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Psychosocial interaction during a 105-day isolated mission in Lunar Palace 1 ☆

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ABSTRACT

As they are the most important and critical group in space missions, the crewmembers' emotions and interpersonal interactions have gained attention. The crewmembers are confined in an isolated environment, have limited communication with the outside world, and often undergo unpredictable risks, which may lead to the aggravation and acceleration of depression, displacement, and even interpersonal conflicts. These psychological factors could deteriorate the astronauts' effectiveness and safety. Therefore, the aim of the study is to identify the possible patterns over time regarding changes in the emotional states, cohesion and other group dynamics during a 105-day isolation period. The experiment was conducted in an analogue space station at Beihang University, referred to as Lunar Palace 1, which is the first crew made up of all Chinese members. In the experiment, all the crewmembers completed a profile of mood states (POMS) questionnaire every week, along with the group's environment scale (GES) and work environment scale (WES) every two weeks. Following the experiment's isolation period, semi-structured interviews were also conducted as qualitative data. As a result, the following observations were determined: 1) there was no 3rd quarter phenomenon observed during 80 days isolated experiment for Group 3; and the average positive emotions and cohesion of crew were gradually increased with the process. 2) Significant individual differences were identified; and crewmembers possessed different change patterns on psychological state. 3) Crew structure with 1 male and 2 female, less pre-mission team building, and collectivist culture might influence the psychosocial interaction of crew. In summary, the results from Lunar Palace 1 demonstrated that the emotions and climate of Group 3 was in a good state for a successful mission.
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1. Introduction

As they are the most important and critical groups in space missions, the crewmembers' emotions and interpersonal interactions have gained attention [1–4]. Several psychosocial issues have been identified by previous research studies. These issues have resulted due to the increase in mission durations. The astronauts may experience negative influences to their moods and group interactions over time [5–7]. Also, effects due to individual and gender differences have also been found in the space missions and simulated experiments. These various psychosocial issues have been related to the mission duration, with many problems being noticed after the halfway point, referred to as the "3rd quarter phenomenon" [8,9].

It has been determined from previous studies [3,7,10] that confined isolated environments, limited communication with the outside world and unpredictable risks, may lead to the

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aggravation and acceleration of depression, displacement and interpersonal conflicts. It is imperative to conduct related research in order to identify how these factors influence human mental health and performance in space, and also to find possible counter-measures for these psychosocial issues. The 105-day isolated mission in Lunar Palace 1 at China offers us a precious opportunity to study the interaction and related psychological change of crew.

1.1. Literature review

It is necessary for astronauts to be in a good psychological quality state in order to successfully perform space missions. Several previous studies focused on this topic, and have reported that long duration space flights could affect the astronauts' emotions, as well as the group dynamics [2,3,11,12].

Human behaviours are closely related to emotions. In a space capsule or station, the environment is isolated, and communication with the outside is limited to telephone or delayed video. Also, the monotonous working schedule can aggravate loneliness and homesickness, which could trigger negative mood reactions, such as depression and anxiety. Therefore, an astronaut's unstable emotional state could be a threat to the safety and performance of the space flight. Results from the International Space Station and Mir Space Station have shown that during a mission transition (first few weeks into space and back to earth), the astronauts' emotional changes become irregular [13]. Similar negative moods have also been found in both polar expeditions and space analogue experiments [1,14,15]. In addition, research teams have been attempting to identify the possible changing pattern which added governing emotions. In 1991, Bechtel and Berning [9] put forward the “3rd Quarter Phenomenon”, which suggests that after the halfway point of a mission's duration, the crewmembers experience some depressed emotions. However, recent studies have shown that no 3rd quarter phenomenon occurred on the ISS or Mir [12,16]. These results suggest that this phenomenon cannot be applied to all long-duration isolation missions.

As previously mentioned, emotions can influence human behaviour. The crewmembers are the main executors of the space missions, and therefore the interactions among the crewmembers should be an issue to focus on. The group's cohesion, formed by communication and mutual acceptance, can unite crewmembers, as well as strengthen teamwork. The group's cohesion is influenced by the mission phase. Ref. [17] found that crewmembers felt increasing cohesion at the beginning of a space mission on Mir, since they were progressively adapting to the environment, and to each other. Such positive changes were also found in the Arctic Expedition [18]. Also, the crew's size and structure was another factor which affected the cohesion. Since the conflicts between two persons were found to be more difficult to calm, crews formed by three people seemed a more suitable [3] solution. This formation has been used in multiple space missions, such as the Apollo missions. In addition, the gender effect could also affect cohesion. In a simulated space mission (simulation of the flight of the international crew on Space Station, SFICSS-99), one male crewmember intended to kiss a female crewmember, which triggered serious conflicts [11,19]. However, in other studies, there have been reports that the involvement of female crewmembers could strengthen the group's cohesion and fulfil the task [3]. Therefore, there have been no consistent results regarding the gender effect on space missions.

The group dynamics of the space crew also included leadership, along with the perceived support from the outside. Within the mission group, one crewmember was designated as the leader. Efficient leadership can facilitate a space mission [20]. The support and control of the leader are important factors in leadership. Previous studies have suggested that in different mission stages, crewmembers may need different types of leadership [7]. Studies about ISS and MIR also found that the support of the leader was positively related to the group's dynamics [16,21]. However, some studies have shown that individual differences existed in regards to perception of group interactions [5], which might cause that they misunderstand their leaders. Along with the support of the leader within the mission crew, the perceived support from the outside by the crewmembers was also important. These results may indicate that we should offer different types and degrees of outside support for each crewmember. Currently, there have been no related studies in this regard.

So far, there is not publicly report about medium-long duration analogue of space mission crew, which was consisting of all Chinese members. In general, East Asian culture including China is more interdependent, or collectivist, western culture is more individualistic. Whether the conclusion draws from crew comprised of American or Russian will be emerged in Chinese crew is a very important and should be investigated here. It should be the first time that studying on psychosocial interaction of all Chinese crewmembers and control personal.

1.2. Simulated circumstance

The simulated experiment study was conducted in an analogue space station at Beihang University, referred to as Lunar Palace 1, which is an integration test-bed for bio-regenerative life support systems. The facility consisted of one comprehensive cabin with 42 m^2, and one plant cabin with 58 m^2. The comprehensive cabin included 4 private bed rooms, a living room, a restroom, and a room for waste disposal and insect culturing. The construction of Lunar Palace 1 has been divided into two phases: first phase included a comprehensive cabin and one plant cabin, which could provide three people with a life-support environment. In next phase, another plant cabin will be built, which will assist in the protection and safety of four people. Our study was conducted using the equipment of Phase 1, and the construction of Phase 2 is currently undergoing.

The bedroom with door for crewmember is very narrow, which just contain a single bed and a small table. There is only private area to crew members, who can connect Internet with their personal laptop or smart phone in it. But they cannot call outside through the cell phone. The signal of mobile service is shielded since the experimental facility made by metal material. The only one wired phone usually communicated with outside control with no delay.

Several biological experiments and psychological research studies were conducted in Lunar Palace 1. Seven candidates

were selected for the study, which consisted of four males and three females with differing age. They were assigned daily tasks created to imitate the astronauts' schedule, including cultivating and harvesting plant, breeding yellow mealworm, disposing wastes, and other jobs. Lunar Palace 1 regenerating basic living necessities and disposing wastes to provide life support for crew, with aim to satisfy requirement of 60% plant food and 100% O^2 and water for crew.

Finally, there were four crewmembers involved in this experiment. They were selected according professional and psychological performance. All of the crewmembers were from the School of Biological Science and Engineering at Beihang University. They had professional knowledge regarding the equipment, and knowledge of its operation. All had conducted research on this subject for many years.

As shown in Fig. 1, these four crewmembers entered into the capsule at different time points. In the first 15 days, there were two male crewmembers in the cabin, which formed Group 1. Beginning on the 15th day to the 26th day, crewmember "c" joined the team, and formed Group 2 (2 males and 1 female). For the last 80 days, crewmember "b" left the station, while crewmember "d" joined the team. This formed Group 3, containing 1 male and 2 female crewmembers. The group arrangement mainly depended on three points. One was to regulate system operation; the second was to verify the maximum potential for the system; and the last was to conduct psychological research among the variable groups.

We have elaborately discussed the crewmembers' emotional states in Lunar Palace 1 in our previous study [22]. Some findings have to be noticed again: first there is no significant time effect on emotion for the whole mission; second, at the beginning of group 3, tension and anger slightly increased compared to group 2; third, at the first two weeks of mission, edge-significant self-emotional changes were observed among three groups. To extent the previous results, the aim of this study is to identify the possible change pattern over time of the crewmembers' emotional states, cohesion and other group dynamics during 80-day isolation period for Group 3.

2. Method

2.1. Subjects

In this study, we only focused on Group 3, which consisted of two females and one male. They were all Chinese crewmembers ranging in age from 27 to 32. Two of these were PhD students, and one was an assistant professor. Group 3 was confined from day 26 to day 105 of the whole experiment, which meant that the first day of 1st quarter of the study was day 26 of the isolation, and the first day of 4th quarter was day 86 of the experiment.

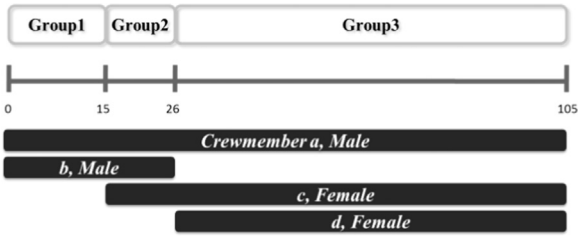

Fig. 1. Subject arrangement of Lunar Palace 1.

As we mentioned before, the mission control personnel were trying to find the optimal crew to balance the system supplement via comparing three groups with different members at the start. System potential of oxygen and other materials is maximum release after the Group 3 entered. All crewmembers were noticed that each group was independent study group. Through this way, we defined last 80 days as one isolated period.

2.2. Measurements

Three psychological scales were employed in the study, adding interview and pro-selection test.

2.2.1. Questionnaire

Once a week, the crewmembers were asked to describe their own mood states using a Profile of Mood State (POMS) questionnaire employed via computer. This version of the POMS had been modified by a Chinese research team to adapt to the Chinese context [23]. The short version of the POMS was a self-administered measure of the crewmembers' current moods or affective states, and consisted of 40 items which were rated 5 point-Likert scales from "not at all" to "extremely". The POMS data could then be consolidated into six factors which were analytically derived from mood variables such as: tension–anxiety; depression–dejection; anger–hostility; confusion–bewilderment; fatigue–inertia; and vigour–activity, as well as a global distress variable (Total Mood Disturbance).The POMS has been previously widely used in isolated, confined and extreme environmental studies [15,16,24], and has been proven to be valid under such conditions.

A Group Environment Scale (GES) was tested once every two weeks among the crewmembers using 90 items. These items consisted of 10 subscales that could measure the actual, preferred and expected social environment of the group. In our study, we employed a GES Chinese version, which is translated from English version, to identify the actual social climate of the group. These 10 subscales assessed the three underlying sets of the dimension: relationship dimensions, personal growth or goal orientation dimensions, and system maintenance and change dimensions. It was found to have a high validity and reliability, and had also been utilised in related research studies [12,16,21].

Similar to the GES, the crewmembers completed a Work Environment Scale Chinese version every two weeks. The WES also contained 90 items divided 10 subscales, and could measure three types of environments. In this study it was used to measure the actual social environment. Each subscales of the GES and WES is composed of nine statements that are responded by the subjects as being either true or false.

2.2.2. Post-mission interview

Individual, semi-structured interviews were performed with each crewmember within a week following their confinement. The same interviewer conducted all of the interviews. The first part of the interview focused on "critical events" that occurred among the crewmembers during the confinement. The subjects were also asked to describe their own reactions to these incidents. The other four parts of the interview were regarding the diet situations, living conditions, work load and self-evaluation. Each interview lasted approximately 90 min, and was audio-recorded for subsequent transcriptions and qualitative analyses.

3. Results

Using the questionnaires data and interview record, we evaluated the psychological state and change of crew. The results and analysis are shown as follows. Then potential reason is supposed and discussed in the section.

3.1. Third quarter effect

For identifying 3rd-quarter decline, one-way ANOVA analysis is employed. Measures according test time are split into four sections. Then the F value is calculated in variance test. In regards to the POMS, the results indicated that there were no differences in the values across the four quarters of the missions on 4 of 5 negative emotions, the positive emotion vigour, and total score of emotion. Follow same approach, results from most of the GES and WES also showed no halfway decrements in the 80 days isolated duration, as reflected by almost all the subscale scores except for two of them. So, there was no evidence of a unique 3rd quarter effect.

However, we did find some changes from the three subscales. Fatigue subscale of POMS shows significant difference during 4 quarters ($F(3,33)=2.980$, $P=0.045$). The crew's fatigue scores became low at the end of the confinement period, which was significant less than the scores at Stage 1. On the interview, crew member told about that they had very heavy workloads in the first few weeks, and had few time for relaxation or entertainment. We suppose that is the reason why fatigue score is decrease during the mission.

In the cohesion subscale, we found that the score of Stage 1 was significantly lower than the other three stages ($F(3,14)=3.662$, $P=0.039$). This may indicate that when the crewmembers were trying to adapt their new environment and crewmates at the beginning of Group 3, they were confronted with some issues or conflicts. This type of condition was also found to occur on Mir, and is referred to as the run-in period [17]. In regards to the autonomy subscale, we found that crewmembers were more autonomous in Stage 4 than in Stages 1 and 2 ($F(3,14)=3.694$, $P=0.038$). Since the working schedules for the crewmembers were almost always decided by outside personnel, this may suggest that the crewmembers were continuously becoming more sophisticated in their daily work, which in turn reflected the crew's gradually increasing autonomy during the confinement.

These results were consistent with an international space station study, in which it was determined that the duration of the confinement did not seem to be a factor in predicting the changes in mood or group social climate [16]. However, compared with previous simulated experiments conducted on the ground, such as the Mars 500 where a significant stage-changing pattern was determined, our findings did not show such pattern [25].

Although results from ANOVA showed that there was no 3rd quarter phenomenon in Lunar Palace 1, we used correlation analysis to identify time effect on crew's psychological changes. We calculated the correlation between duration days and Group 3 crew's subscale scores. Commonly, Pearson correlation coefficient requires multivariate normal distribution data, which is also approximately unbiased. Due to our small sample, we used non-parametric approach, Spearman correlation, instead of conventional Pearson correlation. Limited to the length of paper, here only listed significant Spearman correlation coefficient on Table 1.

In POMS, all subscales were positively related with time except vigour subscale. Five negative emotions and TMD score gradually decreased over time, whereas self-discovery subscale increased. Both in GES and WES, there were 4 out of 10 subscales positively related with time. And work pressure from WES was negatively related with time. Those results showed that Leader Support and Supervisor Support, which were felt increase by crew. They tended to discuss personal problems more. At the same time, group rules also got more explicit. Finally, they felt less work pressure and more innovation.

This result seemed to be inconsistent with the result from ANOVA. That is because that ANOVA test the ratio of between-group variance and within-group variance. In current case, the between-group variance is not sufficient bigger than within-group variance, so the F test was not significant. On the other side, the within-group variance is not very small showing us individual differences are not

Table 1
Correlation coefficient of duration days and subscale means.

Subscale	Coefficient	Sig.
POMS		
Tension–Anxiety	−0.817	0.001
Depression–Dejection	−0.942	< 0.001
Anger–Hostility	−0.858	< 0.001
Fatigue–Inertia	−0.813	0.001
Confusion–Bewilderment	−0.626	0.020
Total mood distribution	−0.952	< 0.001
GES		
Leader support	0.820	0.023
Self-discovery	0.899	0.007
Order & Organisation	0.794	0.030
Innovation	0.928	0.004
WES		
Coworker cohesion	0.899	0.007
Supervisor support	0.899	0.007
Autonomy	0.883	0.010
Work pressure	−0.971	0.001
Innovation	0.794	0.030

Note: The significance with single tail test.

disregarded. ANOVA with repeated measures is available for reducing within-group variance. But in our case, the group 3 is consisting of only 3 subjects. Whatever, even just split them to two group, there is still one group has zero variance. So the ANOVA with repeated measures is unsuited method here. That is a critical limit of small sample size study.

3.2. Individual differences

In order to measure the differences related to the outside climate perception among the crewmembers, we used Friedman tests to analyse the data from 3 questionnaires. The Friedman test is a non-parametric statistical method which was developed to detect differences in treatments across multiple test attempts [26]. Although the score of subscales is interval data, parametric method is unappropriate since very small sample size. Here, we used it to investigate personal difference rather than time effect. So every subject is regarded as a treatment, three measure values on each time point are ranked from 1 to 3 according subscale's score from low to high. Each measurement is treating as a block, and 18 measures are conducted in the dataset. We found significant inter-individual differences for the all 6 subscales of POMS and 10 subscales of GES and WES, as shown in Table 2.

Results show the individual differences across all three questionnaires, which indicated that: there existed significant individual differences in POMS; and crewmembers "c" and "d" were more comfortable with a group environment than crewmember a. In POMS, most of subscales showed significant individual differences among three crewmembers. Crewmember "a" (as a male) differed from the other two members in all subscales. However, both as women, crewmember "c" still differed from crewmember "d" on 6 subscales. It might indicate that gender was not a key factor to affect emotional states. At same time, crewmember "c" has lowest negative emotions and high dynamic.

From GES and WES, we have seen that crewmember "a" showed the lowest satisfaction of group climate and work environment. He feels less explicit about rules and policies in the group. Particularly, crewmember "a" also experienced a higher level of anger and aggression, while with high negative mood states investigated by POMS. On the other side, crewmember "c" consistently showed the highest comfort rating part subscales of the work environment. Crewmember "d" feels more leader support, and more independence, who also feel more freedom of action and expression of feelings. It is maybe related with her role, the leader of the Group 3.

3.3. Individual psychological change

Actually, emotional changes of each subject did not confirm the same pattern. Fig. 2 shows how Total Mood Disturbance of each subject changed over time. At the beginning of the mission, member "a" presented high level of negative emotion. However, it gradually decreased along with the mission going. Crewmember "d" continued to feel slightly increasing negative emotion, whereas crewmember "c" remained stable over the

Table 2
Individual difference in 3 questionnaires.

Subscale	Sig.	Crewmember's rank		
		a	c	d
POMS				
Tension–Anxiety	< 0.001	**2.08**^{c}	**1.21**^{a,d}	**2.71**^{c}
Anger–Hostility	0.007	**2.38**^{c}	**1.38**^{a,d}	**2.25**^{c}
Fatigue–Inertia	< 0.001	**2.71**^{c}	**1.17**^{a,d}	**2.12**^{c}
Depression–Dejection	< 0.001	**2.83**^{c,d}	**1.58**^{a}	**1.58**^{a}
Vigour–Activity	< 0.001	**1.88**^{c}	**2.96**^{a,d}	**1.14**^{c}
Confusion–Bewilderment	< 0.001	**1.79**^{d}	**1.38**^{d}	**2.83**^{a,c}
Total mood distribution	0.001	**2.08**^{c}	**1.17**^{a,d}	**2.75**^{c}
GES				
Leader support	0.005	**1.17**^{d}	1.92	**2.92**^{a}
Expressiveness	0.004	**1.00**^{d}	2.25	**2.75**^{a}
Independence	0.006	**1.42**^{d}	**1.58**^{d}	**3.00**^{a,c}
Anger & aggression	0.015	**2.92**^{d}	1.67	**1.42**^{a}
Order & Organisation	0.023	**1.33**^{c}	**2.42**^{a}	2.25
Innovation	0.023	1.75	**1.42**^{d}	**2.83**^{c}
WES				
Involvement	0.003	**1.08**^{c}	**3.00**^{a}	1.92
Supervisor support	0.006	**1.00**^{c}	**2.83**^{a}	2.17
Clarity	0.035	1.83	**2.75**^{d}	**1.42**^{c}
Innovation	0.043	**1.50**^{c}	**2.75**^{a}	1.75

Note: Data in the table was mean rank of each crewmember ("a", "c", "d" referred to three subjects in Group 3). The **bold** indicates a significant different pair.

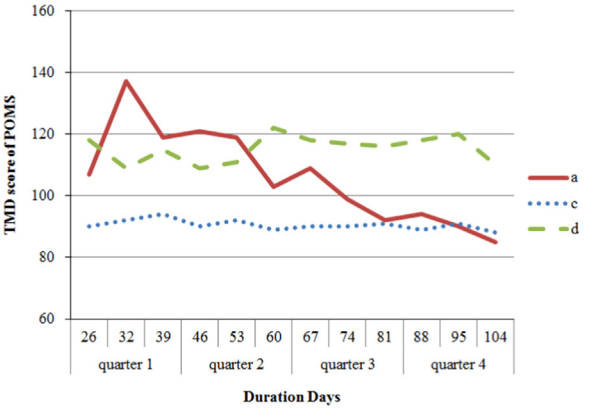

Fig. 2. Changes over time on TMD by subject.

mission. These kinds of change patterns also showed in other subscales, such as anger, depression, and vigour in POMS, and leader support, order & organisation, and innovation in GES.

As generally, crewmember "a" experienced more changes in emotion and group perception than others. Crewmember "c" showed very stable emotional state. Before the mission, we have measure personality of crewmember candidates via the Big Five Personality Scale. That combining the result of post-mission interview will help us to explain the reason.

Crewmember "a" possessed very high level of openness and low nervousness. At the beginning of the mission, he might not adjust to the new group, which caused the intensely increasing TMD and low score of GES and WES. There is a critical event which was mentioned by all

members in the post-mission interview. The first event was considered to be a conflict event regarding crop harvesting methods, which occurred during the period from the 26th to 30th day of confinement, while the Group 3 was just built. Crewmember "a" was main responsibility person of crop harvest, but his operation approach is not supported by other female members. This period matched with intense negative mood disturbance of crewmember "a". Be in progress with the mission, due to his low nervousness, he readjusted his emotions in the station, which was confirmed with later TMD changes. And another key event was occurred on the 50th day of confinement, which is considered to be a joyful activity involving all three members. It is one female crewmember cut his hair for the male member. This may indicate that the crewmembers were more engaged in this group and felt more positive emotions.

For crewmember "c", her personality should be a very important reason to the stability of emotion. She possessed the lowest openness and nervousness among all female candidates. So the events did not affect her mood and other subscale scores strongly. Analysing POMS subscale score of crewmember "d", 5 negative subscales did not change obviously during the mission, but her vigour was decrease after the 46th day of confinement. Maybe it is why her TMD was increased on the last half session as shown in Fig. 2. Because the TMD is obtain via 5 negative emotion scores minus vigour score.

3.4. Structure of crew and leadership

We mentioned that there happened a conflict event and different psychological change patterns during the mission. Therefore, we would like to discuss the reason in this part. There were three factors that should be taken into consideration.

The first one was the structure of crew, which instituted of two female members and one male. However, all male members crew or male as majority in crew are common before this study. Crew structure of male as minority might be a discomfort to the male member. He was the minority and he might have no common topics with females. The narrow confined area of the cabin also is inconvenience to his daily life.

The second reason could be inadequacy of the pre-mission team building. Although all crew candidates were from one big research team before the isolated experiment, but Group 3 members were focused on different study topics and did not conduct collaboration before the mission. So they used some time to adapt to other members and confinement circumstance. Former research production has mentioned that it is beneficial that selected crewmembers and mission control personnel be involved in pre-mission training together [2]. In future Lunar Palace experiments, the training about crew tension and cohesion, the relationship between crewmembers and mission control personnel, and the appropriate use of different leadership roles should be careful considered.

Along with the mission going, leadership role of Group 3 became more and more clear and all three members were more aware of their own responsibility in the team. Especially under collectivist culture, strong team spirit and task-oriented might enhanced team cohesion. As well as, crewmember "a" showed sharply emotion shift. And the average negative emotions of crew are negatively related to duration days too.

4. Summarisation

Because of tiny sample size and un-rigorous experiment design, we acknowledge it as difficult to make any strong causal claims according to results. But there are still some important finds that should be highlighted, which are showed from the 105 days isolated experiment of Lunar Palace 1. 1) This is the first crew that was made up of all Chinese members. The scale measure data demonstrated that the group climate and emotions of Group 3 were found to be in a good state to success of mission. 2) There was no 3rd quarter phenomenon observed during 80 days isolated experiment of Group 3. And the average positive emotions and cohesion of crew were gradually increased with the process. 3) Significant individual differences were identified, and crewmembers possessed different change patterns on psychological state. 4) Crew structure, pre-mission team building, and collectivist culture might influence the psychosocial interaction of crew in Lunar Palace 1.

There are two limitations to the generalisability of the study. For space missions and analogue experiments, very few subjects are challenge to the studies. In our Group 3 only involves 3 subjects, which limit the generalisability of the results, and limit the usage of quantitative method. As Cazes point out that indirect instruments and qualitative tools are more reliable than stranded quantitative measure to such kind research [27]. Another side, 80 days confinement is medium duration. Real space mission at now or on the future will last long duration. Such as half year reside on IIS, and more than 500 days Mars travel. However, we will observe crew interaction and psychological change in long duration isolation while the second phase experiment of Lunar Palace 1.

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