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Psychophysiological and cognitive effects of strawberry plants on people in isolated environments*

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Abstract: In manned deep-space exploration, extremely isolated environments may adversely affect the mood and cognition of astronauts. Horticultural plants and activities have been proven to be effective in improving their physical, psychological, and cognitive states. To assess the effects of applying horticultural plants and activities in isolated environments, this study investigated the influence of viewing strawberry plants on the mood of people in a laboratory experiment as indicated by heart rate, salivary cortisol, and psychological scales. The results showed that heart rate and salivary cortisol were significantly decreased after viewing strawberry plants for 15 min. "Tension" and "confusion" scored using the Profile of Mood States negative mood subscales, and anxiety levels measured using the State-Trait Anxiety Inventory scale were also significantly reduced. This study further explored the impact of viewing strawberry plants on cognition. A notable reduction of the subjects' reaction time after 15-min plant viewing was observed. Based on these findings, a long-duration isolated experiment in a bioregenerative life support system—"Lunar Palace I"—was conducted. A similar trend was obtained that crew members' mood states were improved by viewing the strawberry plants, but no significant change was observed. This study provided some experimental evidence for the benefits of interacting with strawberry plants in isolated environments.

Key words: Isolated environment; Horticultural welfare; Strawberry; Mood; Cognition
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1 Introduction

With the continuous advancement of human space exploration, long-term manned space flights have become a mainstream task in the current aerospace field. In manned deep-space exploration, the astronauts' environment is extreme, and there are many disadvantages such as isolation, confined living space, monotony, and loud noise. These conditions may have adverse effects on their psychology, affecting not only their emotions, cognitive ability, and mental health, but also social communication between them and other people (Shepanek, 2005; Nelson et al., 2013; Wang et al., 2014; Almon, 2019). Based on documented evidence from both USA and Russian space missions, adverse psychosocial reactions among astronauts during prolonged flights are a serious risk to mission success (White and Averner, 2001). Therefore, it is very important to ensure the psychological and behavioral health of the astronauts and to maintain their cognitive ability and work performance.

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Horticultural welfare, which uses plants and plant-related activities to treat and improve people's physical and mental illness, has attracted increasing attention because of its natural and gentle characteristics (Yamane et al., 2004; Wichrowski et al., 2005; Berman et al., 2008; Igarashi et al., 2015; Yu et al., 2017). Many studies have proved that horticultural plants and activities have a good therapeutic effect in improving the physiological, psychological, and cognitive states of people (Simson and Straus, 1998; Song et al., 2013, 2015). Some anecdotes from astronauts on people–plant interactions in space revealed that the affective responses and high level of interest shown by the astronauts were associated with greenery in spacecraft (Zabel et al., 2016; Odeh and Guy, 2017). For example, astronaut Don PETTIT wrote about his experience with zucchini squash plants in his blogs: "Apparently he takes pleasure in my earthy green smell. There is nothing like the smell of living green in this forest of engineered machinery." (NASA, 2012). However, there is currently little direct experimental evidence to support the psychological benefits of growing plants in space (de Micco et al., 2009).

Strawberry (*Fragaria×ananassa* L.) is one of the promising candidate crops for space life-support systems (Massa et al., 2010, 2015). As a herbal fruit crop, the strawberry is rich in vitamins, minerals, dietary fiber, and beneficial phytochemicals such as antioxidants (Perkins-Veazie and Collins, 2001; Luo and He, 2011). Strawberry is also a good candidate for horticultural welfare because of some advantageous characteristics such as its green leaves, yellow and white flowers, fruit shape and color change, and rich aroma that can effectively stimulate vision and smell. To provide evidence to support the benefits of applying horticultural plants and activities in isolated environments, this study selected strawberry as the target plant for horticultural welfare and explored the effects of its intervention on mood and cognition of people in isolated environments.

2 Materials and methods

2.1 Laboratory experiment

2.1.1 Subjects

The subjects were screened before being enrolled in the study and any with color vision or physical or mental disorders were excluded. Those who were habituated to smoking or drinking were also excluded. Finally, a total of 16 university students, 12 males and 4 females, were recruited in the laboratory experiment, with an average age (mean±standard deviation (SD)) of (23.8±2.5) years and an average body mass index (mean±SD) of (21.0±2.5) kg/m^2. Before the experiment, the subjects were informed only of the study procedures and requirements, without knowing the purpose of the study, and they voluntarily signed the informed consent form. The protocol included permission to photograph the subjects. The names of all subjects were coded throughout the whole study process to protect their privacy.

2.1.2 Experimental design

The laboratory experiment was conducted in an empty room with an area of 1.5 m×1.5 m. The surrounding area was closed with silver-white opaque material to shield from noise or interruption and create a closed workspace.

The laboratory experiment consisted of independent two-part experiments. The first part aimed to study the influence of strawberry plants on mood and was set up with three groups, including an experimental group (strawberry plant group) and two control groups (artificial strawberry model group and blank control group), as shown in Fig. 1. The strawberry plant group used real strawberry plants, while the artificial strawberry model group used an artificial plastic strawberry model; a blank control group was used to compare the effects on mood regulation of sitting still or viewing the plants during breaks. The 16 subjects participated in all three groups. To balance the order effects produced by repeated measurements, the experiment was designed as a randomized crossover trial, and a random number table was used to assign the order of the three tests randomly for each subject. To reduce the impact of "exercise" or "fatigue" on the results, the three tests of each subject were conducted separately with an interval of 5–7 d. The experimental procedure is shown in Fig. 2a. After 20 min of a work task such as solving difficult Sudoku puzzles (a logical task of reasoning numbers), the subjects filled out the psychological scales and collected their saliva samples. They then either viewed the strawberry plants or artificial strawberry model, or just sat down to have a rest without plants or plant replicas for 15 min. Finally, the subjects

Fig. 1 Experimental scenes from the laboratory experiment
(a) Strawberry plant group; (b) Artificial strawberry model group; (c) Blank control group

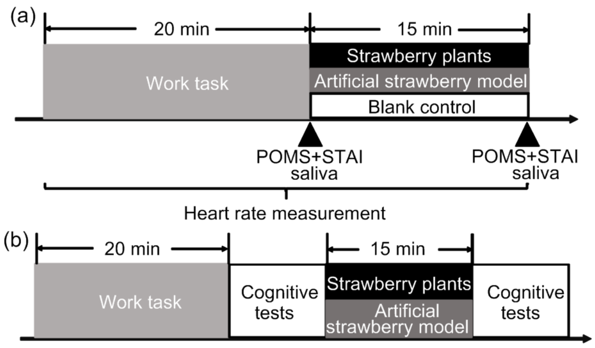

Fig. 2 Flow diagram of the laboratory experiment
(a) Experiment procedure of the influence of strawberry plants on mood; (b) Experiment procedure of the influence of strawberry plants on cognition. POMS: Profile of Mood States; STAI: State-Trait Anxiety Inventory

again filled out the psychological scales and collected their saliva samples. The heart rate data of the subjects were recorded throughout the whole test.

The second part aimed to investigate the influence of strawberry plants on cognition by two test groups: a strawberry plant group and an artificial strawberry model group. The 16 subjects participated in two tests and the order of the two tests for each subject was randomized. The experimental procedure is shown in Fig. 2b. After 20 min of a work task, the subjects completed three tests of cognition (attention span, digit span, and choice reaction time) using the Psykey psychological teaching system (Psyche-Ark Ltd., Beijing, China). Then they viewed the real or artificial strawberry plants for 15 min. Finally, the subjects again completed the three cognitive tests.

2.1.3 Physiological indices

Real-time heart rate data were recorded using the BioHarness™ Physiology Monitoring System (BIOPAC Systems Inc., Goleta, CA, USA). The data acquisition frequency of the heart rate was 1 Hz (1.008 s). The average heart rate values (1-min interval) of the subjects before and after the 15-min treatments for each group were calculated using AcqKnowledge® software (BIOPAC Systems Inc., Goleta, CA, USA).

Salivary cortisol, which reliably shows an increase under stress, can reflect the activity of the endocrine system. Therefore, salivary cortisol concentration can be used to indicate human stress levels. According to the diurnal variation of salivary cortisol, all tests in the first part of the experiment were scheduled to be performed after 2:00 p.m., at which time the rate of change in salivary cortisol slowed down. The interval between the three test groups for each subject was 5–7 d, and all three tests were carried out at the same time of day, so that the effects of natural rhythm of salivary cortisol levels over time and the interaction between different treatments were eliminated. Saliva samples were collected using a saliva collection aid (Sarstedt, Nümbrecht, Germany) and stored in a −80 °C refrigerator after pretreatments. Salivary cortisol was detected using a human cortisol enzyme-linked immunosorbent assay (ELISA) kit (Rigorbio Ltd., Beijing, China).

2.1.4 Psychological indices

The Chinese versions of two psychological scales with satisfactory validity and reliability, namely the Profile of Mood States (POMS) and State-Trait Anxiety Inventory (STAI), were used to assess the subjective emotional responses of the subjects. The short version of the POMS (Wu and Wang, 2015; Collado et al., 2017) comprised 40 adjectives describing seven subscales: tension (T), anger (A), fatigue (F), depression (D), vigor (V), confusion (C), and self-esteem (S-E).

The total mood disturbance (TMD) score was calculated using the formula: TMD=100+T+A+F+D+C−V−S-E. Anxiety level was investigated using the STAI state anxiety subscale (Spielberger, 1983; Yu et al., 2017) which contains a total of 20 questions.

2.1.5 Cognitive indices

The effects of strawberry plants on the cognition of people were analyzed using the PsyKey psychological teaching system (Wang, 2010) to measure the change of attention span, digit span, and choice reaction time before and after the 15-min viewing of the strawberry plants or artificial strawberry model.

In the test of attention span, 80 pictures were randomly displayed. The number of red dots in the picture was 5–12 and the duration of each picture was 250 ms. The percentage of correct responses to different red points was counted (calculated from the five red dots). The number of dots for the first 50% correct reaction was obtained through a linear interpolation method and used as the results of the attention span test.

In the test of digit span, unrelated numbers were randomly presented in a series. The length of the number sequence was between 3 and 12, and the subjects were asked to repeat them in the same order. This was carried out up to 30 times (three times for each digit span) and stopped after three consecutive failures.

In the test of choice reaction time, two kinds of stimuli were randomly presented in the experiment: a red or a green circle, each appearing 20 times. When a dot of one color appeared, the subjects needed to press the button of the same color as soon as possible. The average time taken to make the correct reactions was used as the choice reaction time and the number of wrong reactions was also recorded.

2.1.6 Statistical analysis

All data analyses were performed using SPSS 20.0 (IBM Corp., Armonk, NY, USA). For physiological and psychological indices, one-way repeated measures analysis of variance (ANOVA) was used, followed by a Bonferroni post-hoc test if the effects of between-groups were significant. Paired *t*-tests were used to compare the change in cognitive indices between the strawberry plant group and the artificial strawberry model group. Data are expressed as mean±standard error (SE). For all tests, $P<0.05$ was considered statistically significant. Effect size estimates for one-way repeated measures ANOVA were determined with partial η^2 (η^2=0.01 was a small effect, 0.06 a medium effect, and 0.14 a large effect) and for paired *t*-tests with Cohen's *d* (*d*=0.2 was a small effect, 0.5 a medium effect, and 0.8 a large effect).

2.2 Long-duration isolated experiment

2.2.1 Subjects

The participants were four students (two males and two females) of Beihang University (Beijing, China) with an age (mean±SD) of (28.0±2.0) years who were non-smokers and had no history of physical or psychological disorders. Alcohol, tobacco, and caffeine intake were prohibited throughout the experimental periods. Before the experiment, a full explanation of the research was provided and informed consent was obtained from all participants, except that the purpose of this experiment was not revealed.

2.2.2 Experimental design

The long-duration isolated experiment in the bioregenerative life support system (BLSS) was conducted in an analogue space station at Beihang University, referred to as Lunar Palace 1 (Li et al., 2016; Hao et al., 2018, 2019). The comprehensive cabin of Lunar Palace 1 included four private bedrooms, a living room, a bathroom, and a room for insect culturing (Fig. 3). This experiment was carried out in the bedrooms which had a volume of 2.0 m×1.5 m×2.5 m (length×width×height). This research was supported by the "Lunar Palace 365" project in which eight volunteers were divided into two groups (two females and two males in each group). Group 1 entered for an initial stay on May 10, 2017. After 60 d, Group 1 was replaced by Group 2, who stayed for 200 d. Group 2 came out on Jan. 26, 2018, and Group 1 reentered and stayed until May 15, 2018. The daily tasks of the volunteers were heavy and they needed to complete tasks according to the schedule, including feeding yellow mealworms, treating urine and sewage, and collecting environmental microbial samples. Moreover, the volunteers were isolated from the outside during missions in the cabins. Therefore, their psychological stress levels would be high. This study was conducted in the middle stage of the third phase of the

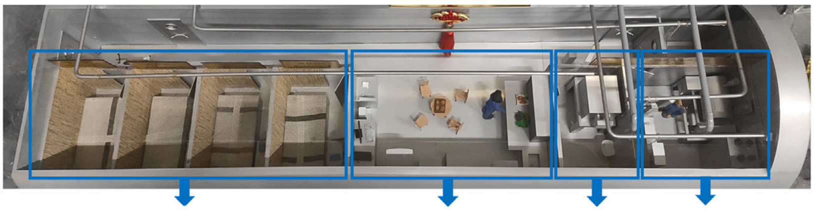

Fig. 3 Model of the comprehensive cabin of Lunar Palace 1

"Lunar Palace 365" project (Mar. 2018 to Apr. 2018). When the experiment began, volunteers (Group 1) had already lived in the isolated environment for more than 60 d.

The long-duration isolated experiment involved only the strawberry plant treatment and was conducted in two days. Four participants were randomly divided into two groups. On the first day, the first group viewed the strawberry plants, while the second group provided assistance, such as preparing experimental materials, and collecting questionnaires and saliva samples. After a week, they switched tasks: the second group viewed the strawberry plants and the first group provided assistance. On the day of the test, the participants' activities were restricted to the comprehensive cabin where there were no plants. The specific process of the test was as follows: firstly, the participants filled out the POMS questionnaire and their saliva samples were collected; then they viewed the strawberry plants for 15 min; finally, the participants again filled out the POMS questionnaire and their saliva samples were collected. The indicators of the participants before and after viewing the strawberry plants were compared.

2.2.3 Measurement indices

Salivary cortisol, a type of stress hormone, is a reliable parameter of stress reactions in humans and its sampling procedure is simple and non-invasive. Saliva samples from four subjects were collected into tubes before and after a 15-min strawberry viewing. The saliva collection tubes (Sarstedt, Nümbrecht, Germany) consisted of plastic tubes containing a cotton wool swab. The samples were frozen immediately and sent to the laboratory for the analysis of cortisol levels.

The participants were asked to describe their own mood states using a POMS questionnaire. The POMS has been previously widely used in isolated, confined, and extreme environment studies (Palinkas and Houseal, 2000; Palinkas et al., 2004; Wu and Wang, 2015), and has been proven to be valid under such conditions.

2.2.4 Statistical analysis

All data analysis was performed using SPSS 20.0. The Wilcoxon signed rank test was conducted to compare differences between pretest and posttest measurements. Data are expressed as mean±SE. For all tests, $P<0.05$ was considered statistically significant. Effect size estimates for the test were determined with r (r=0.1 was a small effect, 0.3 a medium effect, and 0.5 a large effect).

3 Results

3.1 Impact of strawberry plants on heart rate

Heart rate reflects the activity of the autonomic nervous system. When people are nervous or flustered, the heart rate is relatively high, whereas when they are calm or relaxed, the heart rate is relatively low. The results showed significant differences among the three groups ($F(2, 30)=7.670$, $P=0.002$, partial $\eta^2=0.338$). As shown in Fig. 4a, Bonferroni post-hoc test revealed that the mean change in heart rate (post-value minus pre-value, a negative sign indicating a reduction, and a positive sign indicating an increase) was significantly lower in the strawberry plant group ((−2.69±0.65) beats/min) than in the artificial strawberry model group ((−0.64±0.43) beats/min, P=0.027), and the blank control group ((0.33±0.55) beats/min, P=0.035). The initial heart rate values were (82.18±

2.03) beats/min in the strawberry plant group, (81.99±1.89) beats/min in the artificial strawberry model group, and (80.73±2.14) beats/min in the blank control group.

3.2 Effect of strawberry plants on salivary cortisol concentration

Salivary cortisol concentration can be used to indicate the level of stress. To analyze the impact of strawberry plants on the stress of subjects, we detected the cortisol levels. The results in the laboratory experiment showed that there was a significant difference among the three groups (F(2, 30)=3.482, P=0.044, partial η^2=0.188). The mean change in cortisol (post-value minus pre-value, a negative sign indicating a reduction and a positive sign indicating an increase) was significantly lower in the strawberry plant group ((−0.37±0.15) μg/dL; initial value: (1.88±0.18) μg/dL) than in the blank control group ((0.39±0.24) μg/dL; initial value: (1.91±0.13) μg/dL), P=0.035 (Fig. 4b). The results of the long-duration isolated experiment showed that the salivary cortisol concentration was reduced after 15-min strawberry viewing, from (1.90±0.31) to (1.71±0.31) μg/dL (Table 1). Although there was no statistical difference, the P-value was relatively small (P=0.068) and the effect size was large (r=0.65).

3.3 Improvement of negative emotional states by strawberry plants

To detect the influence of strawberry plants on people's emotional states, scores at the scale level were calculated and analyzed. For the subscale "tension" in the laboratory experiment (F(2, 30)=5.378, P=0.010, partial η^2=0.264), the mean change in tension score was significantly lower in the strawberry plant group (−1.79±0.45) than in the blank control group (0.33±0.22; P=0.007). For the subscale "confusion" in the laboratory experiment (F(2, 30)=7.495, P=0.002, partial η^2=0.333), the mean change in confusion score was significantly lower in the strawberry plant group (−2.56±0.62) than in the artificial strawberry model group (0.13±0.63; P=0.014) and the blank control group (−0.20±0.43; P=0.015). For the TMD in the laboratory experiment, there was a significant difference among the three groups (F(2, 30)=3.345, P=0.049, partial η^2=0.182). The mean change in TMD score was significantly lower in the strawberry plant group (−6.94±4.48) than in the blank control group (7.87±3.21; P=0.042) (Fig. 5a). In the results of analysis of state anxiety using STAI (F(2, 30)=6.405, P=0.005, partial η^2=0.299), the mean change in anxiety score was significantly lower in the strawberry plant group (−3.64±1.33) than in the artificial strawberry model group (1.50±1.53; P=0.040) and the blank control group (2.79±1.84; P=0.005) (Fig. 5b). The results of the long-duration isolated experiment showed that after a 15-min strawberry viewing, all negative emotion scores in the POMS questionnaire decreased, and all positive emotion scores increased, but the differences were not statistically significant (Table 1).

3.4 Increase of reaction rate after viewing strawberry plants for 15 min

The attention span and digit span of subjects in the laboratory experiment were improved after 15 min

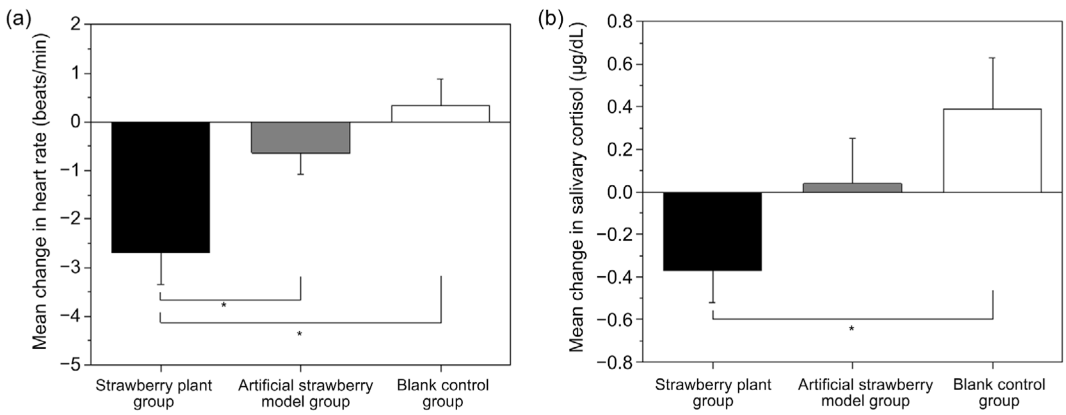

Fig. 4 Mean change in the physiological indices among three groups in the laboratory experiment

(a) Mean change in heart rate; (b) Mean change in salivary cortisol. All values are presented as mean±standard error (SE), n=16. * P<0.05

of strawberry viewing, and the number of wrong reactions was reduced, but there was no significant difference compared with the artificial strawberry model group. However, the choice reaction time was shortened by 28.73 ms, which was significantly lower than that in the artificial strawberry model group (P=0.006, Cohen's d=1.12; Table 2).

4 Discussion

This study aimed to explore the effects of strawberry plants on the mood and cognition of people in isolated environments. The heart rate is a basic index of autonomic nervous system activation, and a drop in heart rate indicates a state of relaxation. From

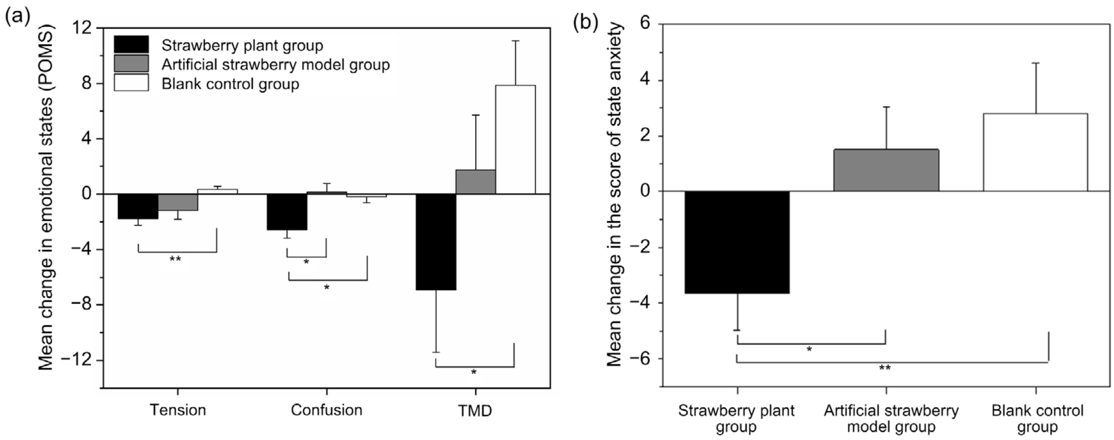

Fig. 5 Mean change in the psychological indices among three groups in the laboratory experiment
(a) Mean change in emotional states (POMS); (b) Mean change in the score of state anxiety. All values are presented as mean±standard error (SE), n=16. * P<0.05, ** P<0.01. POMS: Profile of Mood States; TMD: total mood disturbance

Table 1 Effects of viewing strawberry plants on salivary cortisol concentration and emotional states of people in the long-duration isolated environment

Time	Salivary cortisol (μg/dL)	Tension	Anger	Fatigue
Before strawberry viewing	1.90±0.31	1.50±0.96	1.25±1.25	5.25±1.93
After strawberry viewing	1.71±0.31	0.25±0.25	0.25±0.25	1.25±0.95
P	0.068	0.180	0.317	0.109
Effect size (*r*)	0.65	0.47	0.35	0.57

Time	Depression	Confusion	Vigor	Self-esteem	TMD
Before strawberry viewing	1.50±0.87	1.25±0.48	9.00±2.48	6.25±2.10	95.50±6.76
After strawberry viewing	1.00±0.71	0.75±0.48	13.50±2.33	8.25±1.65	81.75±4.91
P	0.157	0.157	0.144	0.195	0.068
Effect size (*r*)	0.50	0.50	0.52	0.46	0.65

POMS: Profile of Mood States; TMD: total mood disturbance. Values are presented as mean±standard error (SE), n=4

Table 2 Mean change in the cognitive indices between the strawberry plant group and the artificial strawberry model group in the laboratory experiment

Group	Attention span	Digit span	Choice reaction time (ms)	Number of wrong reaction
Strawberry plant group	0.38±0.37	0.13±0.34	−28.73±7.97	−0.33±0.18
Artificial strawberry model group	−0.01±0.37	−0.53±0.32	7.77±8.23	0.08±0.27
P	NS	NS	0.006**	NS
Effect size (Cohen's *d*)	0.26	0.50	1.12	0.45

NS: no significant difference. Values are presented as mean±standard error (SE), n=16. ** P<0.01

the results, we could see that, compared with the artificial strawberry model group and the blank control group, the heart rate was significantly reduced in the strawberry plant group (Fig. 4a), which indicated that people felt more relaxed and calmer after viewing strawberry plants than after viewing the artificial strawberry model or just sitting still. Some previous studies that examined physiological responses to a natural environment had reported similar results. Park et al. (2010) conducted field experiments in 24 forests across Japan, and found that forest environments promote a lower heart rate than city environments. Lee et al. (2011) found that the heart rate of young Japanese male subjects significantly decreased after forest bathing compared with their heart rates in urban environments.

To further determine the effects of strawberry plants on the mood of people, we detected the level of cortisol, as an indicator of the activity of the endocrine system (Groemer et al., 2010; Roma et al., 2011; Collado et al., 2017). Previous studies had shown that a decrease in stress levels led to a decrease in cortisol levels (Park et al., 2007; Tsunetsugu et al., 2010; Beil and Hanes, 2013). The results of the laboratory experiment showed that viewing strawberry plants for 15 min obviously decreased the cortisol level (Fig. 4b), indicating that a 15-min strawberry viewing was more beneficial for relieving stress than just sitting still.

The results of emotional questionnaires in the laboratory experiment showed that viewing strawberry plants for 15 min significantly reduced negative mood states, such as tension and confusion, state anxiety level, and mood disturbance (Fig. 5). These findings indicated that strawberry plants could significantly alleviate the negative emotions of people, which is consistent with previous studies conducted in forest environments (Horiuchi et al., 2013; Ochiai et al., 2015).

Emotion is one of the important factors affecting cognition (Nolen-Hoeksema et al., 2008; Smallwood et al., 2009). From the results of the emotionally related indicators, we knew that the mood of people could be significantly improved by the 15-min strawberry viewing. We then evaluated the cognition of subjects after viewing strawberry plants for 15 min, and found that the choice reaction time of the subjects was significantly shortened, which was conducive to the improvement of alertness. Although the attention span and digit span were improved, there were no significant differences compared with the artificial strawberry model group. This may be related to individual differences among the subjects, or to the fact that the subjects were tested immediately after strawberry viewing, and changes in attention and memory improvement had not yet occurred. Gidlow et al. (2016) compared the psycho-physiological responses of walking in natural and urban environments, and found that significant environmental differences in memory function did not manifest until 30 min after leaving the natural environment.

This study used a randomized crossover design to counterbalance order effects which might otherwise have significantly influenced the results of mood and cognition. The color of the strawberry plants may be an important factor affecting psychophysiological and cognitive benefits. Studies have shown that the color of plants can be sensed by intrinsically photosensitive retinal ganglion cells (ipRGCs) and be projected through the retinohypothalamic tract to the paired hypothalamic suprachiasmatic nuclei, as well as to a number of other nuclei involved in regulating physiology and behavior (Hattar et al., 2002; Hannibal et al., 2014). This may induce neurobehavioral and neuroendocrine responses, and ultimately impact mood and productivity. From the results, the strawberry plants had better effects on emotional and cognitive regulation than the artificial strawberry model. We inferred that in addition to the role of color vision, volatile organic compounds in strawberry plants may play an important role. Previous studies indicated that some plant volatiles were beneficial to people's mental emotions, such as relieving anxiety and depression (Matsumoto et al., 2014), and maintaining memory in individuals with Alzheimer's disease or other memory impairments (Lu et al., 2016). In addition, McCabe and Rolls (2007) found that vegetable odor could activate some areas in the orbitofrontal cortex and agranular insula. However, the effect of volatile organic compounds of strawberry plants on human emotions and cognition remains to be confirmed. Moreover, the novelty may also contribute to the benefits of strawberry plants on people in isolated environments.

To verify the results of the laboratory experiment in a more realistic space simulated environment, we conducted a long-duration isolated experiment in

China's "Lunar Palace 1." The results of the experiment showed that the cortisol level of the crew members was reduced after 15 min of strawberry viewing, which was consistent with the results of the laboratory experiment, indicating that viewing strawberry plants did help relieve the stress level of people in isolated environments. There was no significant difference in the result of the POMS questionnaire, perhaps because of individual differences and a small sample size. However, the low *P*-values suggest that 15 min of strawberry viewing could to some extent help improve the crew members' negative emotional states and increase their positive mood.

These findings provide scientific evidence that strawberry plants may improve the mood and cognition of people in isolated environments. In manned deep-space exploration, plants such as strawberries, which are suitable for use as a positive intervention for psychological and physical health, can be cultivated in the space station. On the one hand, food can be provided for the astronauts. On the other hand, the strawberry plants are expected to positively adjust the mood of the astronauts and shorten the reaction time to improve their alertness. This study had a few limitations. First, the number of subjects was small, especially for the long-duration isolated experiments. Second, the effects of fractal properties in plants were not considered. The certain ranges of structural dimensionality in plants may be related to their beneficial effects. Third, the duration of exposure to plants in isolated environments was not investigated in this study. Fourth, there was no real space station carrying out experiments. Whether the results of this research could be applied in space requires further research. Despite some limitations, our findings provide insights for future research directions in areas related to the improvement of psychophysiological and cognitive problems of people in isolated environments.

5 Conclusions

In this study, viewing strawberry plants for 15 min decreased cortisol levels, relieved negative emotions such as tension and confusion, and improved emotional states in both laboratory and long-term isolated environments. At the same time, 15-min strawberry viewing significantly reduced the choice reaction time of people, and the reaction rate was markedly increased, which contributed to an improvement in alertness.

Contributors

Zhao-ming LI, Hui LIU, and Hong LIU designed the study. Zhao-ming LI and Wen-zhu ZHANG performed the experiments. Hui LIU and Hong LIU supervised the study. Zhao-ming LI performed data analysis and drafted the manuscript. Hui LIU and Hong LIU contributed the editing and revision of the manuscript. All authors read and approved the final manuscript. Therefore, all authors had full access to all the data in the study and take responsibility for the integrity and security of the data.

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Compliance with ethics guidelines

Zhao-ming LI, Hui LIU, Wen-zhu ZHANG, and Hong LIU declare that they have no conflict of interest.

This study was approved by the Science and Ethics Committee of School of Biological Science and Medical Engineering in Beihang University, Beijing, China (Approval ID: BM20180003). All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all participants for being included in the study.

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中文概要

题　目：草莓对隔离环境中人的生理、心理及认知的影响

目　的：探究草莓对隔离环境中人的生理、心理及认知的影响，为改善深空探测等隔离环境中乘员的情绪和认知提供新的可能措施。

创新点：定量研究了草莓对隔离环境中人的生理、心理及认知的影响，并在研究中同时纳入了实验室短期模拟隔离实验和真实环境下的长期隔离实验。

方　法：在实验室实验中，通过测量心率、唾液皮质醇和心理量表等指标，并与草莓模型和静坐对比，研究观察草莓对情绪的影响；采用注意广度、短时记忆广度和选择反应时测试，进一步探究草莓对认知的影响。基于实验室实验的结果，在生物再生生命保障系统中进行长期隔离实验，进一步验证隔离环境中草莓对人情绪的正向调节作用。

结　论：本研究中，在实验室短期模拟隔离实验和真实环境下的长期隔离实验下，观察草莓 15 分钟可降低皮质醇水平，并减轻紧张和困惑等负面情绪。同时，15 分钟的草莓观赏使隔离环境中人的选择反应时显著降低，反应力明显加快，有助于警觉性的提高。

关键词：隔离环境；园艺福祉；草莓；情绪；认知