Research on the Specificity of Electrophysiological Signals of Human Acupoints Based on the 90-Day Simulated Weightlessness Experiment on the Ground

Yun Wang, Zhiqi Fan, Mixia Wang, Juntao Liu, Shengwei Xu, Zeying Lu, Hao Wang, Yilin Song, Yiding Wang, Lina Qu, Yinghui Li, and Xinxia Cai

***Abstract*—Acupoint specificity for diseases has consistently been the focus of acupuncture research owing to its excellent prospects for clinical diagnosis and treatment. However, the specificity of cardiovascular and sleep functions in terms of electrical signals at acupoints remains unclear. In this study, five volunteers were recruited and their electrophysiological signals of GV20 (baihui), RN17 (danzhong), PC6 (neiguan), and SP6 (sanyinjiao) and the corresponding sham points, Pittsburgh sleep quality index, blood pressure, and echocardiography were monitored over four periods of 90-day head-down bed rest (HDBR). The results demonstrated that the power and characteristic amplitude of the acupoints were more significant than those of the sham points under normal conditions. And along with the altered physiological condition of the body after HDBR, the differential signal characteristic amplitude (DSCA) and the power of the acupoints were decreased to a larger extent than those of the sham points. In addition, the difference between the power of acupuncture and sham points was also reduced. During the recovery period, except for GV20, the power and DSCA of other acupoints did not return to normal. In terms of DSCA, GV20 is related to human sleep function and other acupoints are related to cardiovascular function. The above results show that the electrophysiological signals of acupoints are disease-specific and more accurately reflect the changes of physiological homeostasis. The research conduces to the development of acupuncture-based disease diagnosis and treatment integrated methods, and the realization of the portable and accurate diagnosis and regulation of diseases in space medicine.**

***Index Terms*—Acupoint specificity, electrophysiological signal, head-down bed rest, disease diagnosis.**

Manuscript received May 6, 2021; revised September 24, 2021; accepted October 12, 2021. Date of publication October 15, 2021; date of current version October 28, 2021. This work was supported in part by the National Key Research and Development Program of China under Grant 2017YFA0205902; in part by the National Natural Science Foundation of China under Grant 61960206012, Grant 62121003, Grant 61975206, Grant 61971400, Grant 61973292, Grant 61775216, and Grant 61771452; in part by the State Key Laboratory of Space Medicine Fundamentals and Application, Chinese Astronaut Research and Training Center under Grant SMFA19K05; in part by the Scientific Instrument Developing Project of the Chinese Academy of Sciences under Grant GJJSTD20210004; in part by the China Manned Space Advanced Research Project under Grant ES-2-NO.0027; and in part by the Youth Innovation Promotion Association, Chinese Academy of Sciences (CAS). *(Corresponding authors: Xinxia Cai; Yinghui Li.)*

This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by the Ethics Committee of the China Astronaut Research and Training Centre, and performed in line with the Principles of the Declaration of Helsinki.

Yun Wang, Mixia Wang, Juntao Liu, Shengwei Xu, Zeying Lu, Hao Wang, Yilin Song, Yiding Wang, and Xinxia Cai are with the State Key Laboratory of Transducer Technology, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing 100190, China (e-mail: xxcai@mail.ie.ac.cn).

Zhiqi Fan is with the College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen 518060, China.

Lina Qu and Yinghui Li are with the State Key Laboratory of Space Medicine Fundamentals and Application, China Astronaut Research and Training Center, Beijing 100094, China (e-mail: yinghuidd@vip.sina.com).

Digital Object Identifier 10.1109/TNSRE.2021.3120756

I. Introduction

ACUPUNCTURE is an important component of Traditional Chinese Medicine and has been popular and accepted among healthcare professionals worldwide [1]. Studies have confirmed that RN17 [2] (danzhong), PC6 [3] (neiguan), and SP6 [4] (sanyinjiao) showed promising efficacy in the treatment of cardiovascular diseases. Similarly, the GV20 [5] (baihui) acupoint can improve the sleep conditions in animal and volunteer studies. Functionally, the acupoint specificity is an important indicator of the pathological and physiological state of the human body. Studies have shown that changes in acupoints status are highly associated with the condition of internal organs [6]–[8], which may be resulted from the cutaneous neurogenic inflammation [9]–[12]. Acupoint specificity provides a potential method for quantifying acupoint characteristics and disease diagnosis [13]. Acupoint specificity has been verified from iconography [14], heat [15], morphology [16], [17], electricity [18]–[20], etc. The analysis of bioelectrical signals of acupoints is an important method to study acupoint specificity, which is critical for clinical diagnosis and treatment. At present, research on the electrical signals of human acupoints is divided into electrical impedance analysis and potential analysis [21]. In this study, the electrical potential of the acupoints was selected as the research object.

Weightlessness is an extreme environment that alters the cardiovascular system and sleep conditions [22], [23]. Head-down bed rest (HDBR), ranging from several hours to several months, has been widely used to simulate the physiological effects of weightlessness. Since 1986, most experiments have been performed using the −6° HDBR model in male volunteers [24]. Studies show that long-term HDBR can lead to heart damage [25], a reduction in plasma volume [26], changes in blood pressure [25], brain nerve disorders [27], [28], and sleep disorders [29]. It remains a challenge to relieve and treat weightlessness related dysfunctions for current aerospace medicine. Research on the HDBR model will deepen our understanding of the physiological condition of living organisms in space and conduce to the development of space medicine.

In this study, we collected the electrophysiological signals of GV20, RN17, PC6, SP6, and their corresponding sham points, as well as the blood pressure, echocardiography, and Pittsburgh sleep quality index (PSQI) of the volunteers who were in HDBR for 90 days. The results show that the electrophysiological signals at RN17, PC6, and SP6 are specific for cardiovascular function, and GV20 is specific for sleep function.

II. Materials and Methods

A. Subjects

The present study was a participating project of the 90-day HDBR project, held by the China Astronaut Research and Training Centre in Shenzhen in 2019. Five healthy male volunteers (age: 31 ± 4 years; weight: 65 ± 5.2 kg; height: 167.8 ± 4.7 cm) were used in the experiments. The study was approved by the ethics committee of the centre, per the principles of the Declaration of Helsinki. Before agreeing to participate in the experiment, all subjects received oral and written explanations regarding HDBR and the test. Subjects were free to withdraw from the study.

B. Apparatus

The ME-16-USB System (Multichannel Systems, Germany) was used for bioelectricity signal acquisition synchronously. The sample rate was set to 30 kHz and the amplification factor was set to 1000. A needle (0.25 mm × 40 mm) was used as the working electrode (Fig. 1), which was made of austenitic stainless steel (06Cr19Ni10) by Hwato (China) and inserted into acupuncture points and sham points (15 mm to the right of the acupuncture points). Two surface electrodes were used as the reference electrode and ground, respectively. R7EXP (Mindray, China) was used to detect echocardiography.

C. Head-Down Bed Rest

As shown in Fig. 2a, the subjects were asked to lie at exactly −6° HDBR for 90 days. The subjects completed all daily activities in the −6° head-down posture, such as eating, washing, bathing, urinating, defecation, and entertainment. By using a movable −6° transfer bed, volunteers were transferred to

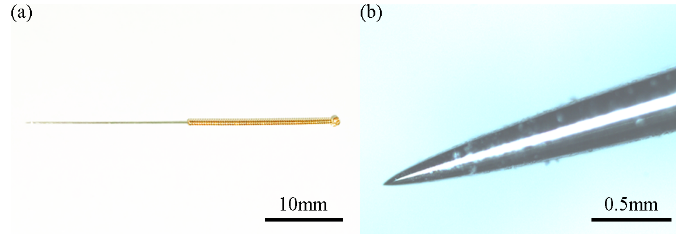

Fig. 1. Acupuncture needle appearance. (a) The overall picture of the needle body (0.25mm * 40mm). (b) Tip morphology.

a quiet room at 26°C ± 1.5°C (temperature) and 65 ± 5% (humidity) for acupuncture and data acquisition. The subjects had 15 days of acclimation before HDBR and 30 days of recovery after HDBR.

D. Acupuncture Procedures

The volunteers were informed in advance to stay calm and awake, with palms facing up. Acupuncture was performed by the same qualified Chinese medicine doctor to ensure operational accuracy and consistency. As shown in Fig. 2b, four different acupoints scattered on the chest, head, upper limbs, and lower limbs were chosen, including GV20, RN17, PC6, and SP6. The sham point was taken 15 mm to the right of the acupuncture point [30], [31], as shown in Fig. 2c, 2d, 2e, and 2f. To ensure the reliability of the results, the insertion depth of the acupuncture needles was the same between acupuncture points and corresponding sham points and the penetration was approximately 1.65 cm. The doctor only implanted the needle, without using acupuncture techniques such as rotation or lifting.

E. Data Acquisition and Statistics

Five minutes after the needle was applied to the volunteers, all recording procedures were performed. The implanted acupuncture needles, ground electrodes and reference electrodes were connected to the ME-16-USB System to detect nerve activity. A ground electrode and a reference electrode of the acupoints on the upper body were placed on the right shoulder (Fig. 2b). A ground electrode and a reference electrode of the acupuncture points of the lower body were placed under the knee (Fig. 2b). After measurement, MATLAB software was used to analyse the electrophysiological data. Data were collected on the 10th day of the preparation period, the 60th day of HDBR, the 90th day of HDBR, and the 30th day of the recovery period. Statistical analyses and graphs were performed with OriginPro 2020 (OriginLab Corporation, Northampton, USA). Data were calculated as the mean ± SEM. A two-sample analysis was used. Statistical significance of $P < 0.05$ was set for all analyses. Pearson's correlation coefficients between the characteristics of electrophysiological signals and physiological indicators are evaluated. If the significance (P) was less than 0.05, the correlation coefficient (r) would be displayed.

F. Electrophysiological Signal Analysis

A series of bandstop filters were used to remove the 50 Hz frequency interference from the power system.

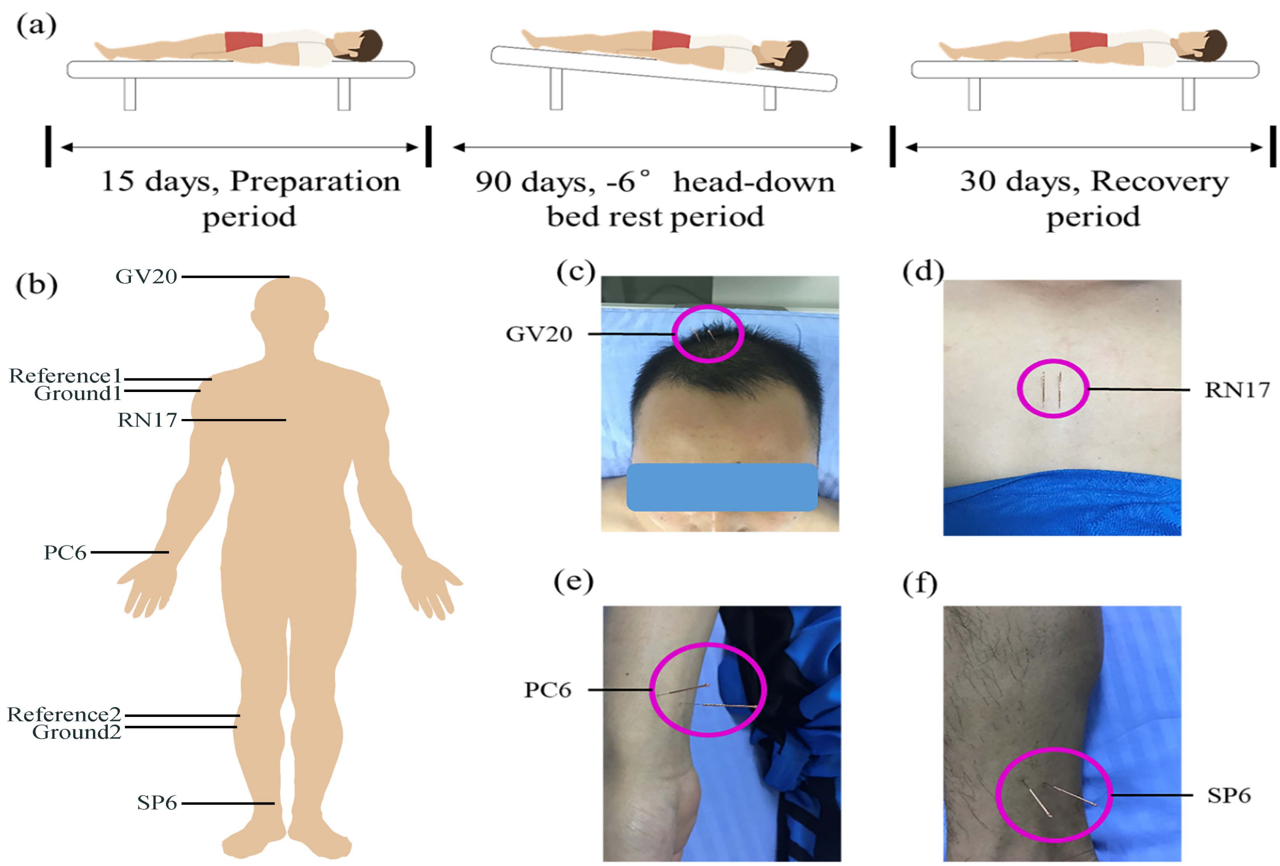

Fig. 2. Experimental design. (a) Head-down bed rest (HDBR) experimental arrangement. (b) Acupoint distribution. Acupuncture by a professional doctor. (c) probe placement at GV20. (d) probe placement at RN17. (e) probe placement at PC6. (f) probe placement at SP6. In c, d, e, and f, the needle on the right is the acupuncture point and the needle on the left is the sham point.

After denoising, the power spectral density and power were used as signal characteristics in the frequency domain to analyse the difference between the signal of the acupoint and the signal of the sham point. The power spectrum characteristics of acupoint electrophysiological signals were mainly distributed between 0 Hz and 40 Hz.

The characteristic amplitude (CA) was defined as one of the characteristic values. The extraction steps of CA were as follows: The raw signal was low-pass filtered (40 Hz). Waves were detected as positive deflections of the filtered signal between two consecutive negative deflections below the zero-crossing. A threshold was defined individually for each channel, using the difference between the median of the peak amplitude of all positive waves and the median of the peak amplitude of all negative waves. Only waves whose peak amplitudes were both higher than the threshold were regarded as characteristic waves [32]. In addition, the CA of the differential signal was used to explore the unique signal characteristics of the acupuncture point compared to the sham point.

G. Collection of Pittsburgh Sleep Quality Index, Blood Pressure, Echocardiography

The PSQI was used to assess the sleep quality of subjects. The scale was composed of 19 self-evaluated items and five other-evaluated items. The scores of the self-evaluated items were then counted and summed. The higher the score, the worse the sleep quality. The blood pressure of volunteers was tested at 6:30 am. Volunteers were lying flat and relaxed on a $-6°$ bed and their echocardiographic images were detected at 8:00 – 11:30 am.

III. Results

During the experiment, the signal at the acupuncture points exhibited the same changing trend as the signal at the sham points. The fluctuation of the signals became smoother after HDBR and was restored to different extents during the recovery period (Fig. 3).

A. Analysis of Power

In the present study, the power spectral densities and the total powers of signals were evaluated and compared between acupoints and sham points.

Before HDBR, the signal was detected when the human body was flat. The powers of all signals were mainly distributed in the range of 0–40 Hz and peaked at around 2 Hz (Fig. 4). The peaks of the acupuncture point were higher than the peaks of the corresponding sham point. Furthermore, the total powers at GV20, RN17, PC6, and SP6 were increased by 4.16%, 151.47%, 18.33%, and 13.23%, respectively, compared to the powers at the corresponding sham points (Fig. 4a–4d).

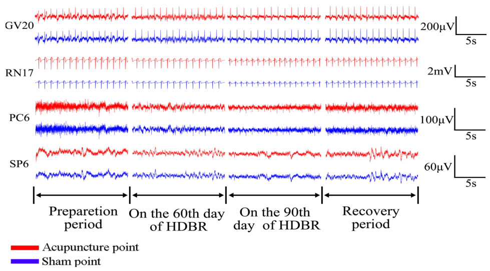

Fig. 3. The electrophysiological signal of GV20, RN17, PC6, SP6, and corresponding sham points during the preparation period, the 60th day of HDBR, the 90th day of HDBR, and the 30th day of the recovery period. The red signal is the signal at the acupuncture point and the blue signal is the signal at the sham point.

During the head-down bed rest period, the signal was detected when the participant was lying on the −6° bed. The peaks of all acupuncture points and all sham points did not shift but declined by varying degrees (Fig. 4). Compared with the powers before HDBR, the powers on the 60th day of HDBR at four acupuncture point (GV20, RN17, PC6, and SP6) dropped to 286.42 μW, 38658.67 μW, 46.62 μW, and 14.89 μW, respectively, while the powers at the corresponding sham points dropped to 282.86 μW, 21210.25 μW, 38.77 μW, and 14.12 μW, respectively (Fig. 5a–5d).

On the 90th day of HDBR, the peaks of all acupuncture and sham points did not move but declined by varying degrees (Fig. 4). Compared with the peaks of the corresponding sham point, the peaks of the acupuncture point changed more significantly. On the 90th day of HDBR, the powers at GV20, RN17, PC6, and SP6 were decreased by 27.06%, 44.72%, 42.90%, and 55.16%, respectively, compared with the powers before HDBR. On the 90th day of HDBR, the powers at the sham point were decreased by 24.85%, 31.40%, 36.55%, and 52.00%, respectively, compared with the powers before HDBR (Fig. 4a-4d).

As shown in Fig. 5, on the 90th day of HDBR, compared with the powers at the corresponding sham point, the powers at the four acupoints (GV20, RN17, PC6, SP6) were 1.10%, 102.67%, 6.51%, and 5.80% higher in sequence.

On the 30th day of the recovery period, the signal was detected when the human body was lying flat. The peaks of all acupuncture points and all sham points did not move but all recovered by varying degrees (Fig. 4). On the 90th day of HDBR, the power at GV20 rose to 353.12 μW, while the power at the corresponding sham point rose to 344.88 μW; the power at GV20 rose to 42495.03 μW, while the power of at the corresponding sham point rose to 22264.88 μW; the power at PC6 rose to 55.52 μW, while the power at the corresponding sham point rose to 46.08 μW; the power at SP6 rose to 22.06 μW, while the power at the corresponding sham point rose to 20.36 μW. (Fig. 5a–5d)

B. Analysis of Characteristic Amplitude

Power spectrum density distribution diagram demonstrated that the signal was mainly distributed in the low-frequency range and the CA was calculated after the signal was processed by a low-pass filter at 40 Hz, based on its distribution characteristics, as shown in Fig. 6. Before HDBR, the CA at the acupuncture points were all higher than the CA at the corresponding sham points. Before HDBR, compared with the corresponding sham points, the CAs at the four acupoints (GV20, RN17, PC6, SP6) were higher by 1.44%, 56.05%, 7.66%, and 7.79%, respectively. On the 90th day of HDBR, compared with the corresponding sham points, the CAs at the four acupoints (GV20, RN17, PC6, SP6) were higher by 1.32%, 46.14%, 3.83%, and 6.78%, respectively.

C. Analysis of Differential Signals of Acupoints

For further analysis, the differential signals between acupuncture points and their corresponding sham points were used to evaluate the specificity of acupuncture points. By calculating the characteristic amplitude of the differential signal (DSCA), it was revealed that on the 90th day of HDBR, the DSCAs at GV20, RN17, PC6, and SP6 were decreased by 12.56%, 38.53%, 67.47%, and 30.93%, respectively, compared with the DSCAs before HDBR. (Fig. 7a–7d)

On the 30th day of the recovery period, compared with the DSCA before the HDBR, the DSCA at GV20 was 1.47% higher (Fig. 7a). However, the DSCA at RN17 was 29.97% lower (Fig. 7b). Similarly, the DSCAs at PC6 and SP6 were lower by 38.77% and 26.40%, respectively (Fig. 7c and 7d).

D. Associations Between Electrophysiological Signal and Blood Pressure, Echocardiography, Pittsburgh Sleep Quality Index

The above results showed that the powers and DSCAs of the electrophysiological signals of the acupoints, the cardiovascular and sleep functions of volunteers were altered after HDBR. Pearson's correlation was used to evaluate the relationship between electrophysiological signals, cardiovascular function, and sleep function indicators, as shown in Fig. 8. Pittsburgh sleep quality index (PSQI) was negatively correlated with the power of GV20 ($r = -0.74$, $P < 0.005$), the power of SP6 ($r = -0.67$, $P < 0.005$), the power of PC6 ($r = -0.62$, $P < 0.05$), and the DSCA of GV20 ($r = 0.60$, $P < 0.05$), respectively. Systolic blood pressure (SBP) was positively correlated with the power of GV20 ($r = 0.79$, $P < 0.001$), the power of SP6 ($r = 0.83$, $P < 0.001$), the power of PC6 ($r = 0.78$, $P < 0.001$), the power of RN17 ($r = 0.83$, $P < 0.001$), the DSCA of SP6 ($r = 0.76$, $P < 0.001$), the DSCA of PC6 ($r = 0.88$, $P < 0.001$), and the DSCA of RN17 ($r = 0.88$, $P < 0.001$), respectively. Diastolic blood pressure (DBP) was positively correlated with the power of RN17 ($r = 0.89$, $P < 0.001$), the DSCA of SP6 ($r = 0.90$, $P < 0.001$), the DSCA of PC6 ($r = 0.77$, $P < 0.001$), and the DSCA of RN17 ($r = 0.80$, $P < 0.001$), respectively. LVEDD was negatively correlated with the power of RN17 ($r = -0.72$, $P < 0.005$), the DSCA of SP6 ($r = -0.71$, $P < 0.005$), the DSCA of PC6 ($r = -0.74$, $P < 0.005$), and the DSCA of RN17 ($r = -0.85$, $P < 0.001$), respectively. Left ventricular end-systolic diameters (LVESD) was negatively correlated with the power of SP6 ($r = -0.53$, $P < 0.05$), the power of PC6 ($r = -0.53$, $P < 0.05$), the power of RN17 ($r = -0.80$, $P < 0.001$), the DSCA of SP6 ($r = -0.74$, $P < 0.005$), the DSCA of PC6 ($r = -0.81$, $P < 0.001$), and the DSCA of RN17 ($r = -0.87$, $P < 0.001$), respectively.

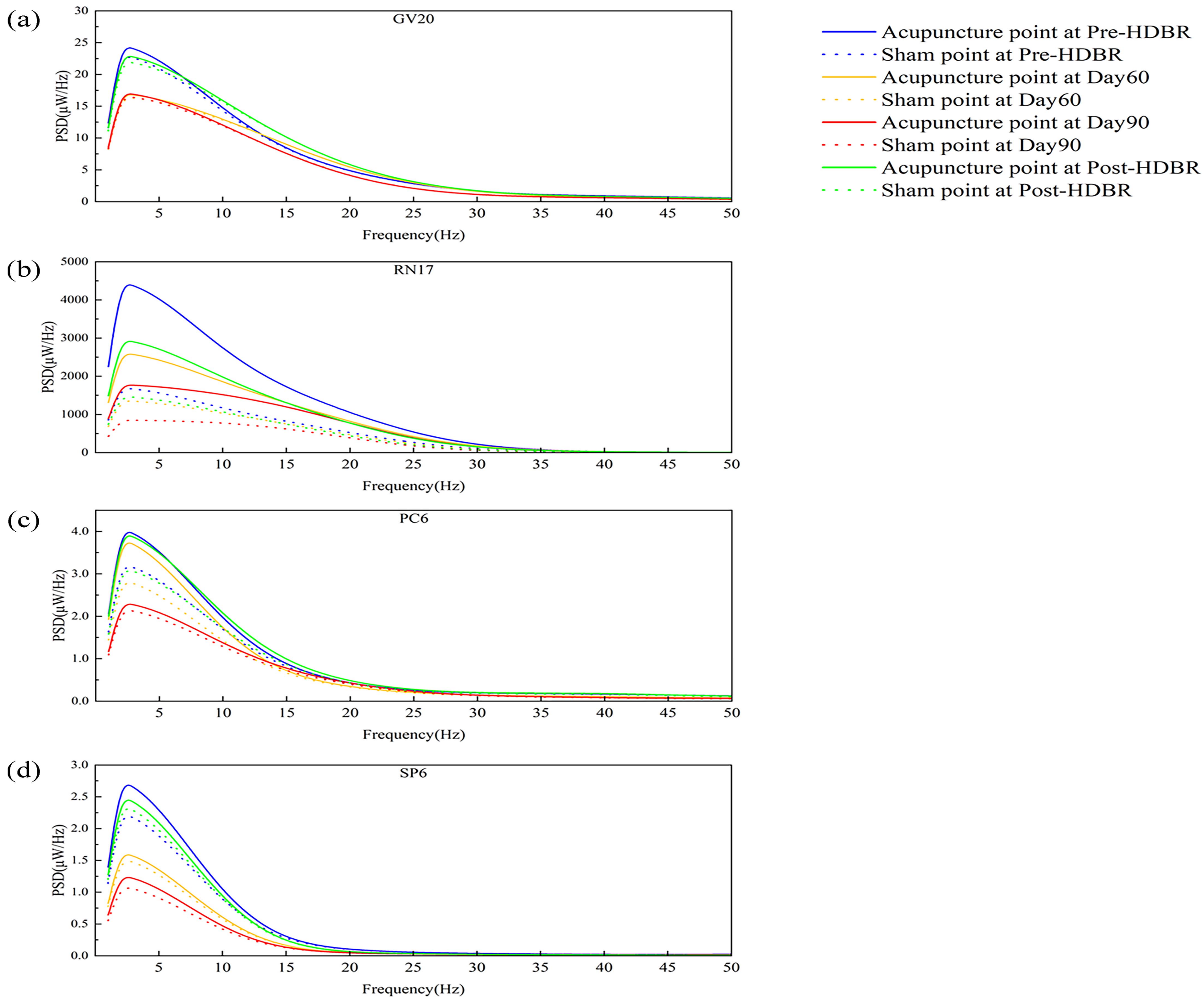

Fig. 4. The power spectral density of the signal during four periods (n = 5). (a) GV20 and its corresponding sham point; (b) RN17 and its corresponding sham point; (c) PC6 and its corresponding sham point; (d) SP6 and its corresponding sham point. The power peaked at around 2 Hz.

IV. Discussion

Recently, it has been verified that acupuncture point signals are specific to the changes in the physiological homeostasis. In this study, changes in the electrophysiological signals of the acupuncture points resulted by HDBR were studied. The main findings indicated that long-term bed rest in a -6° head-down position caused specific changes in the electrophysiological signals of acupuncture points, which were associated with resulted disorders in the volunteers' cardiovascular and sleep functions. In addition, the electrophysiological signals of acupuncture points as well as cardiovascular and sleep functions were restored to a certain extent during the recovery period.

According to the power spectrum density, the powers of the acupuncture points and sham points were mainly distributed in the low-frequency band and the peaks were located at around 2 Hz, which is in line with the previous findings [18]. The peaks of all signals were decreased but not shifted after 90 days of the HDBR, indicating the reduction in the total power of electrophysiological signals of the acupoint related to the dysfunction of human bodies.

Furthermore, the power and the CAs of the four acupuncture points were always higher than that of the corresponding sham points even if at different positions on the body. This might be related to the fact that acupuncture points were located at the sites of known histological structure concentrations, e.g., blood vessels, nerve bundles, nerve branches, free nerve endings, and various receptors [33]–[35].

On the 60th day of HDBR, the powers of the acupoints decreased to varying degrees, among which the power of SP6 decreased most significantly. Similarly, the DSCAs of the acupoints also decreased to varying degrees and the DSCA of RN17 exhibited the most significant decrease.

Substantial evidence has revealed that there is sensitization at acupuncture points [6]–[8]. After 90 days of HDBR, the changes in the power and the CA of the four acupuncture points were more significant than the changes at the corresponding sham points. Acupuncture points are probably the

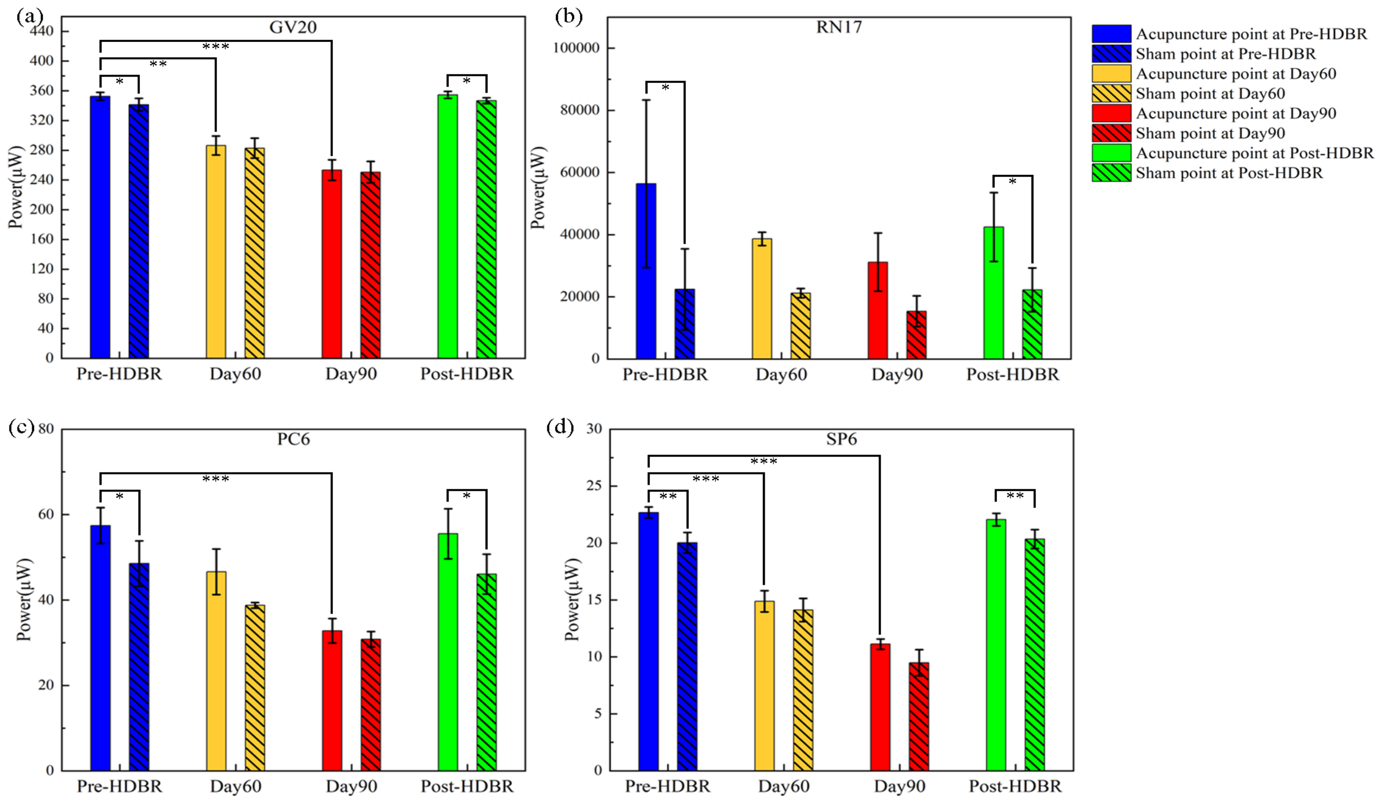

Fig. 5. The power analysis of the signal during the preparation period, the 60th day of HDBR, the 90th day of HDBR, and the 30th day of the recovery period. (n = 5). (a) The power of GV20 in the four periods and the power of the corresponding sham points. (b) The power of RN17 for each of the four periods and the power of the corresponding sham points. (c) The power of PC6 in the four periods and the power of the corresponding sham points. (d) The power of SP6 in the four periods and the power of the corresponding sham points. A two-sample analysis was used and the error is expressed by the standard error of mean (SEM). (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

sites that exhibit a more potent response compared to other sites, and the distinction between the change of acupuncture point and the change of sham acupoint played an essential role in the acupoint research [1], [36]. In other words, the pathological or physiological changes in the human body can be reflected by the position on the body surface and acupoints can more effectively reflect changes in the related functions of the human body.

In addition, after 90 days of HDBR, the differences in the power between four acupuncture points and the sham points decreased, as did the difference in the CA. It was postulated that the shape of the acupuncture point was a cylinder [33], and the signal of the sham point was measured at a certain distance from the central axis of the acupuncture point. The closer the sham point was to the edge of the acupuncture point, the closer the characteristic values of the two signals were. Our results suggested that the fields of related acupuncture points might expand as the body changes [37], [38], verifying the theory that visceral nociception would stimulate the acupoint receptive field from the electrical signal of the acupoint.

Currently, it is acknowledged that HDBR effectively simulate the impact of the microgravity environment on the human body, which can harm human cardiovascular and sleep conditions [39]. In the present study, blood pressure and echocardiography were used to determine damage to the human cardiovascular system. The reduced blood pressure, increased ventricular volume, and stable stroke volume indicated that systemic arterial vasodilation and deterioration of the heart's pumping ability, increasing the potential risk of cardiovascular disease, which was consistent with previous studies [25], [40], [41]. It should be noted that these risks still existed after 30 days of the recovery period, except for the increased stroke volume. In addition, by using the PSQI [42], it could be found from the volunteers' subjective understanding of their sleep status that HDBR would reduce their sleep quality.

As previously reported, the electrophysiological signals of acupoints are disease-specific [18], [43]. Studies have shown that GV20 can be used to treat sleep disorders while RN17, PC6, and SP6 can be used for the treatment of cardiovascular disorders, which is in agreement with the relevant Chinese medicine theories [2]–[5]. In this study, during the recovery period, except that the signal at GV20 was higher than the signal before HDBR - which was consistent with the recovery of sleep quality - the signals at the other three acupoints were lower than the signal before HDBR, which was consistent with cardiovascular recovery. By analysing the Pearson's correlation between the electrophysiological signals of acupoints and the cardiovascular function indicators and sleep function indicators, it was clear that the DSCA of GV20 was only negatively correlated with sleep function. In contrast, the DSCA of the other three acupoints (RN17, PC6, and SP6) were exclusively related to cardiovascular function indicators. The power of GV20, PC6, and SP6 was

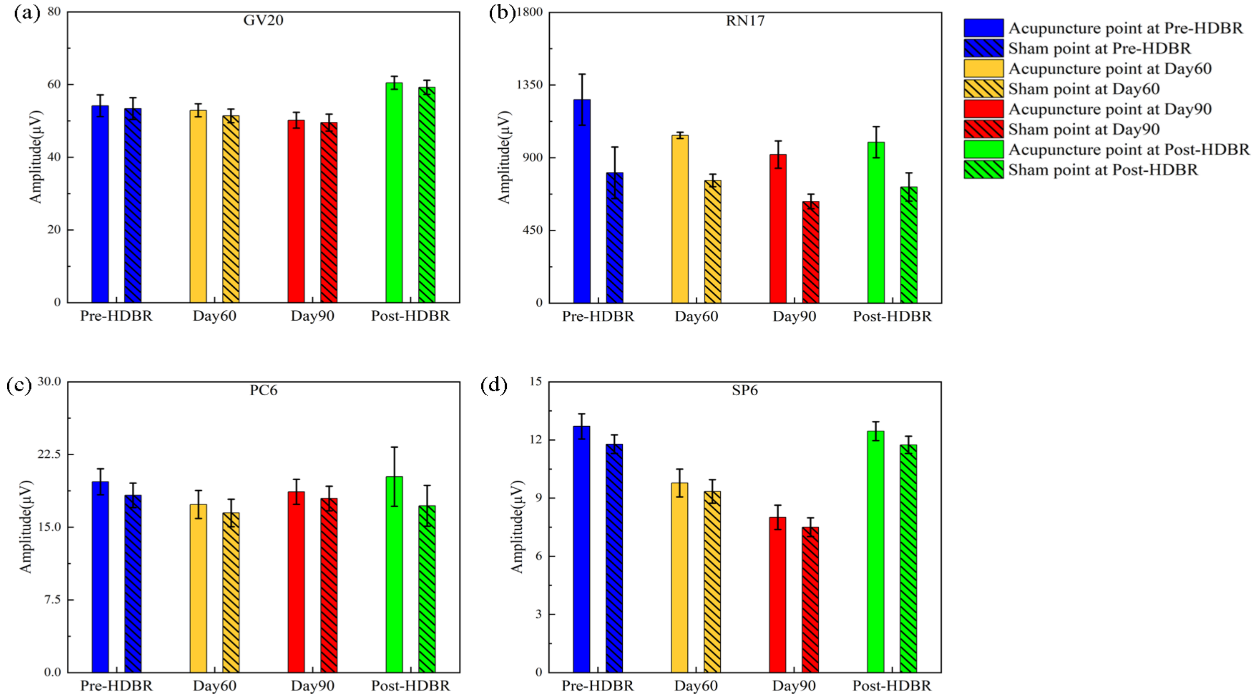

Fig. 6. Analysis of the characteristic amplitude of acupoints in four periods (n = 5). (a) The characteristic amplitude of GV20 in the four periods and the characteristic amplitude of the corresponding sham points. (b) The characteristic amplitude of RN17 in the four periods and the characteristic amplitude of the corresponding sham points. (c) The characteristic amplitude of PC6 in the four periods and the characteristic amplitude of the corresponding sham points. (d) The characteristic amplitude of SP6 in the four periods and the characteristic amplitude of the corresponding sham points.

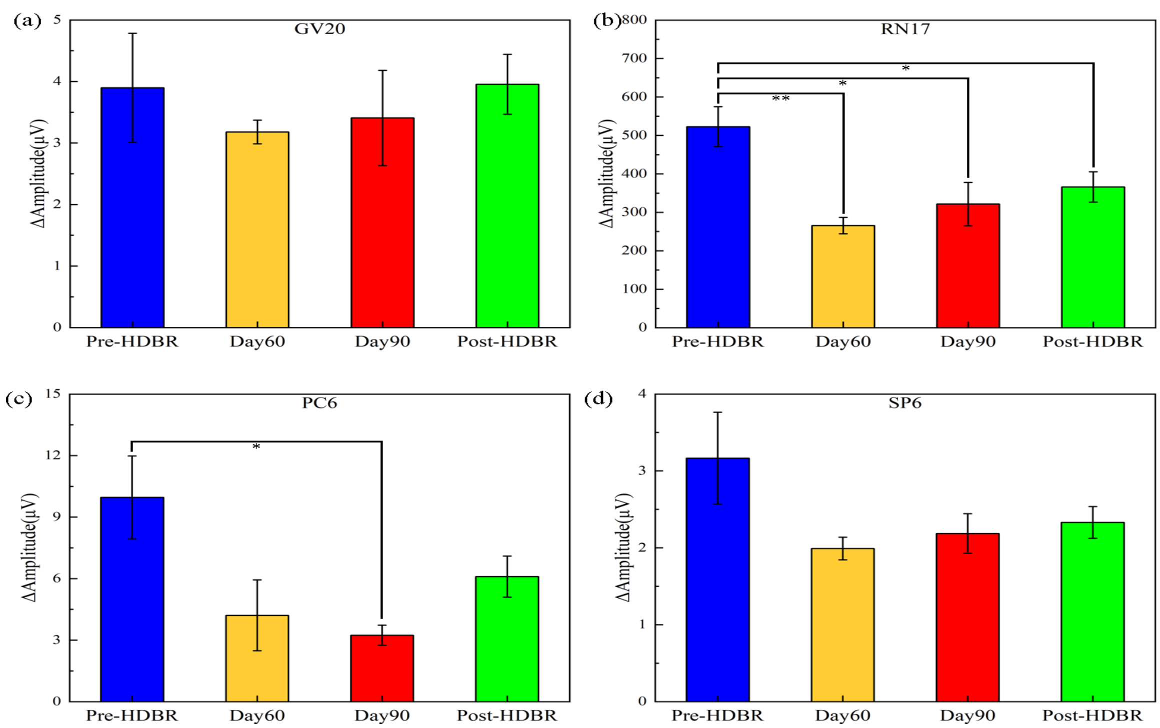

Fig. 7. Analysis of the characteristic amplitudes of the signal at different acupoints over four periods (n = 5). (a) The characteristic amplitudes of the differential signals of GV20 were 3.90 μV, 3.18 μV, 3.41 μV, and 3.96 μV respectively; (b) The characteristic amplitudes of the differential signals of RN17 were 522.91 μV, 265.63 μV, 321.42 μV, and 366.21 μV respectively; (c) The characteristic amplitudes of the differential signals of PC6 were 9.96 μV , 4.21 μV, 3.24 μV, and 6.10 μV respectively; (d) The characteristic amplitude of the differential signal of SP6 was 3.17 μV, 1.99 μV, 2.19 μV, and 2.33 μV respectively. The analysis uses two-sample analysis, and the error is expressed by the standard error of mean (SEM). (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

highly correlated with sleep quality and systolic blood pressure while the power of RN17 was significantly correlated with blood pressure, LVEDD, and LVESD. A possible explanation for this phenomenon was that the electrophysiological signals of acupuncture points could reflect the relevant functions of the human body in a targeted manner.

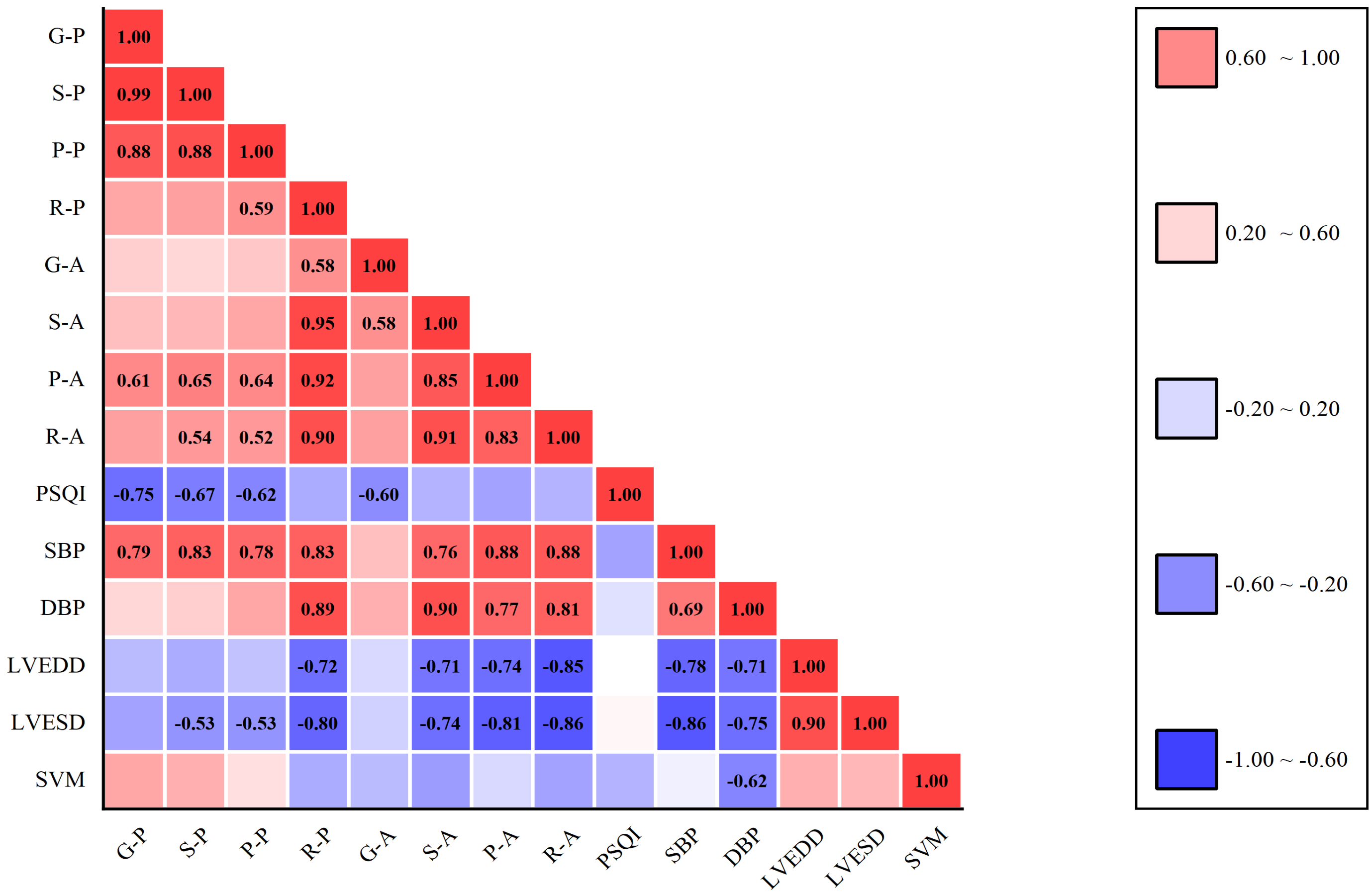

Fig. 8. Autocorrelation between electrophysiological signal and blood pressure, echocardiography, PSQI (correlation values with a $p < 0.05$ are shown in the figure). G-P: Power of GV20; S-P: Power of SP6; P-P: Power of PC6; R-P: Power of RN17; G-A: Characteristic amplitude of the differential signal (DSCA) at GV20; S-A: DSCA at SP6; P-A: DSCA at PC6; R-A: DSCA at RN17; PSQI: Pittsburgh sleep quality index; SBP: systolic blood pressure; DBP: diastolic blood pressure; LVEDD: left ventricular end-diastolic diameters; LVESD: left ventricular end-systolic diameters.

V. Conclusion

This is the first time to explore the changes in the electrophysiological signal analysis of acupoints during the simulated weightlessness. Essentially, we found that the powers and the CAs of the electrophysiological signal at the acupoints were higher than the corresponding sham points, which may be related to the distribution characteristics of the acupoints. After 90 days of HDBR, cardiovascular dysfunction and PSQI increased. Compared with sham points, there were significant reductions in both powers and CAs of acupuncture points, indicating that acupuncture points were closely related to alteration in pathological homeostasis. In addition, differences in the power and the CA between acupuncture points and their corresponding sham points were reduced, indicating that the range of related acupuncture points increased during the abnormal body conditions. During the recovery period, the change in DSCA of the RN17 acupoint was similar to the changes in blood pressure and the index of echocardiography, while that of the GV20 was similar to the change in the PSQI. These results might partially explain the specificity of the electrophysiological signals of acupuncture points for related diseases. Future work should focus on exploring the deep mechanism of the electrophysiological signals of acupoints, which conduce to promoting disease diagnosis and treatment based on acupoint specificity in clinical and aerospace medicine.

Author Contributions

Yun Wang: Conceptualization, Acupuncture operation, Data: analysis, statistics, Writing - original draft, review & editing. Zhiqi Fan: Acupuncture operation, Writing - review & editing. Mixia Wang: Data: analysis, statistics, Writing - review & editing. Juntao Liu, Shengwei Xu, Zeying Lu, Hao Wang: Acupuncture operation, Data: analysis, statistics, Writing - review & editing. Yilin Song: Writing - review & editing. Yiding Wang: Writing - review & editing. Yinghui Li: Conceptualization, Writing - review & editing. Xinxia Cai: Conceptualization, Writing - review & editing, Project administration.

Conflicts of Interest

None of the authors have any competing interests to declare.

References

[1] F. Li *et al.*, "What is the acupoint? A preliminary review of acupoints," *Pain Med.*, vol. 16, no. 10, pp. 1905–1915, Oct. 2015.

[2] Y. Kurono, M. Minagawa, T. Ishigami, A. Yamada, T. Kakamu, and J. Hayano, "Acupuncture to Danzhong but not to Zhongting increases the cardiac vagal component of heart rate variability," *Auton. Neurosci.*, vol. 161, nos. 1–2, pp. 116–120, Apr. 2011.

[3] Y. Ren, Z. Chen, R. Wang, Y. Yu, D. Li, and Y. He, "Electroacupuncture improves myocardial ischemia injury via activation of adenosine receptors," *Purinergic Signal.*, vol. 16, no. 3, pp. 337–345, Sep. 2020.

[4] K.-Y. Huang, C.-J. Huang, and C.-H. Hsu, "Efficacy of acupuncture in the treatment of elderly patients with hypertension in home health care: A randomized controlled trial," *J. Alternative Complementary Med.*, vol. 26, no. 4, pp. 273–281, Apr. 2020.

[5] K.-I. Takeishi *et al.*, "Acupuncture improves sleep conditions of minipigs representing diurnal animals through an anatomically similar point to the acupoint (GV20) effective for humans," *Evidence-Based Complementary Alternative Med.*, vol. 2012, Feb. 2012, Art. no. 472982.

[6] E. M. Choi, F. Jiang, and J. C. Longhurst, "Point specificity in acupuncture," *Chin. Med.*, vol. 7, no. 1, pp. 1–5, Feb. 2012.

[7] J.-J. Xing, B.-Y. Zeng, J. Li, Y. Zhuang, and F.-R. Liang, "Acupuncture point specificity," *Int. Rev. Neurobiol.*, vol. 111, pp. 49–65, Jan. 2013.

[8] H. Tan *et al.*, "Understanding acupoint sensitization: A narrative review on phenomena, potential mechanism, and clinical application," *Evidence-Based Complementary Alternative Med.*, vol. 2019, Aug. 2019, Art. no. 6064358.

[9] P.-J. Rong *et al.*, "Peripheral and spinal mechanisms of acupoint sensitization phenomenon," *Evidence-Based Complementary Alternative Med.*, vol. 2013, Sep. 2013, Art. no. 742195.

[10] Y.-Q. Li, B. Zhu, P.-J. Rong, H. Ben, and Y.-H. Li, "Effective regularity in modulation on gastric motility induced by different acupoint stimulation," *World J. Gastroenterol.*, vol. 12, no. 47, pp. 7642–7648, Dec. 2006.

[11] W. He *et al.*, "Cutaneous neurogenic inflammation in the sensitized acupoints induced by gastric mucosal injury in rats," *BMC Complementary Alternative Med.*, vol. 17, no. 1, p. 141, Mar. 2017.

[12] D.-H. Kim *et al.*, "Acupuncture points can be identified as cutaneous neurogenic inflammatory spots," *Sci. Rep.*, vol. 7, no. 1, p. 15214, Nov. 2017.

[13] K.-T. Yung, "A birdcage model for the Chinese meridian system: Part II. The meridian system as a birdcage resonator," *Amer. J. Chin. Med.*, vol. 32, no. 6, pp. 985–997, 2004.

[14] K. Qiu *et al.*, "Does the acupoint specificity exist? Evidence from functional neuroimaging studies," *Current Med. Imag.*, vol. 16, no. 6, pp. 629–638, Jul. 2020.

[15] Y. D. Kwon, J. H. Lee, and M. S. Lee, "Increased temperature at acupuncture points induced by weight reduction in obese patients: A preliminary study," *Int. J. Neurosci.*, vol. 117, no. 5, pp. 591–595, May 2007.

[16] Z.-Q. Zhao, "Neural mechanism underlying acupuncture analgesia," *Prog. Neurobiol.*, vol. 85, no. 4, pp. 355–375, Aug. 2008.

[17] T.-C. Kuo, C.-W. Lin, and F.-M. Ho, "The soreness and numbness effect of acupuncture on skin blood flow," *Amer. J. Chin. Med.*, vol. 32, no. 1, pp. 117–129, 2004.

[18] Q. Zhou *et al.*, "Power spectral differences of electrophysiological signals detected at acupuncture points and non-acupuncture points," *Acupuncture Electro-Therapeutics Res.*, vol. 39, no. 2, pp. 169–181, Aug. 2014.

[19] S. P. C. Ngai, A. Y. M. Jones, and E. K. W. Cheng, "Lung meridian acupuncture point skin impedance in asthma and description of a mathematical relationship with FEV1," *Respirat. Physiol. Neurobiol.*, vol. 179, nos. 2–3, pp. 187–191, Dec. 2011.

[20] L. Turner, W. Linden, and C. Marshall, "Electrodermal activity at acupuncture points differentiates patients with current pain from pain-free controls," *Appl. Psychophysiol. Biofeedback*, vol. 38, no. 1, pp. 71–80, Mar. 2013.

[21] S. Grimnes and Ø. G. Martinsen, "History of bioimpedance and bioelectricity," in *Bioimpedance and Bioelectricity Basics*. London, U.K.: Academic, 2000, ch. 9, pp. 313–319.

[22] H. Sandler, "Cardiovascular effects of inactivity," in *Inactivity: Physiological Effects*, H. Sandler and J. Vernikos, Eds. New York, NY, USA: Academic, 1986, ch. 2, pp. 11–47.

[23] H. Sandler, D. J. Goldwater, R. L. Popp, L. Spaccavento, and D. C. Harrison, "Beta blockade in the compensation for bed-rest cardiovascular deconditioning: Physiologic and pharmacologic observations," *Amer. J. Cardiol.*, vol. 55, no. 10, pp. D114–D119, Apr. 1985.

[24] A. P.-Le Traon, M. Heer, M. V. Narici, J. Rittweger, and J. Vernikos, "From space to earth: Advances in human physiology from 20 years of bed rest studies (1986–2006)," *Eur. J. Appl. Physiol.*, vol. 101, no. 2, pp. 143–194, Sep. 2007.

[25] M. Shiraishi, T. Kamo, S. Nemoto, M. Narita, M. Kamegai, R. M. Baevsky, and I. I. Funtova, "Blood pressure variability during 120–day head-down bed rest in humans," *Biomed. Pharmacotherapy*, vol. 57, pp. 35–38, Oct. 2003.

[26] L. B. Johansen *et al.*, "Haematocrit, plasma, volume and noradrenaline in humans during simulated weightlessness for 42 days," *Clin. Physiol.*, vol. 17, no. 2, pp. 203–210, Mar. 1997.

[27] Y. Ishizaki *et al.*, "Changes in mood status and neurotic levels during a 20-day bed rest," *Acta Astronaut.*, vol. 50, no. 7, pp. 453–459, Apr. 2002.

[28] C. W. DeRoshia and J. E. Greenleaf, "Performance and mood-state parameters during 30-day 6° head-down bed rest with exercise training," *Aviation Space Environ. Med.*, vol. 64, no. 6, pp. 522–527, Jun. 1993.

[29] D.-J. Dijk *et al.*, "Sleep, performance, circadian rhythms, and light-dark cycles during two space shuttle flights," *Amer. J. Physiol. Reg. Integr. Comp. Physiol.*, vol. 281, no. 5, pp. R1647–R1664, Nov. 2001.

[30] X. M. Zhu and B. Polus, "A controlled trial on acupuncture for chronic neck pain," *Amer. J. Chin. Med.*, vol. 30, no. 1, pp. 13–28, Jan. 2002.

[31] J. Kong, R. L. Gollub, J. M. Webb, J.-T. Kong, M. G. Vangel, and K. Kwong, "Test–retest study of fMRI signal change evoked by electroacupuncture stimulation," *Neuroimage*, vol. 34, no. 3, pp. 1171–1181, Feb. 2007.

[32] V. V. Vyazovskiy, B. A. Riedner, C. Cirelli, and G. Tononi, "Sleep homeostasis and cortical synchronization: II. A local field potential study of sleep slow waves in the rat," *Sleep*, vol. 30, no. 12, pp. 1631–1642, Dec. 2007.

[33] Z.-J. Zhang, X.-M. Wang, and G. M. McAlonan, "Neural acupuncture unit: A new concept for interpreting effects and mechanisms of acupuncture," *Evidence-Based Complementary Alternative Med.*, vol. 2012, Mar. 2012, Art. no. 429412.

[34] X. Yan *et al.*, "Do acupuncture points exist?" *Phys. Med. Biol.*, vol. 54, no. 9, pp. N143–N150, May 2009.

[35] D. Zhang *et al.*, "Role of mast cells in acupuncture effect: A pilot study," *Explore*, vol. 4, no. 3, pp. 170–177, May/Jun. 2008.

[36] K. J. Cheng, "Neuroanatomical basis of acupuncture treatment for some common illnesses," *Acupuncture Med.*, vol. 27, no. 2, pp. 61–64, Jun. 2009.

[37] Y. Chae *et al.*, "The alteration of pain sensitivity at disease-specific acupuncture points in premenstrual syndrome," *J. Physiol. Sci.*, vol. 57, no. 2, pp. 115–119, Apr. 2007.

[38] X. Qi *et al.*, "Distribution of algesia sensitized acupoints in the patients of intestinal cancer," *Zhongguo Zhen Jiu*, vol. 37, no. 9, pp. 963–966, Sep. 2017.

[39] P. Norsk, "Blood pressure regulation IV: Adaptive responses to weightlessness," *Eur. J. Appl. Physiol.*, vol. 114, no. 3, pp. 481–497, Mar. 2014.

[40] N. Navasiolava *et al.*, "Vascular and microvascular dysfunction induced by microgravity and its analogs in humans: Mechanisms and countermeasures," *Frontiers Physiol.*, vol. 11, p. 952, Aug. 2020.

[41] P. Norsk, "Adaptation of the cardiovascular system to weightlessness: Surprises, paradoxes and implications for deep space missions," *Acta Physiol.*, vol. 228, no. 3, Mar. 2020, Art. no. e13434.

[42] E. A. Winiger, L. N. Hitchcock, A. D. Bryan, and L. C. Bidwell, "Cannabis use and sleep: Expectations, outcomes, and the role of age," *Addictive Behav.*, vol. 112, Jan. 2021, Art. no. 106642.

[43] M.-C. Cheung, A. S. Chan, and J. Yip, "Microcurrent stimulation at shenmen acupoint facilitates EEG associated with sleepiness and positive mood: A randomized controlled electrophysiological study," *Evidence-Based Complementary Alternative Med.*, vol. 2015, pp. 1–11, Feb. 2015.