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Clinical efficacy of vibration stimulation therapy to relieve acute exercise fatigue

Juncheng Xie[a], Junliang Wang[c], Gang Xu[a], Shaoxiong Li[a], Yongtao Wang[b], Meihong Fu[d], Guangtao Liu[c], Chaoning Ji[c], Tao Zhang[c], Shicheng Liu[c] and Tangyi Liu[a,*]
[a]*School of Acupuncture, Moxibustion and Tuina, Shanghai University of Traditional Chinese Medicine, Shanghai, China*
[b]*School of Basic Medicine, Shanghai University of Traditional Chinese Medicine, Shanghai, China*
[c]*Shanghai Rongtai Health Technology Corporation Limited, Shanghai, China*
[d]*International Center for Aging and Cancer, Hainan Medical University, Hainan, China*

Abstract.
BACKGROUND: Previous studies showed that local vibration stimulation therapy was effective in relieving fatigue, and the effects of different modes of vibration stimulation therapy were further investigated.
OBJECTIVE: This study aimed to examine the effects of different vibration stimulation modes on relieving acute exercise fatigue based on the multiphysiological indicators such as heart rate variability (HRV), skin conductance level (SCL), and ratings of perceived exertion (RPE) subjective scale.
METHODS: Sixty participants selected from the dragon boat team of the Shanghai University of Traditional Chinese Medicine were divided into acupoint stimulation group (20 participants), muscle stimulation group (20 participants), and control group (20 participants) by complete randomization.
RESULTS: (1) RPE: both stimulation groups showed a significant increase compared to the control group. (2) Heart rate values: the difference between muscle stimulation group and control group was statistically significant; (3) SCL: the two stimulation groups had significantly higher and statistically significant differences in SCL (max) and SCL (mean) values compared to the control group; the muscle stimulation group had statistically significant differences in SCL (min) compared to the control group, and the acupoint stimulation group had statistically significant differences in SCL (v) compared to the control group; (4) HRV (hf): The difference between the acupoint stimulation group and the muscle stimulation group was statistically significant.
CONCLUSION: (1) Both stimulation groups are part of vibration therapy, which can relieve sympathetic tension and regulate the vegetative nervous system's relaxation effect. (2) The meridian-vessel theory may be related to the acupoint stimulation group. The low-level visceral regulation centers in the spinal nerve segment region, where the acupoints are located, trigger changes in autonomic tone and enhance parasympathetic nerve activity to relieve acute motor fatigue. (3) The muscle stimulation group may be due to the 30-Hz vibration frequency's ability to raise muscle epidermal temperature, which increases blood flow and reflexively inhibits sympathetic excitation.

Keywords: Acute sports fatigue, fascial gun, vibration therapy

1. Introduction

Acute exercise fatigue is an unavoidable phenomenon when the physiological processes of the organism cannot be sustained at a specific level or cannot maintain a predetermined intensity of exercise in the

*Corresponding author: Tangyi Liu, School of Acupuncture, Moxibustion and Tuina, Shanghai University of Traditional Chinese Medicine, Shanghai, China. E-mail: ltyabc@sina.com.

performance of sports activities and exercise [1]. The intensity of exercise increases with the increase in the level of sports competition nowadays. The process from training to fatigue generation in competitive training leads to changes in various aspects of the organism's physiology, biochemistry, and psychology, such as changes in neuronal function, slowing of heart rate (HR) and increase in blood pressure, changes in sympathetic nerve activity, and changes in mood, among others [2]. Related studies have shown that delayed management of acute athletic fatigue leads to an increase in sports injury events or triggers sports anxiety, depression, and an increase in the rate of various types of occupational accidents depending on the fatigue group [3–5]. Further, the incidence of sudden death in athletes has increased rather than decreased [6]. The lack of immediate and effective interventions is one of the main reasons for these conditions. Therefore, exploring an immediate and effective intervention is necessary.

Vibration therapy refers to mechanical vibration through energy transfer. It produces corresponding vibration waves to stimulate the neuromuscular system and the relevant receptors, which convert the mechanical stimulation into electrical signals to the body to produce biological effects, thus achieving the therapeutic effect of improving human functions [7,8]. Vibration therapy was first performed using the traditional Tuina method of vibration. In this method, the hand or palm is used to rapidly vibrate specific acupuncture points at a frequency of more than 300 times per minute, which has the effects of broadening the chest and regulating the qi, warming the meridians and relieving pain, soothing the tendons and meridians, activating the blood and moving the qi, and warming the yang and tonifying the deficiency. In modern related studies [9,10], vibration therapy can instantly and effectively relieve athletic fatigue, improve muscle strength, and relieve delayed muscle soreness. Fascial gun technology is an emerging technology in recent years and has been gradually applied in the medical field. The mechanism of action of this technology is similar to that of vibration therapy, which can promote blood circulation, increase blood flow, relieve soft tissue adhesions and contractures, and promote the recovery of muscle and fascial elasticity through high-frequency vibration and deep relaxation of the fascia [11]. Therefore, this study used the fascial gun technique to observe the effects of different stimulation methods of the fascial gun in relieving acute sports fatigue, thus providing a new research perspective for relieving acute sports fatigue.

2. Materials and methods

2.1. Study design

This study used a completely randomized design with three different treatment groups in a randomized controlled study (ratio 1:1:1). Randomization sequences were generated using the SPSS Statistics software. The study groups included vibratory stimulation of acupoints using a fascia gun (acupoint stimulation group), vibratory stimulation of selected muscles using a fascia gun (muscle stimulation group), and sedentary rest treatment (control group).

2.2. Study participants

The participants in this study were all from the dragon boat team of the Shanghai University of Traditional Chinese Medicine. The inclusion criteria were as follows: (1) athletes of the dragon boat team of the Shanghai University of Traditional Chinese Medicine, aged 18–24 years, in good health, with no abnormalities found in the routine physical examination; (2) subjective sensation of fatigue immediately after training, with ratings of perceived exertion (RPE) of $\geqslant 18$; and (3) extreme fatigue immediately after heavy exercise training. Those who met all the aforementioned criteria were included

Table 1
Borg's RPE scale

6	No exertion at all
7	
8	Extremely light
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

in the study. The exclusion criteria were as follows: (1) those who had subjective sensation of fatigue immediately after the end of heavy exercise training, with an RPE < 17; (2) those whose symptoms failed to reach extreme fatigue after heavy exercise training; and (3) those with recent sports injuries who could not resume normal training, and those who could not complete the treatment according to the experimental requirements. The discontinuation criteria were as follows: (1) poor compliance during the experiment, affecting the evaluation of effectiveness and safety; and (2) withdrawal during the experiment or withdrawal due to various other reasons before the end of the treatment. The diagnostic criteria were as follows: The 6–20 grading (RPE) scale of Swedish scholar Borg [12] was used for assessing fatigue intensity. The scoring criteria were as follows: 7–8 points: extremely light; 9–10 points: very light; 11–12 points: light; 13–14 points: somewhat hard; 15–16 points: hard; 17–18 points: very hard; and 19–20 points: extremely hard. An RPE $\geqslant 18$ was classified as an acute motor fatigue state [13] (Table 1). The number of participants was 60, including 23 men and 37 women.

2.3. Procedure

This study was conducted in the gymnasium of the Shanghai University of Traditional Chinese Medicine. First, the participants were assessed to determine whether they met the eligibility criteria, and baseline characteristics data were collected. After conducting the assessment, participants were provided a rowing machine to perform a simulated rowing exercise with a prescribed pulp frequency of 2:00–2:15. The rowing resistance with an initial level of 3 was used, starting with increasing 1 frame of resistance after 3 min and increasing 1 frame of resistance every 2 min thereafter, with an upper limit of resistance of 10 frames and an upper limit of rowing time of 30 min to observe the HR reaching 180+. The pulp frequency exceeded 2:15 and could not return within 30 s. The participant's immediate RPE score of $\geqslant$ 18 was adjudged exhaustion. The HR, skin conductance level (SCL), heart rate variability (HRV), and blood oxygen saturation (SPO_2) were measured using the "Human Fatigue Detection and Assessment System" developed by the Institute of Traditional Chinese Medicine Engineering, Shanghai University of Traditional Chinese Medicine, immediately after the determination of exhaustion. The recording time was 2 min, and the testing site was the Shaochong point. Moreover, the data were collected using the same method after the treatment.

2.4. Intervention

The intervention for the control group was 15 min of sedentary rest.

The intervention for the acupoint stimulation group (acupoint group) was as follows: a ROTAI-G20 fascial gun made by Shanghai Rongtai Health Technology Corporation Limited with a frequency of 30 Hz and an amplitude of 9 mm equipped with a conical head was selected. The acupoints of the upper limbs (shoulder point and Quchi point), lumbar region (large intestine Yu and kidney Yu), and lower limbs (ring jump, Yanglingquan, and foot Sanli) were stimulated for 15 min.

The intervention for the muscle stimulation group was as follows: a ROTAI-G20 fascial gun with a frequency of 30 Hz and an amplitude of 9 mm equipped with a ball head was selected. The muscles of the upper limbs (deltoid and trapezius), lumbar region (erector spinae), and lower limbs (gluteus maximus, rectus femoris, and gastrocnemius) were stimulated for 15 min.

2.5. Observation indexes

Each observation index was collected before and after the intervention. The subjective index included the fatigue subjective perception score using Swedish scholar Borg's 6–20 grading (RPE) scale, and the physiological indexes included HR, SCL, HRV, and SPO_2.

2.6. Sample size

The study used a completely randomized design with the F test and one-way analysis of variation (ANOVA) calculations using SPSS Statistics 15.0 software. Based on previously reported HRV (lf/hf) values, this study required 60 participants (20 in each of the three groups) to obtain 90% certainty (power $= 1 - \beta$) at the $\alpha = 0.05$ (two-sided) level of significance after accounting for a 20% shedding rate to detect statistical differences in clinical outcomes among the three groups.

2.7. Statistical analysis

SPSS Statistics 24.0 software was used to analyze the data, and the measurement data were expressed as mean $\pm$ standard deviation. For the measurement data that conformed to a normal distribution with homogeneous variance, one-way ANOVA was used for comparison between groups. The least significant difference test was used for a two-way comparison, while the rank-sum test for comparing multiple independent samples was used for data with nonnormal distribution or nonhomogeneous variance. The Mann-Whitney U test was used for two-way comparison, and 95% confidence interval (CI) of median difference was estimated using the Hodges-Lehmann method. The between-group effect values were expressed as η^2, with 0.01, 0.06, and 0.14 being small, medium, and large effects, respectively. The two comparison effect values were expressed as r (0.10, 0.30, 0.50) or d (0.20, 0.50, 0.80), with $P < 0.05$ indicating a statistically significant difference.

3. Results

All randomized participants were treated and included in the analysis. Table 2 provides the descriptive and anthropometric data for the test samples, with no significant differences between the characteristics of the three groups. Table 3 summarizes the changes in indicators before and after the intervention in each group, expressed as mean $\pm$ standard deviation. The table shows that most of the indicators improved after the treatment, but the most significant improvements occurred in RPE, HR, SCL (max), and SCL (mean), with a shift in effect size from small to large. The changes in SCL (min), SCL (v), and HRV (hf) were

Table 2
Baseline characteristics of participants

Group	No. of participants	Age	Sex-wise count of participants		BMI	Base heart rate
			Male	Female		
Acupoint stimulation group	20	19.60 ± 1.31	7	13	22.27 ± 0.66	73.95 ± 9.75
Muscle stimulation group	20	20.60 ± 2.37	8	12	22.52 ± 1.19	72.70 ± 10.48
Control group	20	20.50 ± 2.69	8	12	20.77 ± 0.44	73.75 ± 9.79
$F/H/c^2$		0.294	0.932		2.385	0.914

more significant, with effect sizes reaching moderate levels, and this difference was indeed statistically significant: RPE ($P = 0.001$, $\eta^2 = 0.30$), HR ($P = 0.009$, $\eta^2 = 0.15$), SCL (max) ($P = 0.003$, $\eta^2 = 0.17$), SCL (min) ($P = 0.016$, $\eta^2 = 0.11$), SCL (v) ($P = 0.044$, $\eta^2 = 0.07$), SCL (mean) ($P = 0.006$, $\eta^2 = 0.16$), and HRV (hf) ($P = 0.020$, $\eta^2 = 0.10$). The exception was that after the intervention, the effect of HRV (lf/hf) did not improve and the effect size was smaller, even though no statistical difference existed before and after the HRV (lf/hf) intervention.

Table 4 depicts the effect sizes (r, d) for the pairwise comparisons of the groups and the results of the *post hoc* tests. The results of the pairwise comparisons were as follows: (1) RPE was significantly different between the two stimulation groups compared with the control group. Compared with the difference between the acupoint stimulation group and the control group (Mean Difference: 2.00, 95% CI: 3.00 to 1.00, $P < 0.001$, $r = 0.57$), the difference between the muscle stimulation group and the control group (Mean Difference: 2.00, 95% CI: 3.00 to 1.00, $P < 0.001$, $r = 0.61$) had a greater effect. Moreover, it was assumed that the muscle stimulation group was better for RPE recovery. No difference was found between the two stimulation groups. (2) In the HR scores, a significant difference was found between the muscle stimulation group and the control group (Mean Difference: 7.20, 95% CI: 11.90 to 2.50, $P = 0.003$, $d = 0.97$), and no significant difference was found between the other two groups(muscle stimulation group and acupoint stimulation group;acupoint stimulation group and the control group). Moreover, it was assumed that the muscle stimulation group was better for HR recovery. (3) In the SCL (max) index, the acupoint and muscle stimulation groups were significantly different from the control group: the acupoint stimulation group versus the control group (Mean Difference: 14.79, 95% CI: 4.74–23.98, $P = 0.003$, $r = 0.47$) and the muscle stimulation group versus the control group (Mean Difference: 10.90, 95% CI: 3.76–19.53, $P = 0.004$, $r = 0.045$). No significant difference was found between the two stimulation groups. Combining the effect values and P values observed, it was concluded that the effect of the acupoint and muscle stimulation groups on SCL (max) was similar. (4) In the SCL (min) index, the two stimulation groups were significantly different from the control group: the acupoint stimulation group versus the control group (Mean Difference: 5.40, 95% CI: 0.24–13.30, $P = 0.042$, $r = 0.32$) and the muscle stimulation group versus control group (Mean Difference: 8.72, 95% CI: 3.54–13.76, $P = 0.005$, $r = 0.44$). It was considered that the muscle stimulation group had a better recovery effect. (5) In the SCL (v) index, a significant difference was observed only between the acupoint stimulation and the control groups (Mean Difference: 2.38, 95% CI: 0.34–5.13, $P = 0.014$, $r = 0.39$). (6) In the SCL (mean) index, the two stimulation groups were significantly different from the control group: the acupoint stimulation group versus the control group (Mean Difference: 8.99, 95% CI: 3.37–17.32, $P = 0.006$, $r = 0.43$) and the muscle stimulation group versus the control group (Mean Difference: 9.90, 95% CI: 3.90–16.14, $P = 0.005$, $r = 0.44$). No significant difference was found between the two stimulation groups. Combined with the observation of effect values and P values, it was concluded that the effect of the two stimulation groups on SCL (mean) was similar. (7) In HRV (hf), a significant difference was found between the acupoint stimulation and the muscle stimulation group (Mean Difference: 12.47, 95%

Table 3
Empirical data before and after treatment for each group (mean ± standard deviation)

Indicator	Pre-intervention					Post-intervention				
	Acupoint stimulation group	Muscle stimulation group	Control group	P value	η^2	Acupoint stimulation group	Muscle stimulation group	Control group	P value	η^2
RPE	18.50 ± 0.60	18.55 ± 0.61	18.45 ± 0.67	0.902	0.03	8.75 ± 0.85	8.65 ± 0.81	10.45 ± 1.50	0.001	0.30
HR	185.90 ± 7.02	183.20 ± 5.98	183.20 ± 10.94	0.188	0.02	88.65 ± 4.45	86.15 ± 7.66	93.35 ± 8.78	0.009	0.15
SCL (max)	28.80 ± 10.09	31.06 ± 10.51	27.86 ± 12.77	0.322	0.05	44.91 ± 21.89	38.53 ± 12.47	27.99 ± 12.33	0.003	0.17
SCL (min)	23.98 ± 6.60	26.40 ± 9.47	23.57 ± 9.93	0.394	0.002	31.87 ± 13.53	32.73 ± 9.88	25.09 ± 11.61	0.016	0.11
SCL (v)	4.80 ± 8.11	4.66 ± 4.21	4.29 ± 4.90	0.804	0.03	13.04 ± 20.69	5.80 ± 5.22	2.90 ± 1.97	0.044	0.07
SCL (mean)	25.99 ± 6.92	28.33 ± 9.53	25.28 ± 10.69	0.319	0.005	36.15 ± 14.01	35.20 ± 10.74	26.34 ± 11.85	0.006	0.15
HRV (hf)	13.51 ± 8.53	14.76 ± 7.95	13.69 ± 6.53	0.859	0.005	36.10 ± 18.42	22.59 ± 12.09	27.92 ± 9.33	0.020	0.10
HRV (lf)	8.08 ± 6.00	8.38 ± 5.12	8.33 ± 4.50	0.856	0.03	19.31 ± 10.53	12.88 ± 8.24	16.18 ± 7.88	0.093	0.05
HRV (lf/hf)	0.57 ± 0.15	0.56 ± 0.14	0.61 ± 0.12	0.596	0.02	0.53 ± 0.11	0.56 ± 0.13	0.56 ± 0.15	0.679	0.01
SPO_2 (mean)	99.10 ± 1.17	99.59 ± 0.56	99.10 ± 1.80	0.360	0.001	97.96 ± 1.17	98.07 ± 1.56	98.45 ± 1.49	0.493	0.01

Table 4
Mean differences (95% CI), P values, and effect size between groups

Indicators	Pre-intervention			Post-intervention		
	MD (95% CI)	P value	r/d	MD (95% CI)	P value	r/d
RPE						
Acupoint stimulation vs control	0.00 (0.00–0.00)	0.883	0.03	−2.00 (−3.00 to −1.00)	< 0.001	0.57
Muscle stimulation vs control	0.00 (0.00–0.00)	0.661	0.07	−2.00 (−3.00 to −1.00)	< 0.001	0.61
Acupoint stimulation vs muscle	0.00 (0.00–0.00)	0.771	0.05	0.00 (0.00–1.00)	0.665	0.08
HR						
Acupoint stimulation vs control	1.50 (−4.00 to 7.00)	0.542	0.10	−3.75 (−8.45 to 0.95)	0.116	0.51
Muscle stimulation vs control	−2.00 (−6.00 to 4.00)	0.516	0.10	−7.20 (−11.90 to −2.50)	0.003	0.97
Acupoint stimulation vs muscle stimulation	3.50 (−1.00 to 8.00)	0.133	0.24	3.45 (−1.25 to 8.15)	0.147	0.46
SCL (max)						
Acupoint stimulation vs control	2.36 (−3.36 to 7.28)	0.372	0.14	14.79 (4.74–23.98)	0.003	0.47
Muscle stimulation vs control	4.09 (−2.26 to 10.58)	0.156	0.22	10.90 (3.76–19.53)	0.004	0.45
Acupoint stimulation vs muscle stimulation	−2.27 (−8.62 to 3.08)	0.449	0.13	2.73 (−6.08 to 14.97)	0.570	0.09
SCL (min)						
Acupoint stimulation vs control	2.03 (−3.10 to 5.72)	0.344	0.15	5.40 (0.24–13.30)	0.042	0.32
Muscle stimulation vs control	3.43 (−1.62 to 7.93)	0.245	0.18	8.72 (3.54–13.76)	0.005	0.44
Acupoint stimulation vs muscle	−1.54 (−5.87 to 2.32)	0.425	0.13	−2.19 (−8.74 to 4.80)	0.482	0.11
SCL (v)						
Acupoint stimulation vs control	0.26 (−1.05 to 1.33)	0.695	0.06	2.38 (0.34–5.13)	0.014	0.39
Muscle stimulation vs control	0.34 (−1.05 to 2.17)	0.561	0.09	1.37 (−0.17 to 4.34)	0.093	0.27
Acupoint stimulation vs muscle stimulation	−0.28 (−1.94 to 0.99)	0.675	0.07	0.83 (−1.73 to 4.16)	0.490	0.11
SCL (mean)						
Acupoint stimulation vs control	2.36 (−3.10 to 6.52)	0.344	0.15	8.99 (3.37–17.32)	0.006	0.43
Muscle stimulation vs control	3.77 (−1.60 to 2.17)	0.152	0.23	9.90 (3.90–16.14)	0.005	0.44
Acupoint stimulation vs muscle stimulation	−1.52 (−6.44 to 2.88)	0.499	0.11	−0.02 (−8.02 to 7.89)	1.000	0.00
HRV (hf)						
Acupoint stimulation vs control	−0.18 (−5.07 to 4.71)	0.942	0.02	6.30 (−2.36 to 16.42)	0.130	0.24
Muscle stimulation vs control	1.07 (−3.82 to 5.96)	0.663	0.14	−5.53 (−13.79 to 0.36)	0.070	0.29
Acupoint stimulation vs muscle stimulation	−1.25 (−6.13 to 3.64)	0.611	0.16	12.47 (2.74–23.68)	0.012	0.40
HRV (lf)						
Acupoint stimulation vs control	−0.83 (−4.24 to 3.01)	0.607	0.08	3.04 (−3.32 to 10.02)	0.365	0.14
Muscle stimulation vs control	−0.075 (−3.53 to 3.83)	0.968	0.007	−4.06 (−8.49 to 1.24)	0.110	0.25
Acupoint stimulation vs muscle stimulation	−0.74 (−3.93 to 3.05)	0.655	0.07	5.70 (−0.07 to 12.79)	0.051	0.31
HRV (lf/hf)						
Acupoint stimulation vs control	−0.03 (−0.12 to 0.06)	0.486	0.22	−0.03 (−0.12 to 0.05)	0.426	0.23
Muscle stimulation vs control	−0.04 (−0.13 to 0.05)	0.356	0.29	−0.004 (−0.09 to 0.08)	0.933	0.03
Acupoint stimulation vs muscle stimulation	0.01 (−0.08 to 0.10)	0.819	0.001	−0.03 (−0.11 to 0.05)	0.475	0.23
SPO_2 (mean)						
Acupoint stimulation vs control	0.00 (−0.40 to 0.30)	0.967	0.06	−0.40 (−1.80 to 0.30)	0.243	0.18
Muscle stimulation vs control	0.20 (0.00–0.50)	0.107	0.26	−0.30 (−1.40 to 0.40)	0.401	0.13
Acupoint stimulation vs muscle stimulation	−0.15 (−0.70 to 0.10)	0.144	0.23	−0.10 (−1.40 to 0.80)	0.829	0.03

CI: 2.74–23.68, $P = 0.012$, $r = 0.40$), and it was concluded that the recovery effect of the acupoint stimulation group was better in this index. (8) Compared with the control group, the two stimulation groups showed favorable effects on HRV (lf) and SPO_2 (mean) after the intervention, but no significant difference was found among the three groups and between the two stimulation groups. (9) Compared with the control group, no significant change in HRV (lf/hf) was found in the acupoint stimulation group after the intervention, and the effect in the muscle stimulation group became smaller compared with that before the intervention, and no significant difference was found between the two stimulation groups.

4. Discussion and conclusion

The occurrence of acute exercise fatigue is an inevitable phenomenon in sports training and physical activity. If fatigue is not addressed immediately, it will not only impact training but also produce adverse reactions in the body. Therefore, active relaxation is usually used for post-exercise recovery. Current measures for active relaxation at home and abroad include cold therapy, stretching, massage, foam axis, vibration therapy, and so forth. Active relaxation brings many benefits, such as accelerating HR recovery, accelerating the discharge of metabolites, relieving delayed muscle soreness, and so forth, thus facilitating the body's faster recovery to normal. Traditional Chinese Medicine believes that sports fatigue may be caused by abnormal emotions, abnormal diet, and disorders of internal organs, which may manifest as difficulties in fatigue recovery, fatigue accumulation, and a decrease in resistance. Although TCM classifies sports fatigue into three categories, such as somatic fatigue, visceral fatigue, and mental fatigue, athletes do not have only one type of externally manifested symptoms, so relying on massage or stretching alone does not provide good relief [14]. A related study [15] concluded that stimulating the acupuncture points through vibration could effectively relieve athletic fatigue, with the best relief effect being achieved by the meridian points on the bladder, stomach, and large intestine [16]. Therefore, the present study was designed to vibrate and stimulate the meridian points on the bladder, large intestine, and stomach, and the related muscles using the tendon gun technique to observe the effect of different stimulation modes on relieving acute exercise fatigue.

The mode of action of the fascial gun technique is similar to that of vibration stimulation therapy in that it stimulates the muscles, fascia, and deep soft tissues by vibration to promote blood circulation; increases blood flow to the local tissues, thereby accelerating the elimination of metabolites; and stimulates the stretch reflex in the muscle spindle, thereby relaxing the muscles. The fascial gun is more convenient, compact, practical, and can be adjusted to different needs in terms of vibration frequency and stimulation surface [17]. The myofascial gun can relieve muscle tension and restore muscle condition by stimulating specific muscles or acupuncture points with certain frequencies of vibration and a specific stimulating gun head [18], effectively relieving subjective pain and improving explosive muscle force [18,19]. Studies revealed that a specific fascial gun stimulating acupuncture points could significantly improve explosive muscle force and play the same effect as meridian acupressure [20]. However, only a few studies to date reported on relieving acute sports fatigue using fascia guns in China and abroad; therefore, this study was conducted to observe the effect of the fascia gun technique in relieving acute sports fatigue based on multiple physiological indicators by designing different fascia gun stimulation methods.

4.1. Effects of different stimulus modalities on RPE scores

The subjective physical sensation scale (RPE) [21] is the most widely used scale in current sports medicine to determine exercise intensity and thus evaluate the degree of exercise-related fatigue, representing proprioceptive exercise intensity. The RPE scale reflects changes in subjective psychology, and changes in RPE are related to physiological variables such as HR and blood lactate concentration [22], reflecting changes in physiological function. It is an objective supplement to some physiological and biochemical indicators, and can accurately reflect the body function of in combination with physiological and biochemical indicators. The test results showed that after the intervention, the differences in RPE scores were significant in all the three groups ($P < 0.05$), and the differences were statistically significant ($P < 0.05$) between the two stimulation groups and the control group, while no differences were found between the two stimulation groups. This indicated that the subjective fatigue of the participants was significantly reduced when the acupoints and muscles were stimulated using the fascial gun, indicating that vibration relaxation is a mechanical, physical stimulation that stimulates the vegetative nervous system and thus causes a relaxation effect on the body, ultimately reducing the subjective fatigue.

4.2. *Effects of different stimulation patterns on the electrodermal activity*

Numerous studies [23,24] have shown that the autonomic nervous system, consisting of sympathetic and parasympathetic nerves regulated by brain activity in the brainstem, is involved during muscle contraction. The activation of the autonomic nervous system causes significant effects on the HR, blood pressure, and electrical skin activity. Electrical skin activity refers to changes in sweat gland activity and is mainly controlled by the sympathetic branch of the autonomic nervous system. When the sympathetic nerves are excited, the sweat glands are active, and sweat secretion subsequently increases, resulting in moist skin due to sweat filling, thereby decreasing epidermal electrical resistance and increasing skin conductance. This index can be used to directly assess mental fatigue and stress intensity [25–28]. As research advanced, the electrical skin activity could also be used to assess muscle fatigue and could be considered an alternative method for effectively monitoring muscle fatigue due to its easy availability from superficial electrodes and lack of invasiveness [24].

The results of this study showed that the differences in all values of SCL between the three groups were statistically significant, with significant differences in SCL (max), SCL (min), and SCL (mean) between the two stimulation groups after the intervention and the control group. No differences were found between the two intervention groups. A significant difference in SCL (v) was found between the acupoint stimulation and the control groups after the intervention. This difference in the acupoint stimulation group may be related to the meridian-visceral theory. The acupoints selected for this study were located in the lower visceral regulatory centers in the spinal nerve segment region, upstream to the visceral regulatory centers in the brain, and integrated to cause the corresponding visceral reflexes via sympathetic and parasympathetic efferents. It leads to changes in autonomic tone, modulates autonomic activity, and inhibits sympathetic activity; therefore, the SCL values in the acupuncture point group were higher than before the intervention. This resulted in higher SCL values in the acupoint stimulation group compared with the muscle stimulation group probably because the 30-Hz vibration frequency could promote the increase in muscle epidermal temperature by stimulating muscles. This, in turn, promoted the increase in blood flow, accelerated the elimination of metabolites such as lactic acid, prompted fatigue recovery, and reflexively inhibited sympathetic excitation.

4.3. *Effects of different stimulation modes on the electrocardiogram activity*

HRV has recently been used to quantify the autonomic activity of the heart after exercise because it can reflect sympathetic and parasympathetic changes through the frequency domain indexes hf, lf, and hf/l of HRV and can be used in combination with electrical skin activity to assess exercise fatigue and monitor exercise status [30]. Related studies [29–31] have shown that when the body is fatigued, sympathetic nerves are significantly active and parasympathetic nerve activity is reduced, resulting in an increase in the HR, a decrease in hf, and an increase in lf/hf. When the hf value increases, it represents an increase in vagal efferent activity, and when the lf/hf ratio decreases, a shift occurs from sympathetic to parasympathetic activity, which is consistent with the present study. The results showed that after the intervention, the differences in HR and HRV (hf) were statistically significant in all three groups, with statistically significant differences in HR in the two stimulation groups compared with the control group. The muscle stimulation group had a greater effect on the HR than the acupoint stimulation group and had a faster heart recovery rate. The differences in HRV (hf) in the acupoint stimulation group were statistically significant compared with the muscle stimulation group, and no differences were found between the two intervention groups compared with the control group. Although the values of lf and lf/hf in the acupoint and muscle stimulation groups were not statistically significant, the values before and after the intervention showed that lf in the two stimulation groups was still elevated after the intervention. The elevated lf reflected the enhanced sympathetic efferent activity, which might be because the fascial gun technique belonged to the vibration stimulation therapy, and the after-effect of the vibration stimulation therapy made the proprioceptive receptors remain in an excited state after a period of vibration [9]. The decrease in the lf/hf ratio represented an enhanced parasympathetic activity; the lf/hf value of the acupoint stimulation group decreased, while that of the muscle stimulation group remained unchanged. Further, the effect of the muscle stimulation and the control groups decreased after the intervention, which might be due to the effect of vibration stimulation on the muscle stimulation group alone and faster HR recovery after the exercise, thus delaying the parasympathetic magnitude of the decrease in sympathetic activity. Combined with the SCL index, it was therefore observed that the two stimulation groups were able to relieve sympathetic excitability, and the acupoint stimulation group was able to effectively relieve sympathetic excitability and enhance parasympathetic activity, while the muscle stimulation group did not have a significant modulation of parasympathetic activity possibly due to its ability to rapidly recover HR.

4.4. *Effects of different stimulation modes on SPO_2*

Oxygen saturation can reflect the stress level of the body's exercise load, and high-intensity exercise can lead to a significant decrease in the body's oxygen saturation. A study revealed that the different levels of fatigue caused by different exercise intensities correspondingly triggered changes in the body's physiological indicators, manifesting in the cardiovascular aspects of the recovery rate of oxygen saturation [32]. This was not consistent with the present study, which showed that the differences in the values of oxygen saturation in the three groups were not statistically significant. The post-intervention values were significantly lower than the pre-intervention values in this study, which might be because the participants were often trained in rowing sports and the differences in the physical quality of the participants, and their tolerance to fatigue varied.

Based on the results of the aforementioned physiological indicators, it was found that both the stimulation groups could affect RPE, HR, SCL (max), and SCL (mean), and the differences between the two groups were not significant. The acupoint stimulation group had significant effects on SCL (v) and HRV (hf), and the muscle stimulation group had significant effects on SCL (min). Therefore, it was concluded that using the fascial gun technique to stimulate either acupoints or muscles could alleviate acute exercise fatigue. The two groups were able to relieve acute motor fatigue using different mechanisms due to the different stimulation modes. Based on the physiological indices, it was concluded that the mechanism of relieving fatigue in the acupoint stimulation group involved its ability to relieve sympathetic excitability and enhance parasympathetic activity, while the mechanism of relieving fatigue in the muscle stimulation group involved its ability to regulate sympathetic activity.

Although this study provided a new research perspective and means to relieve acute exercise fatigue, it had some shortcomings. The HRV (hf), HRV (lf/hf), and SPO_2 values were not statistically significant, which might be due to individual differences. During the experiment, we ignored the biomechanical effect of the pressure applied by the fascial gun on the treatment site of the body and the changes in electrical resistance of different acupuncture points. These deficiencies need further investigations in future studies.

Ethical compliance

Research experiments conducted in this study using animals or humans were approved by the ethics committee and responsible authorities of our research organization. We followed all guidelines, regulations, and legal and ethical standards in terms of using humans or animals in this study.

Conflict of interest

The authors declare no conflicts of interest.

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