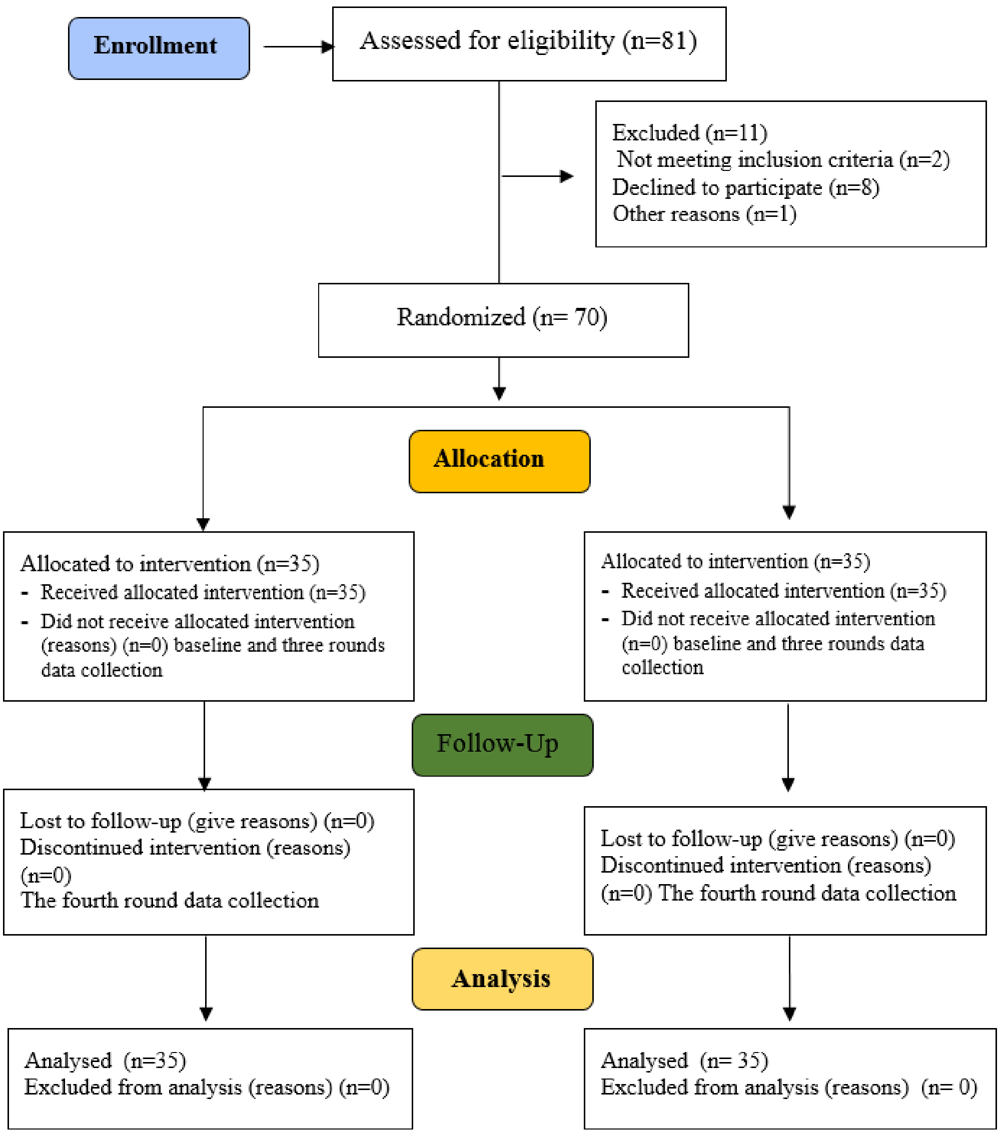

Figure 1. Enrollment flowchart illustrating the participant recruitment and selection process

Participants were subjected to a standardized fatigue exercise, lying on their stomachs with arms extended beyond their heads. They repeatedly raised their feet and arms as high as possible until exhaustion. PPT was then measured for all participants. Next, participants in the LFVT group received 10 minutes of vibration therapy, while those in the control group simply rested quietly in the same environment. Immediately following the intervention, both groups provided data on various measures including SAR, PPT, HRV, and VAS scores. These measurements were repeated again 24 hours later as shown in Figure 2. The design of this study was registered through the Thailand Clinical Trials Registry (TCTR20221229001).

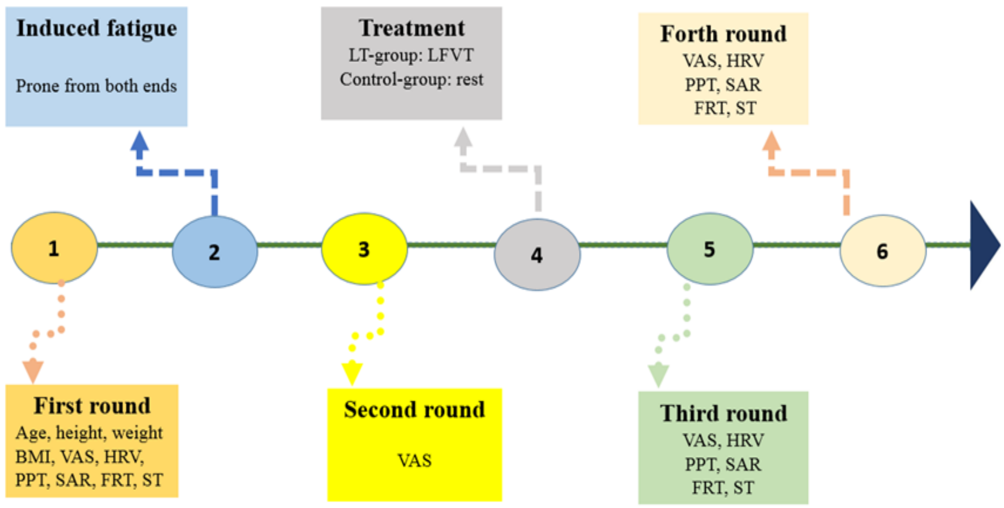

Figure 2. The flow chart outlining the procedure of data collection and treatment

2.3. Intervention protocol

Participants in the experimental group received a 10-minute LFVT session delivered by a trained therapist. The LFVT was applied along the paravertebral muscles on both sides of their lower back using a device vibrating at 8 Hz with an amplitude of 0.2 mm (TK AMC-888 Infrared Massager, China). During this time, the control group rested quietly in the same prone position. After all data collection, participants in the control group were also offered the same LFVT session if they wished.

2.4. Outcome measurements

This study aimed to comprehensively assess the effects of LFVT on participant recovery using various outcome measures. Four parameters were chosen:

2.4.1. PPT

An objective measure of muscle sensitivity, measured using an algometer (Algometer Combo, OE-220, Japan) that applied pressure until the participant felt slight pain or discomfort. Higher PPT indicated better threshold to pressure, suggesting reduced muscle fatigue [15]. The pressure was vertically applied towards the lower back muscles. The participants were instructed to press the button attached to the algometer when they felt a little pain or discomfort, and then the number on the screen stopped. This number was taken as the PPT. It was conducted three times and taken as the average value for analysis. The PPT was the primary outcome of this study.

2.4.2. VAS of fatigue perception

This subjective measure allowed participants to directly report their level of fatigue on a 10-cm scale, with 0 representing no fatigue and 10 representing the most severe fatigue [16].

2.4.3. SAR

Measured with a trunk flexibility machine (Kedao TZCS-1, China), it gauged lower back flexibility. Previous research suggested a negative correlation between lower back fatigue and SAR, making it a relevant indicator of recovery [17]. The participants removed their shoes and sat on a flat pad with legs straightened before the body. Then, they pushed the ruler indicator with their fingertips as far as possible, and the screen showed the number of SAR. It was measured three times and taken as the average value for analysis.

2.4.4. HRV

This measure reflected the variation in heart rate, with higher variability indicating a healthier nervous system and potentially faster recovery from fatigue [18]. HRV was measured using an HRV device (uBioMacpa version 1.0, Korea). Using the smartphone, talking, or sleeping during the protocol was forbidden. The HRV data was recorded on a computer whose software matched to the HRV device. The pulse sensor attached to the computer was clamped to the participants' index fingertips, and the HRV data was recorded for 5 minutes.

The reliability of each outcome measure was evaluated using the Intraclass Correlation Coefficient (ICC), ensuring consistency and trustworthiness of the data. All measurements achieved excellent or high reliability, with ICC values ranging from 0.85 to 0.99 [19]-[22]. This high level of reliability strengthens the confidence in the study's findings.

2.5. Statistical analyses

Statistical analysis was carried out using SPSS software version 26.0. First, normality of the data was checked using the Kolmogorov-Smirnov test. All group data was confirmed to be normally distributed. To compare pre- and post-intervention measurements within each group (LFVT and control), a paired-samples t-test was conducted. For comparisons between the two groups (LFVT and control), an independent-samples t-test was used.

Additionally, an analysis of covariance (ANCOVA) was employed to control for baseline differences between the groups. This analysis used the baseline measurement as a covariate to examine the post-intervention data and assess any remaining significant differences between the groups after accounting for the initial variation. A p-value of less than 0.05 was regarded as statistically significant.

3. RESULTS AND DISCUSSION

The demographic and baseline pre-test data of the participants are presented in Table 1. The baseline weight, height, and age had no significant difference between the two groups, and there were no significant differences between the two groups before the treatment protocol in the VAS, PPT, SAR, or HRV. After the induced fatigue, the two groups had no significant difference in the PPT.

Table 2 compares within-group data among the pre-, immediately post, and 24 hours later for each variable. Within the LFVT group, the results showed improvement with PPT and VAS immediately after the intervention or 24 hours later. Within the control group, VAS had improvement 24 hours later compared with immediately after the intervention, but the PPT had adverse effects immediately after the intervention compared with the baseline and 24 hours later compared with the baseline.

Table 3 shows the between-group comparison of mean differences in the post-intervention and 24 -hour follow-up using ANCOVA. Statistically significant difference occurred in average heartbeat (AHB), PPT, SAR, and VAS immediately after the intervention. There was also statistically significant difference in PPT and SAR for the immediately after the intervention and the 24-hour follow-up period. None of the HRV data had a significant change except the AHB immediately after the intervention.

Until now, there have not been enough trials with athlete-specific populations about the fatigue and recovery of lower back muscles [23], this study is the first to fill the gap. After the intervention in this study, we verified the immediate and short-term effects of LFVT on lower back muscle recovery. The findings of this study were that the PPT and VAS were improved within the LFVT group, whereas HF and AHB were not improved in the control group as shown in Table 2. Moreover, the between-group comparison revealed that the LFVT could significantly affect the parameters of PPT and SAR as shown Table 3.

Table 1. Comparison on the demographic characteristics and baseline between the two groups

	LFVT group mean (standard deviation)	Control group mean (standard deviation)	p-value
Age (years)	20.6(1.24)	20.37(1.57)	0.502
Height (cm)	1.74(0.03)	1.73(0.05)	0.375
Weight (kg)	66.4(6.65)	67.63(7.84)	0.481
BMI (kg/m^2)	21.75(1.92)	22.43(2.34)	0.195
HRV			
LF (ms^2)	7.13(1.16)	6.96(0.52)	0.449
HF (ms^2)	6.79(0.84)	6.49(0.91)	0.164
LF/HF	1.10(0.87)	1.12(0.78)	0.158
AHB (beats/min)	87.22(24.43)	76.64(23.52)	0.069
SDNN	55.15(33.64)	57.96(38.86)	0.748
RMSSD	47.88(30.32)	46.64(30.87)	0.866
Other parameters			
PPT (kg)	3.54(0.77)	3.81(1.05)	0.229
VAS (cm)	3.31(1.95)	3.45(1.67)	0.749
SAR (cm)	12.45(6.85)	13.96(5.86)	0.324
PPT* (cm)	3.57(0.76)	3.83(1.10)	0.176

Abbreviations: years, age of participants; height, height of participants, weight, weight of participants. LF, average sympathetic activity; HF, average para-sympathetic activity; LF/HF, autonomic nerve system balance; AHB, average heartbeat; SDDN, the standard deviation of normal to normal; RMSSD, root mean square standard deviation; PPT, pressure pain threshold; VAS, visual analog scales; SAR, sit-and-reach; PPT *, the PPT value immediately after the induced fatigue

Table 2. Within-group comparisons of outcome measures at baseline, immediately post-intervention, and 24-hour follow-up

Parameters	Before M(SD)	Post-intervention M(SD)	24-hour M(SD)
LFVT group			
HRV			
LF (ms^2)	7.13(1.16)	7.22(0.72)	7.06(1.12)
HF (ms^2)	6.79(0.84)	6.70(0.68)	6.67(0.68)
LF/HF:	1.10(0.87)	1.08(0.93)	1.10(0.97)
AHB (beats/min)	87.22(24.43)	81.79(20.33)	85.71(22.55)
SDNN	55.15(33.64)	51.65(32.64)	51.04(28.28)
RMSSD	47.88(30.32)	49.73(30.60)	49.48(25.46)
Other parameters			
PPT (kg)	3.54(0.77)*	4.12(1.23)	4.21(1.17)***
VAS (cm)	3.17(1.80)*	2.73(1.57)	3.65(1.52)
SAR (cm)	12.45(6.85)	14.50(5.87)	12.50(6.85)
Control group			
HRV			
LF (ms^2)	6.96(0.52)	6.9(0.52)	6.89(0.57)
HF (ms^2)	6.49(0.91)	6.61(0.55)	6.47(0.42)
LF/HF:	1.12(0.78)	1.09(0.95)	1.10(0.95)
Mean bmp(t/m)	76.64(23.52)	76.83(20.66)	76.81(23.42)
SDNN	57.96(38.86)	53.05(28.98)	53.05(28.98)
RMSSD	46.64(30.87)	53.29(36.58)	53.29(36.58)
Other parameters			
PPT (kg)	3.81(1.05)*	3.16(0.81)	3.08(0.81)***
VAS (cm)	3.45(1.67)	4.43(1.22)**	3.20(1.47)
SAR (cm)	13.96(5.86)	13.25(5.65)	11.68(3.61)

Note: *, significantly different comparison between immediate data and baseline; **, significantly different comparison between 24 hours later data and immediately after the intervention; ***, significantly different comparison between 24 hours later data and baseline. Abbreviations: L group, LFVT group; C group, Control group; M(SD), mean (standard deviation)

Table 3. Between-group comparisons of mean differences in the immediately post-intervention and 24 -hour follow-up using ANCOVA

	Immediately post intervention			24-hour follow-up		
Parameters	L group M(SD)	C group M(SD)	P-value	L group M(SD)	C group M(SD)	P-value
HRV						
LF (ms^2)	7.22(0.72)	7.06(1.12)	0.052	6.90(0.52)	6.89(0.57)	0.571
HF (ms^2)	6.70(0.68)	6.67(0.68)	0.396	6.61(0.55)	6.47(0.42)	0.450
LF/HF:	1.08(0.93)	1.09(0.95)	0.449	1.10(0.97)	1.10(0.95)	0.680
AHB (beats/min)	81.79(20.33)	85.71(22.55)	0.002	76.83(20.66)	76.81(23.42)	0.196
SDNN	51.65(32.64)	51.04(28.28)	0.793	53.06(28.98)	53.05(28.98)	0.997
RMSSD	49.73(30.60)	49.48(25.46)	0.201	53.29(36.58)	53.29(36.58)	0.215
Other parameters						
PPT (kg)	4.12(1.23)	3.16(0.81)	0.001	4.21(1.17)	3.08(0.81)	0.001
VAS (cm)	2.73(1.57)	4.43(1.22)	0.001	3.65(1.52)	3.20(1.47)	0.221
SAR (cm)	14.5(5.87)	12.50(6.85)	0.001	12.50(6.84)	11.68(3.61)	0.001

Abbreviations: L group, LFVT group; C group, Control group; M(SD), mean (standard deviation)

Within the LFVT group, PPT significantly improved both immediately after the intervention and 24 hours later compared to baseline as presented in Table 2. This finding aligns with previous studies using local vibration therapy [24] and foam rolling vibration [25], both demonstrating increased PPT. This improvement in pain threshold might be explained by softened lower back tissues and increased skin temperature after LFVT. The increased temperature likely results from stimulated muscle contraction through the tonic vibration reflex and friction generated by the vibration itself. These combined processes expand the vascular bed, leading to increased blood flow and potentially aiding recovery [26]. Interestingly, the control group's PPT did not show similar improvement, suggesting that simply rest for 24 hours after strenuous exercise may not be sufficient to increase pain tolerance. This highlights the potential benefits of LFVT for athletes seeking faster recovery.

The results also showed significant improvements in SAR on between-group comparisons, revealing the immediate and 24-hour effects. Although there was no statistical significance, a trend toward significance was noted (from 12.45 to 14.50) immediately after the intervention. It is believed that maintaining low back flexibility and hamstring may prevent chronic or acute musculoskeletal injuries, low back problems, or fatigue [27]. These findings generally agree with the studies that LFVT is a technique that can be easily used to reduce muscle tension or fatigue [28] and significantly affect SAR [29].

The Gate Control Theory could explain the possible mechanism of both pain reduction and increasing muscle flexibility as measured by SAR. The signals of the painful feeling are distributed around the peripheral skin of the body part that received vibration. According to the theory, the gate allows pain signals to go to the brain through the spinal cord when the gate is open but blocks the pain signals when the gate is closed. The pain signals go along the small nerve fibers, which carry slower messages. When a quick signal (for example, vibration therapy and touch) from a nerve fiber closes the gate, it prevents slower messages from getting through the spinal cord, resulting in less pain [30]. Therefore, the participants in the LFVT group exhibited less VAS of pain and increased SAR immediately after the intervention. It also could be explained that vibration stimulation could activate the proprioceptive sensory system, recruit previously inactive muscle fibers, stimulate spinal functions, and lead to better nervous control of muscular fiber recruitment [31].

This study investigated the effects of LFVT on heart rate, a key indicator of fatigue and recovery. HRV, a measure of heart rate variability, is often used to assess both fatigue levels and post-exercise recovery [32], [33]. As athletes tend to have lower heart rates than their less active counterparts [34], heart rate is also seen as a marker of sympathetic activity. Our findings showed a significant difference in AHB between the LFVT and control groups immediately after the intervention, with the LFVT group experiencing a lower heart rate, HRV paprameters improved but no significantly different between the groups. This suggests LFVT has beneficial effects on heart rate, aligning with previous research on hand vibration therapy [35]. However, another study using whole-body vibration found no significant impact on HRV during recovery [36]. This discrepancy might be due to the different application sites and potential disruption of autonomic nervous system regulation by low-frequency vibration. In our case, the intense nature of the exercise and the application of LFVT on the lower back might have a stronger influence on heart rate regulation. Overall, while LFVT seems promising for improving heart rate and potentially aiding recovery, further research is needed to fully understand its impact on the autonomic nervous system, especially during post-exercise recovery periods.

The immediate effect of LFVT on VAS was found to be significant in the current study when compared between the two groups. This result was similar to a previous study [37], which showed that local vibration therapy had a significant result compared with the control group on muscle soreness. However, this result on VAS did not last for 24 hours. The similar result happened that after the exhausted exercise, the vibration therapy employment could bring positive effect about decreasing the muscle fatigue [38], after the induced fatigue, making use of the body vibration therapy reduced the maximum voluntary isometric contraction and decreased the VAS twenty fours later [39]. Another study reported that the vibration treatment whose frequency was at 50 Hz could have a better result towards the muscle fatigue, but the vibration therapy whose frequency was at 25 Hz had not significant effects [40]. This was not consistent with this study that the LFVT had a better effect for VAS. The reason for this inconsistency may be that the two used different vibration patterns and target muscles.

4. CONCLUSION

This groundbreaking study is the first to explore the effects of LFVT on lower back muscles recovery in college football athletes after fatigue-inducing exercise. Our findings demonstrated significant improvements in most measured parameters following the 8 Hz, 10-minute LFVT application. Notably, LFVT group exhibited significantly better recovery in PPT and SAR compared to the control group. This compelling evidence suggested that LFVT holds promise as a valuable recovery tool for football athletes. However, to further optimize athlete recovery, future research should investigate the effects of LFVT over a longer follow-up period. By expanding the research scope, we can gain deeper insights into the long-term benefits of LFVT and solidify its potential as a mainstream recovery strategy for football athletes and beyond.

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