

Immediate Effect of Local Vibration Therapy for Sport-induced Fatigue Based on Traditional Chinese Medicine's Holistic Theory

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Introduction: Vibration therapy has been widely used and published in alleviating muscle fatigue. However, reports on applying vibration therapy based on the holistic theory of traditional Chinese medicine (TCM) remains limited. This study is to evaluate the immediate effect of vibration therapy on exercise-induced muscle fatigue.

Methods: For this retrospective parallel controlled study, all data were from a previously approved and completed clinical trial. Participants (n=40) in the clinical trial included local Greco-Roman wrestling and Judo athletes in south China. The participants were equally randomly divided into the intervention group (n=20) and control group (n=20). The intervention group received a seven-week vibration intervention-based TCM holistic theory combined with conventional therapy, such as stretching, massage, and flapping, while the control group only received the conventional therapy. Surface electromyography (sEMG) of the lumbar segment of erector spinae was measured for each participant pre- and postintervention, and the two-point discrimination thresholds of the data were differentiated and compared with panel data analysis.

Results: For the control group, the pre- and postintervention sEMG measure showed no significant difference ($p=0.333$), whereas significant difference ($p=0.004$) was observed for the intervention group. Further, the pre- and postintervention two-point discrimination test also showed a significant difference ($p=0.016$) for the intervention group.

Discussion: The application of vibration therapy based on TCM holistic theory may have an immediate effect in reducing sport-induced muscle fatigue from intensive training. Future larger sample size and robust designed clinical trial is warranted to evaluate the long-term effect of the intervention.

Keywords: holistic theory, traditional Chinese medicine, sport, muscle fatigue, vibration therapy

Introduction

Sport-induced fatigue and injury are prevalent among athletes. Since the beginning of this century, world sports have become more competitive. This is closely related to the advancement and breakthrough of world athletes in their physical and psychological capacity and long-term hard training.¹ At the same time, a research report also demonstrates that long-term intensive training and delayed exercise-induced fatigue management increase the likelihood for sport injury frequency and severity among athletes.² An epidemiological study showed that sport injuries average 3.6 times for all athletes, and physical exhaustion and lacking effective

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relaxation are among the leading causes for these injuries.³ Therefore, it is important to provide timely and appropriate management of these adverse events facing the athlete increasing intensive training and to prevent further injuries.

Vibration stimulation has been a common therapeutic practice in managing exercise-induced injuries during the last decade. Reports on vibration stimulation can be characterized as whole-body vibration and local vibration, the former is more commonly used than the latter, and together they provide multifrequency and multi-amplitude vibration modes.^{4,5} Further, a study showed that whole body vibration is positively associated with delayed onset of muscle soreness and decreased athletic performance ability,⁶ as well as increased muscle strength and muscle fatigue relaxation both during and after excises or training.^{7,8} However, strong evidence for these reported outcomes remains limited by insufficient sample size and study designs.

Sports fatigue, in traditional Chinese medicine (TCM), can be classified as three major types (ie, physical, visceral, and mental fatigue) with different syndromes (eg, exercise-induced insomnia, spleen-stomach dysfunction, and kidney qi or chi deficiency). Often, an athlete can have multiple syndromes and these syndromes can mutually affect each other at the same time.⁹ Furthermore, these syndromes can lead to sports injury and negatively affect the quality of training. In view of exercise physiology and TCM, the athletes' local muscle fatigue or injury include physical problems, diet abnormalities, viscera disorders, sleep and emotion abnormalities, and mental disorders, manifesting the difficulty to recover from fatigue, accumulation of fatigue, resistance decline and frequent sports injury in relation to qi movement disorders. In TCM, local muscle fatigue and/or injury refers to exterior or manifestation, called local problems; while diet, sleep and emotion abnormalities are known as interior or root cause, named holistic problems.

It is difficult to obtain satisfactory effect to ameliorate muscle fatigue and sports injury only through therapies like local stretching, massage and physiotherapy, which are usually used for the motor system. In a completed clinical study titled Establishment and Empirical Research—The Evaluation and Maintenance System of Athletes' Physical and Mental Holistic View (project ID: 2012B083), we applied vibration stimulation based on TCM's holistic theory among participant athletes. Specifically, in the study, the holistic intervention

meant the systematic local vibration stimulating the governing meridian, the foot-bladder meridian, and the hand-triple yin meridian as well as the acupoints distributed along the meridians. These meridians and acupoints are assumed helpful in regulating bodily functions for athletes' holistic problems and harmony. Whereas the local intervention refers to local vibration stimulating the related muscle group and its local meridian acupoints. Theoretically, the intervention mode combined with local and holistic intervention can address both symptoms and root causes, and hence better eliminate or improve muscle fatigue from athletes' excessive training. The clinical study is detailed in the methods section. The purpose of the current study is to retrospectively assess the immediate effect of the holistic theory guided vibration therapy on exercise-induced muscle fatigue.

Methods

Study Design

This is a retrospective parallel controlled cohort study and our study data were collected from a completed clinical study in 2015. The clinical study was scientifically reviewed, ethically reviewed and approved, and funded by China National Sports Bureau (project number: 20128083).

Study Subjects

The inclusion criteria for both the interventional and control group were male, first-line athletes from China's Jiangsu Provincial Greco-Roman Wrestling Team and Judo Professional Team. There would have been both male and female athletes from professional teams of Greco-Roman style wrestling, freestyle wrestling, judo and boxing. However, because of the training sites for different teams, the personnel transfer to the national team and the sports injuries or illnesses of several athletes, it turned out that only male athletes from China's Jiangsu Provincial Greco-Roman Wrestling Team and Judo Professional Team could fit the experimental design. The 40 participants were equally assigned into the intervention group (n=20) and control group (n=20), and the two groups of participants are comparable in sharing the same coach, same training schedule, and same training strategies. All study participants provided informed consent in compliance of the guidelines outlined in the Declaration of Helsinki. In addition, the current retrospective study was also approved by the Science and Technology Office of Hohai University in Nanjing, China.

The Intervention Group

Participants in this group received a combination therapy of conventional therapy (the therapy is detailed in the control group section) and vibration therapy based on TCM theory.

TCM holistic intervention: according to the TCM theory, the root causes of the intensive training induced holistic signs and symptoms lies in the malfunction and disorders of the visceral system, mind, and qi circulation. The following three meridian systems were selected during the clinical study for their ruling function of the bodily visceral systems: the governing meridian, the foot-bladder meridian, and the hand-triple yin meridian. These three meridians are illustrated in Figure 1A–C, respectively. During the clinical study, the multidimensional vibration apparatus (see Figure 2A and B) was applied to roll each of the meridian from top to bottom. Such orderly operations help readjust the meridian, blood and qi, regulate the blood and qi flow, calm down the disturbed vitality, and promote the function of the visceral systems.

Local Intervention

It has been widely accepted that muscle fatigue recovery can be achieved through the following conceptual framework. Stimulating relevant acupoints along the meridians helps improve meridian function, restore yin-yang balance, and nourish muscles which in turn promotes muscle



A



B

Figure 2 (A) Multidimensional Vibration Meridian Instrument. **(B)** Multidimensional Transacupoint Vibration Instrument.

Note: Figure 2A and B show the different instruments that were used for vibration therapy during the intervention.

fatigue recovery. According to the protocol of the clinical study, local intervention consists of the following three steps: (1) identify the pain points and/or the muscles with adverse reactions; (2) apply the multivibrator

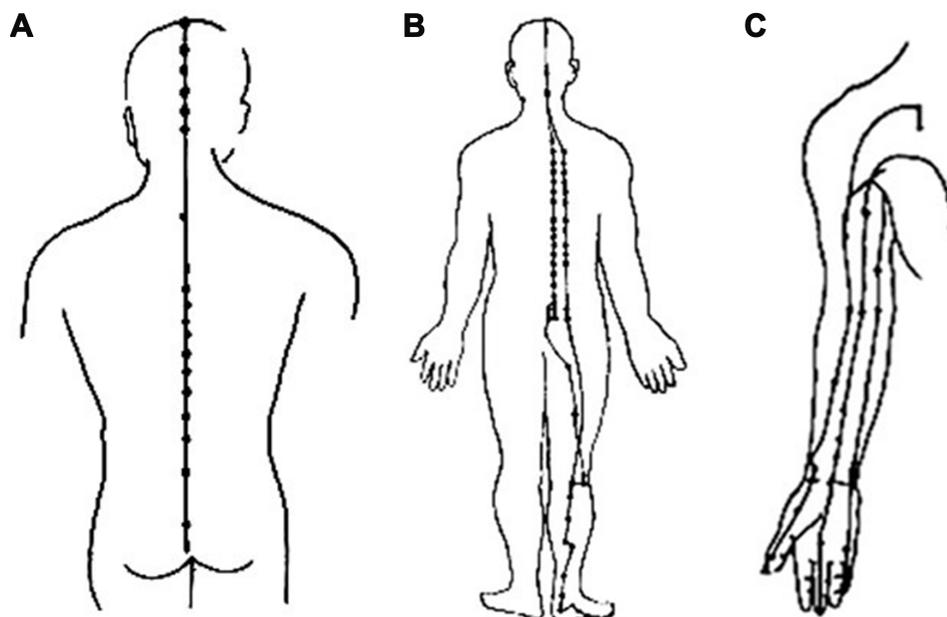


Figure 1 (A) Governing meridian. **(B)** Foot-bladder meridian. **(C)** Hand-triple yin meridian.

Notes: Figure 1A–C illustrate the Traditional Chinese Medicine's meridians that were adopted to guide the local vibration therapies during our intervention.

for meridian and muscle along the affected muscle group and meridian blocks by rolling back and forth for three minutes; (3) apply (ie, point press) the multivibrator for muscle and point on the pain points and/or meridian points by point-pressing for 6–10 min. These steps have been commonly practiced by athletes in the management and prevention of sport-induced muscle fatigue and muscle injuries. In this study, the intervention of vibration therapy guided by TCM meridian holistic theory is primarily demonstrated by the combination of holistic intervention with the local intervention as well as the integration of bodily signs and symptoms with the root of the disorders, in order to improve the outcomes of sport-induced muscle fatigue and injuries.

Stimulator Device Used

In this study, the precise training-rehabilitation combination apparatus (model: GH D/GI-001) was selected. Specifically, two devices ie, (1) the multivibrator of meridian and muscle for holistic stimulation, and (2) the multivibrator of muscle and point for local stimulation) of the apparatus were adopted and applied. The parameters of vibration frequency were pre-set to 45 Hz and 52 Hz.

Intervention Procedures and Schedule

The training season for the participating athletes lasted for seven weeks with one week as a training cycle during February and March 2013. In the meantime, the holistic stimulation was conducted twice a week (every Tuesday and Friday), for 1.5 h duration following the athletes' post-training bath and dinner. The Tuesday session was aimed at exercise-induced muscle fatigue recovery from the two-day intensive training on Monday and Tuesday, while the Friday session was aimed at recovering the one-day moderate training on Friday and preparation for the next intensive training cycle. The conventional intervention was given every day except Tuesday and Friday. The duration of each session was 45 min in the sequence of holistic intervention first and then the local. The operation was completed by the trained assistant study practitioners, supervised and guided by team doctors.

The Control Group

This participants in this group only received the conventional intervention. Conventional intervention, for this study, mainly included therapies such as muscle stretching,

massage, and flapping. These therapies are regularly used for the athletes.

Measurements

Surface electromyography (sEMG-16) in the study is from Shanghai Noucheng Electric Co. Ltd. The video and waveform of myoelectricity can be collected synchronously by a built-in surface myoelectricity signal amplifier (frequency response: 5–500 Hz, error <5%, center distance between two electrodes: 2 cm). The sEMG was used to measure the activities of the lumbar segment of the right erector spinae before and 15 min after the intervention. During the test, the subjects were asked to lie on their stomach on a flat mat, raise hands on their head and bend both ends of the body to the maximum extent, like fly-bird-type static pose (see Figure 3). The measurement was implemented right after the pose was kept stably, and it lasted for 30 seconds. All the subjects were requested to understand the demands of the test and movement essentials clearly with attention concentrated. The surface test electrode was pasted on the most bulge of the measured muscle belly (see Figure 3) and the grounding electrode was at anterior superior iliac spine. The operation was strictly in accordance with requirements of the manual with disposable electrodes.

sEMG Indicators Analysis

sEMG signal refers to the time-series signal of biological point changes of neuromuscular system when the muscle activity is guided and recorded from the muscle surface, which can reflect the sum of the bioelectrical activities of multiple exercise units touched by the electrode in time

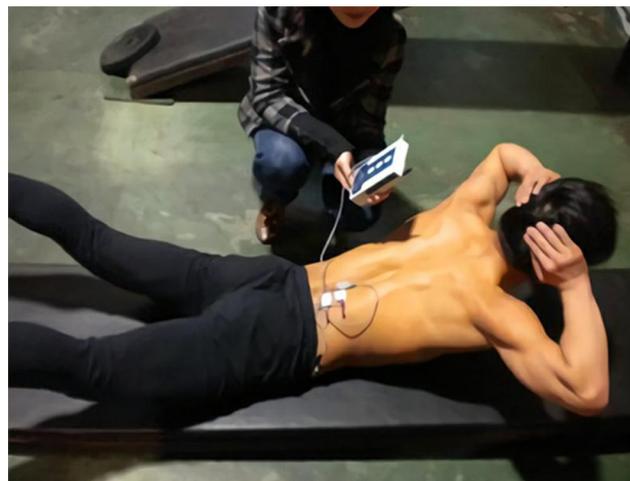


Figure 3 Fly-bird Type.

Note: The body position for the stimulation known as the fly-bird type.

and space.^{10,11} Under the ideal condition, the sEMG signal can objectively reflect the changes of local muscle fatigue to some extent, as sEMG has the advantages of being a noninvasive, simple, dynamic and multitarget measurement. sEMG is representative and thus is suitable for local muscle function evaluation and measurement. It can also be used to evaluate muscle fatigue, predict muscle fiber type, evaluate muscle strength, test the coordination of muscle activities, and be applied to the rehabilitation of muscle function.¹² The common indicators include integral electromyogram, root mean square, median frequency, and mean power frequency. We selected the decline slope of median frequency and mean power frequency as the muscle fatigue index to evaluate the extent of local muscle fatigue. Changes of median frequency and mean power frequency in fatigue are the highlighted objects of many scholars.^{13–15} Generally, the information related to fatigue during muscle activities is reflected in the amplitude and frequency of sEMG signal. The amplitude increases while the frequency decreases, wherein frequency change is more accurate for showing the information. When median frequency and mean power frequency are used to describe the overall change rule of sEMG signal spectrum in each frequency component, it is found that the occurrence and development of muscle fatigue is generally accompanied by the decline of MF and MPF. The decline slope is inversely proportional to the immediate functional state of muscle, namely the smaller the value of median frequency and mean power frequency, the higher the extent of muscle fatigue.

Two-point Discrimination Test

We measured the two-point discrimination thresholds of the muscle which may manifest adverse symptoms after intensive training such as fatigue soreness, stiffness, or activity limitation at pre- and post-test. Two-point discrimination threshold is defined as the minimum distance which we used to distinguish two contacts on the skin and to evaluate fatigue. When the tactile stimulus acts on the human body, the afferent nerve fibers transmit the signals from the specific cutaneous receptors to central nervous system for comprehensive analysis, generating tactile sense. If the examiner stimulates two points at the same time, subjects can distinguish two-point discrimination only when the distance between two points is large enough, or they will merely feel “one” stimulus point when reducing the distance to a certain threshold. The tactile sense will decrease

when fatigue accumulates, so the increment of the threshold can be a valid fatigue indicator proportional to the fatigue.¹⁶ Two-point discrimination threshold gauge (BT-U201A, Beijing Zhonghui Tiancheng Technology Co. Ltd) in the study mainly consists of a vernier caliper and three stimulus points. The stylus A and B are located at both ends of the caliper respectively, the measuring range is 0–130 mm, and the reading accuracy is 0.02 mm; meanwhile, the stylus C is located at the upper end of the caliper. (See Figure 4) Each subject was asked to sit without knowing the measure sites. The examiner placed two styluses vertically and gently on the measure site with equal pressure for two seconds. Five specific values of two-point distance would be identified in the test by decreasing or increasing the spacing between styluses. The number of stimuli were not less than 10 at least for each distance with an interval more than five seconds. After stimulus was exerted, the subject should report immediately whether the number of stimulus points was one or two. The minimum distance where the subject can feel “two” stimulus points would be identified as two-point discrimination threshold of the tested skin. Stylus C was used in the catch trial to verify the consistency of the report. The whole test was arranged right after sEMG. The collected data would be compared to verify the immediate effect of the given intervention.

Statistical Analysis

All our study data were analyzed by using Statistical Package for the Social Sciences (SPSS v. 11.5). The observed data in the study have the following two characteristics: (1) the data of the intervention and control group are composed of time-series of repetitive measurements of the same athlete at

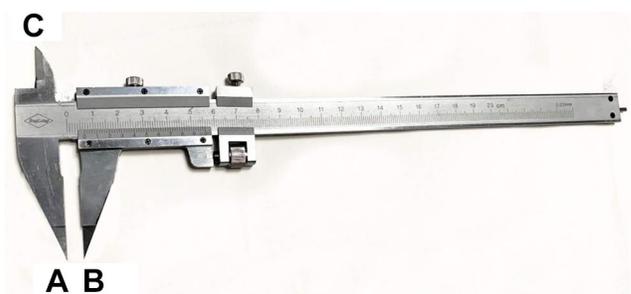


Figure 4 The Two-point Discrimination Threshold Gauge.

Notes: Figure 4 illustrates the Two-point Discrimination Threshold Gauge that was used to measure the accuracy of the pain and fatigue location. In the figure, “A” and “B” were used to measure and obtain pain and fatigue threshold value, and “C” was applied to test and confirm that the threshold was not participant’s subjective feeling.

different times; (2) the sample size is relatively small due to the limited number of top athletes, meanwhile, some of participants dropped out of the trial due to injury or national team recruitment. As a result, the data in this study do not meet the independence and normality hypotheses of the grouping mean *t* test, and it is not eligible to use the conventional *t* test to make intergroup comparison. Therefore, we adopted panel data for modeling and analysis. Panel data is hierarchical or multilevel data fused with time-series data and cross-section data. Panel data analysis method has been well established and widely applied by researchers.¹⁷⁻¹⁹ In view of the missing panel data in the study, the mixed linear model is adopted to analyze and process the test data and discuss the differences.²⁰⁻²²

The pre- and post-test results were regarded as binomial group, and the mixed linear model (see below) was constructed. We set binomial variable x_h representing the grouping of status at the pre- and post-trial, t_{ij} as time factor as group

$$x_h = \begin{cases} 1 & \text{pre - intervention marker} \\ 2 & \text{post - intervention marker} \end{cases} \quad (1)$$

marker, $i = 1, 2, \dots, m$ as athlete number, $j = 1, 2, \dots, n$ as time. The dependent variable y_{hij} represented muscle fatigue indicators, affected by three factors: grouping, athlete, and time. Thus, we can use triple subscripts to identify the dependent variable and construct a mixed linear model of factorial effect:

$$y_{hij} = \beta_0 + \beta_1 t_{ij} + \beta_2 x_h + \epsilon_{hij} \quad (2)$$

Model A

The random variable ϵ_{hij} followed Gaussian distribution with a mean value of 0 and a variance of white noise of σ^2 . Regression coefficients are validated by statistical test to analyze the influence of independent

variables. If regression coefficient β_1 is significant, it means muscle fatigue indicators are significantly affected by time; if regression coefficient β_2 is significant, it suggests the indicators are significantly affected by grouping. In this paper, $p < 0.05$ is set as significant difference in statistics.

Results

This study included 40 participating athletes who were equally assigned to the two study arms. Table 1 shows the statistical results from our mixed linear equation of sEMG data measured from the lumbar segment of the right erector spinae pre- and postintervention. As shown, both the time and grouping effect were not significant ($p = 0.333$ and $p = 0.449$) in the control group, but they were significant ($p = 0.031$ and $p = 0.004$) in the intervention group. These results suggest that the intervention group had a significant change in sEMG measure compared to the pre- and post-data, whereas the change was not significantly detected in the control group.

Table 2 demonstrates the results from our two-point discrimination analysis. It shows that time effect was not significant ($p > 0.05$) regression coefficient β_1 analysis. Nonetheless, grouping effect remains significant ($p < 0.05$) in regression coefficient β_2 analysis. These results revealed the significant differences between the pre- and postintervention in the intervention group.

Discussion

This study contributes to current literature in assessing the immediate effect of local vibration therapy for sport-induced fatigue based on TCM’s holistic theory. In the study, we have compared the sEMG of lumbar segment of right erector spinae between the study control group and the intervention group. Consistently we found statistically

Table 1 Mixed Linear Model Test Results of sEMG

	Molecular df	Denominator df	F	p-value
Control Group				
Intercept	1	7.877	52.14	0.000
Time	15	112.015	1.137	0.333
Group	1	110.133	0.579	0.449
Intervention Group				
Intercept	1	5.692	113.471	0.000
Time	15	118.953	1.883	0.031
Group	1	118.158	8.630	0.004

Notes: Table 1 shows the results of our mixed linear model test of the pre- and post-sEMG data; As shown, the intervention group had a significant change in sEMG measure as comparing the pre- and post-data ($p < 0.05$), whereas the change was not significantly detected in the control group ($p > 0.05$).

Table 2 Intervention Group Mixed Linear Model Test Results of Two-point Discrimination Threshold

	Molecular df	Denominator df	F	p-value
Intercept	1	11.575	266.038	0.000
Time	5	22.806	1.638	0.190
Group	1	17.110	7.112	0.016

Notes: Table 2 demonstrates the results from our two-point discrimination analysis. It shows that time effect is not significant ($p > 0.05$), whereas the grouping effect is significant ($p < 0.05$); These results revealed the significant differences between the pre- and postintervention in the intervention group.

significant positive effect of the intervention. First, our mixed linear model of the panel data showed a significant difference ($p < 0.05$) both in time and grouping effect between the pre- and post-sEMG data in the intervention group, whereas the significance ($p > 0.05$) was detected in the control group (Table 1). Furthermore, our two-point discrimination threshold model test (paired-comparison) showed that the time effect was not significant ($p > 0.05$), while the grouping effect was significant at $p < 0.05$ (Table 2). Our findings suggest that local vibration therapy based on TCM's holistic theory could have an immediate effect in reducing sport-induced muscle fatigue from intensive sport training.

In a separate satisfaction survey (unpublished) about the effect of the same intervention, we enrolled 42 participants who were national top and/or world-champion professional athletes. The survey instrument we created and used consists of five items with a five-point scale: one for not effective at all and five for very effective. With the instrument, participant satisfaction is established if an item is scored three points or more of the effect on the intervention. The content of the instrument is closely related to this paper. The preliminary results showed that majority of the participants reported satisfaction of local vibration therapy on their holistic health (ie, appetite improvement with 83% satisfaction, sleep improvement with 81% satisfaction, and physical symptoms amelioration with 90% satisfaction) and on their bodily local problems (ie, muscle relaxation with 97.8% satisfaction and fatigue recovery with 100% satisfaction).

A large number of studies have shown that vibration stimulation is effective to dredge meridians and better inspire corresponding acupoints. Especially, the vibration in the frequency of 45 Hz~52 Hz can promote heat production of tissues effectively, cause changes of peripheral circulation, expand muscle capillaries to improve

substance exchange and metabolism of muscles,²³ increase the extent of muscle activation,^{24,25} improve the lubrication between the aponeurosis, increase the range of joint motion, and prevent sports injury.²⁶ Furthermore, studies also demonstrated that vibration can improve bone mineral density and bone formation,²⁷ increase the amount of hemoglobin and oxygenated hemoglobin in muscles,²⁸ enhance the rapid strength of muscles,²⁹ stimulate proprioceptors of muscles, especially endings of primary muscle spindle 1a afferent fibers,³⁰ make selective hypertrophy of muscle fibers, and increase the activity of metabolic enzyme creatine kinase in skeletal muscle cells.³¹ During vibration stimulation training, the muscle proprioceptors stay excited to a certain extent; the nerve impulses give rise to slight and continuous alternating contraction of muscles, and the permeability of cell membrane to harmful substances is enhanced. Immediately after the vibration stimulation, the blood flow volume to the skin continuously increases, the blood flow to the skin will accelerate, and the temperature will be relatively high. The acceleration of blood flow benefits the transport of oxygen, the exchange of substances, and the improvement of metabolism speed. On the one hand, its antifatigue ability is enhanced, and on the other hand, it is also conducive to the rapid elimination of physical fatigue.³² This is also an important basis for us to select multi-dimensional vibration instrument and relevant meridian points for holistic or local intervention in the intensive training phase.

Research shows that the higher level of sports and the more intensive training would increase the risk and rate of sport injury. This is particularly the case when sport-induced fatigue is not appropriately managed and fully recovered. In spite of the advancement made in the field of sport-protection and rehabilitation methods and equipment, the existing conventional intervention remains unable to achieve the ideal outcomes, particularly for top professional athletes who often requires prolonged intensive training and have increased risks for injuries. Therefore, findings from this study may fill the gap by contributing an innovative vibration therapy approach in addressing sport-induced fatigue and preventing and reducing sports injuries.

Our study has several limitations. First, our sample size is small. This is limited by the design of the original clinical study focusing on the top professional athletes of a Provincial Greco-Roman Wrestling Team and Judo

Professional Team. There would have been both male and female athletes from teams of Greco-Roman style wrestling, freestyle wrestling, judo and boxing. However, because of the changing training sites for different teams, the personnel transfer to the national team and the sports injuries or illnesses of several athletes, it turned out that only male athletes from China's Jiangsu Provincial Greco-Roman Wrestling Team and Judo Professional Team could fit the experimental design. To address this issue in our data analyses, we have adopted an appropriate statistical method and multidimensional demonstration method. Second, like other retrospective studies, we should pay more attention to the generalization of our study findings when explaining and understanding the study results. Finally, his paper focuses on the immediate effect of the intervention. It would be interesting and important to study the long-term effect of the intervention in the future studies with a larger sample size.

Conclusion

This study contributes to the literature and field of vibration therapy practice in providing the immediate effect of local vibration therapy for sport-induced fatigue based on the holistic concept of traditional Chinese medicine. First, using pre- and postintervention sEMG parameters as the outcome measure for the intervention and control groups, our analytic results showed that the intervention had a positive effect than the conventional therapy on eliminating or improving athletes' muscle fatigue from excessive training. Second, results from our two-point discrimination threshold data further confirmed the above positive findings on the pre- and posteffect of the intervention.

These findings demonstrated that application of vibration therapy based on TCM holistic theory could have an immediate effect in reducing sport-induced muscle fatigue from intensive training. Future larger sample size and robust designed clinical trial is warranted to evaluate the long-term effect of the intervention.

Disclosure

The authors report no conflicts of interest in this work.

References

- Horpe RT, Atkinson G, Drust B, Gregson W. Monitoring fatigue status in elite team-sport athletes: implications for practice. *Int J Sports Physiol Perform.* 2017;12(Suppl 2):S227–S234. doi:10.1123/ijssp.2016-0434
- Yao L. Epidemiological investigation and analysis on sports injury of elite track and field athletes in China. *J Beijing Sport Univ.* 2007;30(3):363–366.
- Yin HG. Epidemiological investigation of sports injury of Chinese first-class throwers. *Sports Res Educ.* 2016;31(3):104–108.
- Alam MM, Khan AA, Farooq M. Effect of whole-body vibration on neuromuscular performance: a literature review. *Work.* 2018;59(4):571–583. doi:10.3233/WOR-182699
- Alghadir AH, Anwer S, Zafar H, Iqbal ZA. Effect of localised vibration on muscle strength in healthy adults: a systematic review. *Physiotherapy.* 2018;104(1):18–24. doi:10.1016/j.physio.2017.06.006
- Lu X, Wang Y, Lu J, et al. Does vibration benefit delayed-onset muscle soreness? A meta-analysis and systematic review. *J Int Med Res.* 2019;47(1):3–18. doi:10.1177/0300060518814999
- Iodice P, Bellomo RG, Gialluca G, et al. Acute and cumulative effects of focused high-frequency vibrations on the endocrine system and muscle strength. *Eur J Appl Physiol.* 2011;111(6):897–904. doi:10.1007/s00421-010-1677-2
- Custer L, Peer KS, Miller L. The effects of local vibration on balance, power, and self-reported pain after exercise. *J Sport Rehabil.* 2017;26(3):193–201. doi:10.1123/jsr.2015-0125
- Zhang S, Ye R, Yu Y, Ma J, Liu B, Liang Y. The categories and diagnostic standards in Chinese traditional medicine for athletic fatigue (in Chinese). *Chin J Sport Med.* 2003;22:47–51.
- Disselhorst-Klug C, Schmitz-Rode T, Rau G. Surface electromyography and muscle force: limits in sEMG–force relationship and new approaches for applications. *Clin Biomech.* 2009;24(3):225–235. doi:10.1016/j.clinbiomech.2008.08.003
- Merletti R, Rainoldi A, Farina D. Surface electromyography for noninvasive characterization of muscle. *Exerc Sport Sci Rev.* 2001;29(1):20–25. doi:10.1097/00003677-200101000-00005
- Cifrek M, Medved V, Tonkovi S, et al. Surface EMG based muscle fatigue evaluation in biomechanics. *Clin Biomech.* 2009;24(4):327–340. doi:10.1016/j.clinbiomech.2009.01.010
- Hägg GM, Luttmann A, Jäger M. Methodologies for evaluating electromyographic field data in ergonomics. *J Electromyogr Kinesiol.* 2000;10(5):301–312. doi:10.1016/S1050-6411(00)00022-5
- Petrofsky JS. Computer analysis of the surface EMG during isometric exercise. *Comput Biol Med.* 1980;10(2):83–95. doi:10.1016/0010-4825(80)90025-6
- Crenshaw AG, Karlsson S, Gerdle B, et al. Differential responses in intramuscular pressure and EMG fatigue indicators during low- vs. high-level isometric contractions to fatigue. *Acta Physiol Scand.* 2010;160(4):353–361. doi:10.1046/j.1365-201X.1997.00168.x
- Han J, Park S, Jung S, et al. Comparisons of changes in the two-point discrimination test following muscle fatigue in healthy adults. *J Phys Ther Sci.* 2015;27(3):551–554. doi:10.1589/jpts.27.551
- Baltagi BH. *Econometric Analysis of Panel Data.* 3rd ed. New York: John Wiley and Sons; 2005.
- Xiao Z. *Analysis of Panel Data.* 2nd ed. Beijing: Peking University Press; 2003:1–4.
- Wu SB. *The Application of Mixed Model of Panel Data Regression Spline.* Xianning (Hubei): Hubei University of Technology; 2017:9–14.
- Chen WW. *Analysis Physical Fitness of 60 to 69-Year Old People in Jiangxi Province Based on Spatial Panel Model.* Nanchang (Jiangxi): East China Jiao tong University; 2016:16–18.
- Yu J, Liu X. Urbanization, social security expenditure and income gap between urban and rural areas—empirical evidence from provincial panel data in China. *Econ Geogr.* 2014;34(03):79–84+120.
- Chen HY. *The Analysis and Application of Panel Data Model.* Tianjin: Tianjin University; 2007:17–20.
- Issurin VB. Vibrations and their applications in sport: a review. *J Sports Med Phys Fitness.* 2005;45(3):324–336.
- Johnston RM, Bishop B, Haven CG. Mechanical vibration of skeletal muscles. *Phys Ther.* 1970;50(4):499–505. doi:10.1093/ptj/50.4.499

25. Clarkson PM, Zigon ST, Kamen G. Post vibratory effects on fractionated reaction time and maximum isometric strength. *Am J Phys Med.* 1980;59(6):271–279.
26. Houston MN, Hodson VE, Adams KKE, et al. The effectiveness of whole-body-vibration training in improving hamstring flexibility in physically active adults. *J Sport Rehabil.* 2015;24(1):77–82. doi:10.1123/jsr.2013-0059
27. Lau RWK, Liao LR, Yu F, et al. The effects of whole-body vibration therapy on bone mineral density and leg muscle strength in older adults: a systematic review and meta-analysis. *Clin Rehabil.* 2011;25(11):975–988. doi:10.1177/0269215511405078
28. Games KE, Sefton JM. Whole-body vibration influences lower extremity circulatory and neurological function. *Scand J Med Sci Sports.* 2013;23(4):516–523. doi:10.1111/j.1600-0838.2011.01419.x
29. Luo J, McNamara B, Moran K. The use of vibration training to enhance muscle strength and power. *Sports Med.* 2005;35(1):23–41. doi:10.2165/00007256-200535010-00003
30. Roll JP, Vedel JP, Ribot E. Alteration of proprioceptive messages induced by tendon vibration in man: a microneurographic study. *Exp Brain Res.* 1989;76(1):213–222. doi:10.1007/BF00253639
31. Gojanovic B, Feih L, Liaudet L, et al. Whole body vibration training elevates creatine kinase levels in sedentary subjects. *Swiss Med Wkly.* 2011;141:w13222.
32. Lohman EB, Petrofsky JS, Maloney-Hinds C, et al. The effect of whole-body vibration on lower extremity skin blood flow in normal subjects. *Med Sci Mon.* 2007;13(2):CR71–6.

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