Sports Medicine and Health Science 5 (2023) 245–250

Contents lists available at ScienceDirect

Sports Medicine and Health Science

journal homepage: www.keaipublishing.com/smhs

Case Report

Can *XunTian* Tai Chi intervention improve the level of emotional regulation of crew members in the Controlled Ecological Life Support System?

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ARTICLE INFO

Keywords:
XunTian Tai Chi
Confined and cramped environment
Occupants
Emotional regulation

ABSTRACT

To explore the appropriate exercise methods and means for astronauts in confined and small isolation conditions, a set of *XunTian* Tai Chi suitable for the spaceflight workforce was created, with the aim of discovering the practical effects of *XunTian* Tai Chi and providing a scientific basis for the subsequent development of new astronaut health maintenance techniques with Chinese characteristics. Using the Controlled Ecological Life Support System (CELSS) as a research platform, we observed the changes in a crew member's emotion regulation-related indexes during 180 days of working and living in a confined isolation chamber through periodic interventions of the *XunTian* Tai Chi and conducted statistical analyses. During the 180-day cabin mission, expression suppression, cognitive reappraisal, attention index, and relaxation index were all lower than those before entering the cabin, suggesting that the crew member's emotion regulation ability decreased during the in-cabin mission. A single Tai Chi exercise could cause favorable changes in the indicators, positively affecting the crew member's emotional regulation. The attention and relaxation indices of the occupants were improved significantly by both single and periodic Tai Chi exercises. After the Tai Chi exercise cycle, the results of each index showed a certain degree of effect. The 180-day ground-based simulation of Tai Chi in the confinement of a space capsule positively affects the occupant's emotional regulation.

Introduction

Manned space missions require astronauts to work and live in a confined and small environment that is far from Earth. This can affect the successful completion of missions. With the development of manned space missions or the implementation of deep-space exploration programs in the future, it is particularly important to regulate the emotional state of astronauts through scientific and rational interventions to ensure the successful completion of their missions.[1]

Tai Chi exercise has been shown to improve the participants' body balance, flexibility, and postural control and to alleviate psychological problems such as depression, anxiety, stress, and mood disorders.[2,3] Traditional Tai Chi practice requires relatively adequate space and is not suitable for practice in the small and confined conditions of manned spaceflight environments. This study was specifically designed to optimize and improve traditional Tai Chi movements based on the environmental conditions and working characteristics of manned space missions and to design a Tai Chi practice suitable for astronauts, space science, and technology workers in confined and small environments, named *XunTian* Tai Chi. To verify the effectiveness of this Tai Chi practice, this study aimed to evaluate the use of Tai Chi practice in simulated space exploration, i.e., Controlled Ecological Life Support System (CELSS). This study of the effects of crew emotion regulation interventions aims to provide a scientific basis for developing new astronaut health maintenance techniques with Chinese characteristics for subsequent manned space missions. The results of this study in a simulated environment are also important for future manned lunar landings and manned Mars

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https://doi.org/10.1016/j.smhs.2023.07.009
Received 31 December 2022; Received in revised form 2 May 2023; Accepted 24 July 2023
Available online 25 July 2023

Abbreviations

Cm	Centimeter
CELSS	Controlled Ecological Life Support System
CNES	Centre National D'Etudes Spatiales
DLR	Deutsches Zentrum für Luftund Raumfahrt
EEG	Electroencephalogram
ERQ	Emotion Regulation Questionnaire
Kg	Kilogram
LF/HF	Low Frequency/High Frequency
Min	Minute
HR	Heart rate
HRV	Heart Rate Variability
PNN50	the proportion of NN50 divided by the total number of NN (R–R) intervals. NN50 is the number of times successive heartbeat intervals exceed 50 ms
R–R	R–R intervals on the electrocardiogram

programs.

Materials and methods

Study conditions

CELSS is a 4-person, 180-day controlled ecological and biosafety system integrated experiment led by China, with the participation of the Centre National D'Etudes Spatiales (CNES), Deutsches Zentrum für Luftund Raumfahrt (DLR), Harvard Medical School, and other countries. The experiment was designed to provide humans with the atmospheric environment and biosecurity materials needed to survive by establishing a closed and controlled ecosystem inside a simulated space capsule and efficiently recycling the atmosphere, water, and food. The experiment will explore new technologies and methods for building artificial ecosystems in confined environments; reveal the physiological, psychological, and behavioral characteristics of humans in long-term confined environments; and provide a technical reserve for the development of human space exploration and interstellar residency.

The CELSS program was operated from June 17, 2016, to December 14, 2016, for a total of 180 days. The period contained three simulation phases: Phase 1 (Period I), 1–71 days after entering the capsule (Earth-Mars flight days); Phase 2 (Period II), 72–108 days (i.e., Mars days. This phase simulates Mars time: 24.65 h per day and night in the capsule, approximately 24 h 40 min); and Phase 3 (Period III), 109–180 days (Fire-Earth flight days). The simulated test phases are shown in Fig. 1.

Ethical approval statement

This study was approved by the Ethics Committee of the China Astronaut Training Center, and all researchers were aware of the study and agreed to publish it. The Ethics Committee of the China Astronaut Training Center reviewed this study (No. ACC201508) and passed the review. All participants gave informed consent to the disclosure of their data during the study.

The participant

This study investigated the emotional regulation of crew member 03 in the CELSS. The participant had a height of 165 cm, weighed 60 kg, was aged 28 years, had a master's degree, and had an electromechanical engineering background. The results of the clinical medical examination, psychological and neurological assessment, and psychological interview before entering the capsule were normal. The participant was right-handed and had no experience in Tai Chi practice.

Research methodology

Changes in the indicators related to the emotional regulation of crew member 03 during 180 days of working and living in the simulated capsule were observed upon subjecting the participant to a *XunTian* Tai Chi intervention. A control test was conducted once before entering the capsule for 3 days, and index data were collected every half month between 18:30 and 19:00 p.m. during the 180 days in the confined capsule, starting from day 14. When the Tai Chi was not practiced, the test data were collected in a quiet state for 5 min, and during the Tai Chi practice cycle, the test data were collected in a quiet state for 5 min before and immediately after the Tai Chi practice. During the Tai Chi practice, data were collected for 5 min before and immediately after the Tai Chi practice.

Test indicators and instruments

(1) Heart rate (HR) and heart rate variability (HRV) were recorded using a polar heart rate monitor, with the main indicators being HR. The proportion of PNN50 (is the proportion of PNN50 divided by the total number of R–R intervals on the electrocardiogram) in the time domain, and low frequency/high frequency (LF/HF) in the frequency domain.

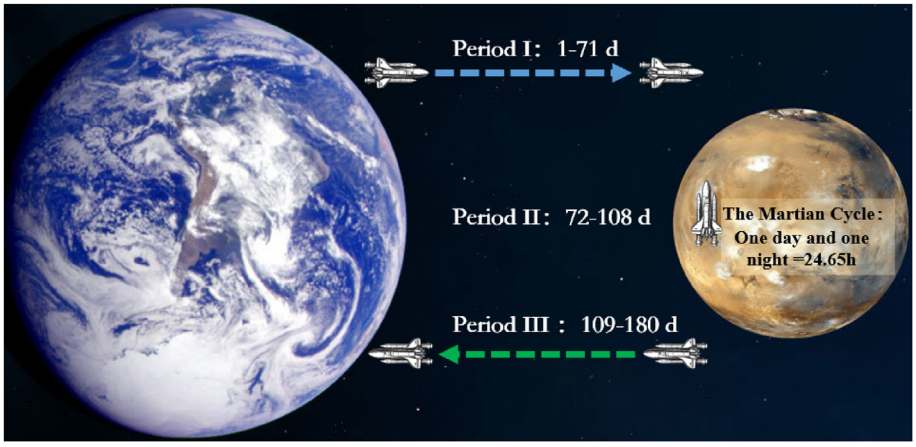

Fig. 1. CELSS diagram of the flight simulation stage
This image simulates the time cycle of the vehicle's flight in three phases: Earth-Mars-Earth.

(2) The Emotion Regulation Questionnaire (ERQ) was divided into two dimensions based on the main indicators: expression inhibition and cognitive reassessment.[2]
(3) A Brain Tech portable wireless dry electrode electroencephalogram (EEG) system was used to record EEG signals, focusing on the components and changes in the EEG signals in the frontal central region, and power spectrum analysis was performed on the obtained EEG signals. The main output indicators were the attention and relaxation indices.

XunTian Tai Chi Exercises and frequency

XunTian Tai Chi Exercises are developed specifically for astronauts and space scientists, and it has been practiced by astronauts on many manned missions in space and has proven to be suitable for practice in conditions of weightlessness and confined space.

In this test, the participant was trained to master the entire set of maneuvers. During the 180 days of the simulated capsule test, there were three cycles of Tai Chi practice: the first cycle was from day 14 to day 40, the second cycle was from day 68 to day 98, and the third cycle was from day 124 to day 153. The rest of the time was spent working and living normally, without practicing Tai Chi. The specific Tai Chi practice cycle is illustrated in Fig. 2.

Mathematical and statistical methods

All test data were collated and summarized using Microsoft Excel and statistically processed and plotted using Statistical Package for the Social Sciences (SPSS) 25.0 and GraphPad Prism 8 version 25.0. The collected data met the conditions of normal distribution using descriptive statistical mean ± standard deviation for the statistical analysis of the data. Some of the data of the individual factors (before and after a single intervention) did not meet the normal distribution, and a non-parametric test was used for these, with $\alpha = 0.05$ as the statistical test level.

Results

Overall trends in the participant's indicators during the 180-day mission

The participant's indicators during the 180-day capsule mission showed a decrease compared with those during the pre-capsule period (Table 1), except for an increase in PNN50 values and a slight increase in LF/HF values. Throughout the 180-day test, HR and PNN50 began to fluctuate significantly as the participant entered the capsule for longer periods of time, with fluctuations gradually increasing after Martian time, peaking at 136 days (at 3/4th of the time in the mission) (Fig. 3).

Changes in the participant's indicators before and after the single practice of Tai Chi on patrol

During the 180-day mission, there were three cycles of the Tai Chi practice. Each index before and after the Tai Chi practice was measured once every half month during the cycle. The results of the changes in each index before and after the single Tai Chi practice are shown in Table 2. Both the attention and relaxation indices increased significantly to different degrees after a single Tai Chi practice session.

Table 1
Comparison of the indicators of the participant before and during the mission.

Test content	Pre-entry data	Data during the mission	Value of change
		Mean ± *SD*	
HR/min	80.31	78.30 ± 9.98	−2.01
PNN50	2.50	7.27 ± 9.49	4.77
LF/HF	0.74	0.91 ± 0.35	0.17
Expressive Suppression	28.00	27.22 ± 3.20	−0.78
Cognitive Reappraisal	42.29	39.75 ± 1.65	−2.54
Attention Index	55.97	44.39 ± 4.85	−11.58
Relaxation Index	49.65	42.97 ± 1.62	−6.68

HR, Heart rate; min, Minute ; LF/HF, low frequency/high frequency.
PNN50, the proportion of NN50 divided by the total number of NN (R–R) intervals. NN50 is the number of times successive heartbeat intervals exceed 50 ms.
Description: Comparison of the indicators of the participant before and during the mission. Difference between before and after use of descriptive statistics.

"Trace effects" on indicators after different cycles of Tai Chi intervention

Fig. 4 shows that the HR increased during the first cycle of Tai Chi dry anticipation and decreased in the second and third intervention cycles. This may be related to Tai Chi proficiency; PNN50 decreased in all three Tai Chi intervention cycles, expression inhibition and cognitive reappraisal changed differently among the intervention cycles, and attention and relaxation indices increased during Tai Chi dry anticipation. In the rest period (when Tai Chi was not practiced) after the end of Tai Chi, most of the indicators declined to some extent; however, the phenomenon of exercise traces may be present. HR, cognitive reassessment, attention index, and relaxation index decreased after exiting the mission compared with those before the mission, while other indicators increased slightly but did not fluctuate significantly.

Discussion

Effects of confined environments on the occupant's indicators

Living in a confined and small space isolated from society for a long time can cause human emotions to deteriorate gradually. The high-intensity work and stress, without timely and effective emotion regulation interventions, will seriously affect human health as well as the successful completion of the mission.[4] Astronauts, submariners, soldiers on special assignments, and staff who need to be quarantined in situ during the current new pandemic are all facing such problems.[5]

During CELSS, crew member 03 was the engineer responsible for the operation and maintenance of all the equipment in the module, which was a very intensive job. The fluctuation in the physiological indicators involved in emotion regulation, i.e., HR and PNN50, gradually increased in, especially when entering the 36-day "Martian time," which is 24 h and

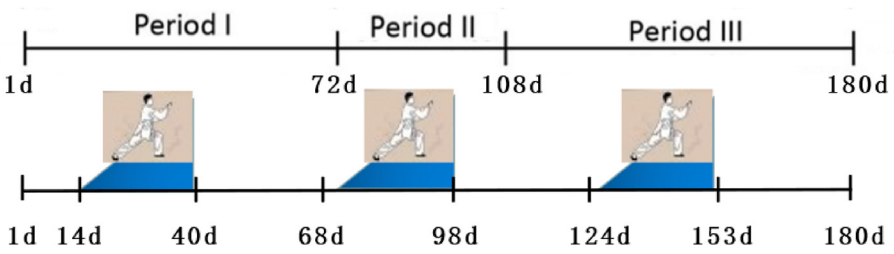

Fig. 2. *XunTian* Tai Chi practice cycle
Description: This picture shows the timing of *XunTian* Tai Chi interventions in different cycles during the flight phase.

Fig. 3. Trends in indicators over the 180-day mission period
Description: Indicator trends for the 180-day mandate period, respectively. Including:PNN50, HR,LF/HF, Expressive Suppression ,Cognitive Reappraisal, Attention index, Relaxation Index. HR, Heart rate; LF/HF, low frequency/high frequency ; PNN50, the proportion of NN50 divided by the total number of NN (R–R) intervals. NN50 is the number of times successive heartbeat intervals exceed 50 ms. Description: The graph illustrates the changes in the subject's physical function throughout the simulated flight cycle.

Table 2
Change in the indicators of the participant before and after a single practice session of *XunTian* Tai Chi (Δ values).

Time	HR	PNN50	LF/HF	Expressive Suppression	Cognitive Reappraisal	Attention index	Relaxation Index
Before	−1.83	−0.90	0.64	4.29	1.00	6.16	11.11
14	−4.18	2.70	0.38	2.14	3.57	9.12	19.00
24	1.11	−0.30	0.09	−0.71	0.71	17.12	9.90
40	2.61	−1.20	0.56	1.43	2.14	19.85	11.47
82	1.90	17.90	−0.84	−2.14	0.00	8.95	19.14
98	5.65	1.40	0.16	−5.00	−0.71	17.85	12.37
136	16.63	−0.90	−0.57	−0.71	1.43	11.16	20.68
153	1.19	−0.90	0.37	0.00	−0.71	8.85	18.39

HR, Heart rate; LF/HF, low frequency/high frequency.
Description: Change in the indicators of the participant before and after a single practice session of *XunTian* Tai Chi. Difference between before and after use of descriptive statistics.

40 min per day and night, resulting in changes in the body's biological rhythm, which in turn causes a series of stressful changes in physiology, psychology, and emotion. HR, PNN50, and attention index decreased, and expression inhibition increased, suggesting that during the "Martian time," crew member 03's HRV was weakened and work efficiency decreased, and crew member 03 focused on expression inhibition strategy for emotion regulation. Inhibition of expression is a response-focused strategy that reduces the subjective experience of emotions by inhibiting the expression of the emotion that is about to occur. Expression suppression is used to achieve emotion regulation by suppressing negative emotions.[6] In contrast, cognitive reappraisal is an antecedent-focused strategy that reduces emotional reactions by changing the understanding of the emotional event and the perceived personal meaning of the emotional event. Cognitive reappraisal was closely related to positive emotional experiences, and the Sport Anxiety Scale (SAS), Severity of Dependence Scale (SDS), HR, and PNN50 values for crew member 03 were almost at their maximum in-cabin values at approximately 135 days, at 3/4th into the 180-day task. Previous studies have found a time-dependent tendency for people's state of mind to begin to decrease halfway through the mission, whether at an uninhabited Arctic weather

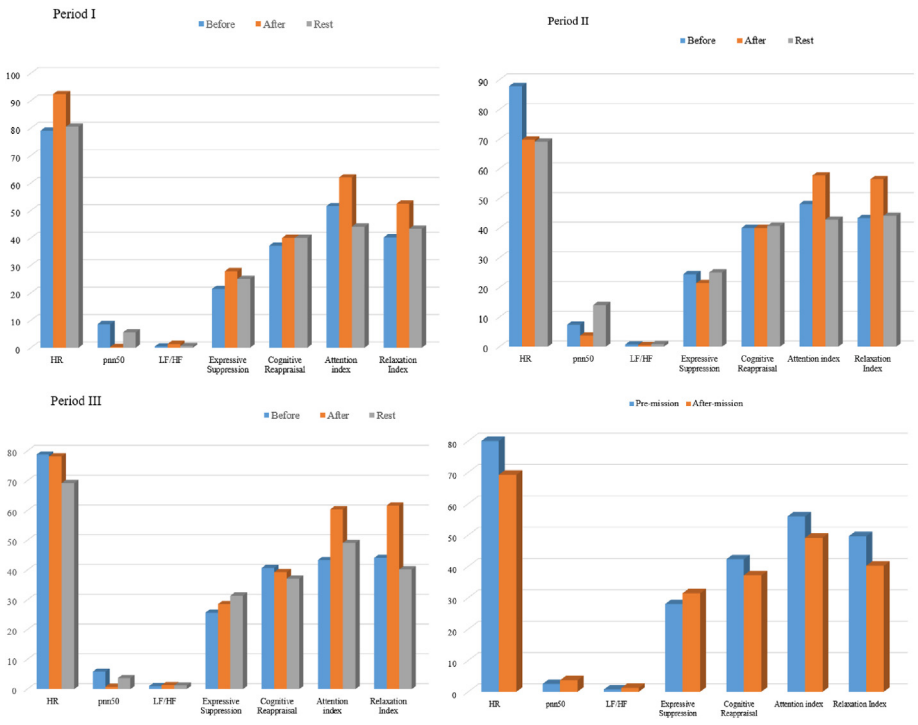

Fig. 4. Changes in indicators before, after, and during the rest period of the different *Xuntian* Tai Chi intervention cycles
HR, Heart rate; LF/HF, low frequency/high frequency ; PNN50, the proportion of NN50 divided by the total number of NN (R–R) intervals. NN50 is the number of times successive heartbeat intervals exceed 50 ms. Description: Changes in the indexes of the subjects before, after and during the rest period of the flight cycle through different *Xuntian* Tai Chi intervention cycles.

station, an Antarctic scientific research station, a radar station high in the mountains, or an isolated border post. In confinement, maximum psychological discomfort tends to occur approximately three-quarters into the isolation period. Psychologists refer to this as the "third-quarter phenomenon," when the central environment drops to a nadir after half the time, as when the body reaches a limit in a long-distance run. When the third-quarter phenomenon occurs, occupants generally show greater emotional intensity in terms of anxiety, depression, and irritability and even experience reduced cognitive ability, difficulty concentrating, and reduced decision-making ability.

Astronauts are likely to face all of these issues during long-term missions, and prolonged periods of isolation and confinement can have considerable and varied effects on brain structures and various complex cognitive controls, including learning and memory formation, space navigation, self-control, and emotional control.[7] These increased psychological and environmental stressors can affect the integrity of an astronaut's mission execution process and execution plan and will also negatively affect health; hence, there is an urgent need for an effective emotion regulation method.

Positive effect of a single XunTian Tai Chi exercise on the emotional regulation of the participant

Tai Chi training is a form of physical and mental exercise suitable for people of all ages with different health conditions worldwide and can promote health and symptom management of chronic diseases.[8,9] Long-term practice of Tai Chi exercises can increase muscle strength, flexibility, balance, and postural control.[10,11] The movements are simple to learn, slow and gentle, graceful, and consistent. Previous studies have shown that Tai Chi has a positive effect on astronauts' mood and EEG power and that consistent practice can improve mood and reduce low-frequency EEG signals.[12] This study is similar to our finding in this research. It was further demonstrated that there was a significant antagonistic effect on sleep deprivation.[13] In this study, the highest immediate HR after Tai Chi practice was at no more than 110 beats per min, which is typical of low-intensity aerobic exercise and does not increase physical or mental fatigue in high-intensity work practitioners.

During the mission, three Tai Chi intervention cycles were set up, the first of which considered the fact that after 14 days in the capsule, the participant became familiar with everything inside and started to shift from the excitement phase to the adaptation phase; the second intervention cycle was to drift backward for 40 min per day during the "Martian time" phase, with 36 days of overlapping stimuli causing the body's biorhythms. During this period, the PNN50 increased significantly after a single session of Tai Chi practice, suggesting increased parasympathetic activity, which can lower the HR and regulate anxiety. The third intervention cycle was conducted around the three-quarter time point during the 180-day mission, which is also when the participant's mood may be at its greatest ebb and flow in psychological terms. Although the interference of external conditioned stimuli on the effects of Tai Chi practice at different stages in this study cannot be ruled out, a single session of Tai Chi practice was still able to exert a positive effect on improving the balance of autonomic regulation, increasing the use of cognitive reappraisal emotion regulation strategies, and decreasing the use of expression inhibition emotion regulation strategies. Therefore, a single session of Tai Chi practice was able to increase the attention and relaxation indices significantly.

The "traces of movement" effect of the cyclical practice of paradisiacal Tai Chi

Most previous studies have focused on the immediate post-exercise effects or comparing changes in the participant's body before and after the exercise intervention.[14] In the case of human spaceflight missions, the exercise interventions chosen by astronauts to reduce the negative effects of environmental conditions on the human body need to have immediate effects, cycle effects, and some sustained effects after the intervention.

A study of patients with chronic pulmonary obstruction found that reduced lung function and exercise capacity could impair physiological health. A 3-month randomized controlled trial confirmed the effectiveness of Tai Chi Qigong in improving the physiology of patients with chronic pulmonary obstruction.[15] A follow-up evaluation of this study further confirmed that Tai Chi Qigong exercises can maintain the beneficial effects for a longer period.[15] In this study, when comparing the data before the "day round" Tai Chi intervention, during the intervention cycle, and during the rest period, the HR decreased in the second and

third intervention cycles, probably due to the proficiency of the Tai Chi exercise. In addition, another study demonstrated that Tai Chi exercise can effectively enhance sustained attention in healthy adults and highlighted the key role of cuneate/pre-cuneate and frontoparietal brain regions in promoting attention in young people while finding changes in brain activity that can be elicited and significantly correlated with attention. This study confirmed that attention and relaxation indices were significantly increased in the Tai Chi intervention period.[16] At the end of the Tai Chi intervention period, after a 1-month break from normal work and life (when Tai Chi was not practiced), most of the index data began to fall back, but the fluctuations were not large, showing a certain "movement trace" effect. The changes in the index data after exit and before entry suggest that the 180 days of the space mission led to a decrease in emotional regulation, but perhaps the changes were not significant due to the Tai Chi intervention, and more attention needs to be paid to the effects of the Tai Chi intervention and the "traces of movement" effect in subsequent studies.

Conclusion

Tai Chi, which astronauts have practiced many times in space, has been proven to have a positive effect on the emotional regulation of the participant in a 180-day simulated capsule confinement test on the ground. Further controlled tests are required to investigate the effects of the Tai Chi practice and the "movement trace" effect.

Submission statement

This manuscript has not been published and is not being considered for publication elsewhere.

Authors' contributions

Feizhou Tong and Chaoming Wu wrote the paper. Shiyun Wu , Lili Wang and Jie Li were responsible for the training program; Junzhi Sun, Yong Hu, and Xiaolu Jing were responsible for the data analysis and processing of the article; Yinghui Li and Yanlei Wang wrote the paper and supervised all the processes.

Ethics approval statement

The study was approved by the ethics committee of the China Astronaut Training Center, and all investigators were aware of the study and gave their consent for publication. The Ethics Committee of the Astronaut Center of China (NO. ACC201508) reviewed this study.

Consent for publication

All participants provided informed consent to disclose their data during the study.

Funding

We thank the China Astronaut Research and Training Center for supporting this stWe thank the China Astronaut Training Center for supporting this study. The project was funded by the Central Universities Basic Research Special Fund (2016ZD002).

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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