Original Article

Mental and Physical Workload, Salivary Stress Biomarkers and Taste Perception: Mars Desert Research Station Expedition

Balwant Rai[1,2], Jasdeep Kaur[2]

[1]Kepler Space University, South Carolina, USA, [2]Simulated, Microgravity and Human Body, JBR Institute of Health Education Research and Technology, Punjab, India

Abstract

Background: Very few studies have been conducted on the effects of simulation of Mars conditions on taste. **Aims:** This study was planned to find the effects of physical and mental workload on taste sensitivity and salivary stress biomarkers. **Materials and Methods:** Twelve crew members were selected. Taste reactions and intensity of the taste sensations to quinine sulfate, citric acid, and sucrose were tested before and after mental and physical tasks for one hour. Also, psychological mood states by profile of mood state, salivary, salivary alpha amylase and cortisol, and current stress test scores were measured before and after mental and physical tasks. **Results:** Average time intensity evaluation showed that after the mental and physical tasks, the perceived duration of bitter, sour, and sweet taste sensations was significantly shortened relative to control group. There were good correlations between average time intensity of sweetness, bitterness, sourness and cortisol levels. **Conclusions:** Taste alterations due to stress can have an effect on the health and confidence of astronauts in long- term space missions. Thus, this issue remains one of the important issues for future human explorations.

Keywords: Amylase, Cortisol, Extreme environment, Mental workload, Saliva, Taste sensation

Address for correspondence: Dr. Balwant Rai, Halgreensgade 1, 3rd, Copenhagen S, 2300, Denmark. E-mail: raibalwant29@gmail.com

Introduction

The buoyancy of humans in exploring extreme space environments has been demonstrated during missions to and around the moon. A mission to Mars however, requires humans to adapt to systemic and complex environments away from the human body's capacity. Astronauts will encounter both physiological and psychological extremes during the journey, while on the Mars terrain, and the return to Earth.

Exposure to microgravity and space environment during short- and long-duration space missions has important medical and health implications in astronauts.[1-7] Other important aspects of the space environment can lead to alterations in the chemosensory perception of foods. The special interest to sensory analysts is the effect of microgravity on the chemical senses.[8] This area has been clearly under-researched in space missions, probably due to its lack of perceived terrestrial benefit. The limited literature that exists about chemosensory research under conditions of microgravity is sometimes contradictory and leaves a window for speculation. Microgravity induces physiological changes including an upward shift of body fluids toward the head, which may lead to an attenuation of the olfactory component in the flavor of foods. Chemosensory changes may also relate to space sickness, shuttle atmosphere, stress, radiation, and psychological factors.[8] It has been reported that that taste was altered in extreme condition during Mars Desert Research station crew-78 and simulated microgravity.[9-11] Of course, one of the best analogues for space exploration is the International Space Station (ISS), and many valuable human factors studies have been conducted there. However, ISS studies are expensive, infrequent, small subject based and there exists many privacy issues relative to Earth-based

Access this article online	
Quick Response Code:	Website: www.najms.org
	DOI: 10.4103/1947-2714.103318

studies. Furthermore, the ISS is an ideal analogue, but there are no field science especially geological sampling, etc. and equivalents. Thus, effect of surfacing activities on human body is not possible to study. However, NASA's Bioastronautics Roadmap and Human Research Integrated Research Plan identify a number of barriers to safe human spaceflight, and some strategies for overcoming them.[12] Of these, some clearly are not appropriate for investigation in analogue environments, such as - risk of carcinogenesis from space radiation and long term effect on health of the remainder. However, many of these issues are acquiescent to analogue research. Moreover, analogue research is relatively safe and inexpensive and permits an easy approach, wherein many of the conditions of space exploration (lengthy periods of isolation, communications latency, crowding, bulky life-support equipment, small heterogeneous crews, packed schedules, etc.) can be experienced in parallel by the participants. Nonetheless, we supposed that human factors analogue studies can provide vital imminent into the risks of human spaceflight and the value of potential countermeasures.

We proposed a hypothesis that mental and physical stress may have noticeably effects on taste during simulated Mars mission during two weeks. So, this study was planned to find the effects of mental and physical stress on taste in extreme conditions [limited food supply and water, limited space to sleep, high workload (workload of experiments and extravehicular activities), multicultural and international environments and to work in spacesuits]. The MDRS, Utah (USA) provides a unique extreme environment. The Mars Desert Research Station (MDRS) is an analog to a Mars surface habitat, constructed for mission simulations according to Mars Reference Mission guidelines,[13] and located in a US southwest desert region relevant to Mars analog geology, biology, and human research. The main aims of station are to develop field tactics based on environmental constraints (being mandatory to work in spacesuits), to test habitat design features and tools, and to evaluate crew selection protocols. Though much warmer than Mars, the desert location was selected as of its Mars-like terrain and appearance. Crew members must wear an analogue space suit simulator (complete analogue space suit simulators) or a "sim suit" when completing tasks outside the Habitat (HAB) to simulate the protection they would need from the harsh Martian environment.[14]

Materials and Methods

Subjects

The 12 crew members were selected from two crews Euro Moon Mars by International Lunar Exploration Working Group and Vrije Universiteit Amsterdam. The ages for the crew members aged 20-26 (23.6 (2.4)) years. The average and calcium intake of the crew members during mission was 2400 kcal/day (range 2090-3200 kcal/day) and 1267 mg/day (1130-1400 mg/day), respectively. Dietary sodium and potassium intake were maintained at 98 (80-103) and 86 (75-120) mmol/day, respectively. Water intake was ad libitum 1236 (1200-1309) mL/day. All participants wore the SenseWear™ Armband (BodyMedia, Inc. Pittsburgh, PA) during mission for energy and sleep analysis. Calcium intake was measured as in previous study.[15] Duration of work (scientific experiments and extravehicular activities) and leisure was measured by maintaining time table diary.

Study design

The subjects were divided into one group starting at 10:30 and second group starting at 13:30. Every subject was tested for one session (for example, control condition and mental workload condition) for 1 day. Each session lasted for about 1 h. Each crew member (12 participants) participated in both the mental and physical workload 30 sessions for each. Physical workload tasks were measuring extravehicular activities for soil and rock sampling. The taste stimuli were exemplars of the sensations of bitterness, sourness, and sweetness. The bitter sample was an aqueous solution of quinine sulfate (1.82 ± 10^{-5} M).[8,16,17] The sour sample was an aqueous solution of anhydrous citric acid (1.37 ± 10^{-2} M), and the sweet sample was an aqueous solution of sucrose (2.63 ± 10^{-1} M). As a mental workload assessed by unique letter method as dercribed in previous study [18]. The purpose of this workload was to produce mental fatigue; the performance of subjects was unimportant. For the physical workload, individuals did extravehicular activity for 1 h. In order to evaluate the change of the mood state before and after the workload, a profile of mood state (POMS) was used.[16,17].

Taste and after-taste intensity were evaluated as dercribed in previous study.[18] For each type of workload, the taste intensity evaluations was carried out twice, before and then following the physical or mental exercise, by means of the Time Intensity (TI) test.[18,19] Subjects performed only one session a day. Following each session, subjects were informally questioned (self-examination) about their feelings. The stress was measured by using current stress test (CST) as described previous study.[20]

Laboratory analysis

Saliva samples were collected before and after mental and physical tasks. The samples were immediately frozen at -4°C, centrifuged and analyzed for biomarkers. The CST was used for measuring stress.[20] Salivary cortisol (Salimetrics Inc., PA, USA) and alpha-amylase (alpha-amylase assay kit, Salimetrics Inc., State college, PA, USA) were measured.

Statistical analysis

Student's *t*-test and ANOVA test was applied. Data were analyzed using SPSS, version 11 (SPSS, Chicago, IL, USA).

Results

Duration of sleep, work and leisure was 482 (143), 542 (178), and 126 (34) minutes, respectively. Following the letter search task (tasks or workload), feelings of tension and fatigue increased while the sense of vigor decreased [Table 1]. It was frequently reported in the subjects' self-examination after the test session that they felt irritable or very tired. Relative to the pre-stress baseline, the average TI function for bitterness showed a decrease in maximum intensity, a reduction in the duration of after-taste and a decrease in total bitterness (area). For sourness, there was change in maximum intensity, and there was a reduction in duration and a decrease in total sourness. The pattern for sweetness was similar to that for sourness and there was a reduction in the duration of after-taste and a decrease in the total amount of taste [Table 2].

Following the physical work (tasks), there was an increase in the senses of fatigue and tension and a tendency for an increase in the sense of vigor [Table 1]. Furthermore, the subjects reported during their self-examinations that they felt an increase both in the sense of fatigue and the sense of vigor induced by physical exercise. Thus, the effects of physical exercise, as shown by POMS and self-examination, were very different from mental exercise. The TI taste evaluation showed that the maximum intensity, the duration of after-taste, and the total amount of after-taste were changed for bitterness and sweetness. For sourness, however, there was a decrease in the intensity and the total amount of taste and the duration of after-taste tended to be reduced [Tables 2 and 3].

CST scores, salivary alpha amylase, and cortisol levels were increased, although increased levels were more in physical tasks as compared to mental workload [Table 4]. So, taste affects more in physical as compared to mental tasks. There were good correlation between CST scores, salivary alpha amylase and cortisol (r = 0.89, r = 0.92). There were good correlation between average time intensity of sweetness, bitterness, sourness and cortisol levels (r = 0.89, r = 0.78, r = 0.84, respectively).

Discussion

The taste intensity of solutions of sucrose, quinine sulfate and citric acid were measured using time intensity techniques. The mental and physical task resulted in a reduction of the duration of taste as supported by previous study.[8,16-19,21] The taste affects were more pronounced in physical as compared to mental tasks. It could be because of physical tasks leads to more stress as compared to mental tasks supported by the fact of higher level of CST scores, salivary alpha amylase, and cortisol levels in physical tasks. Furthermore, stress biomarker cortisol inhibits the neurotransmission of noradrenalin, dopamine, and serotonin, and/or a reduction in the sensitivity of their receptors.[19,21] Taste change is not due to sleep disturbance and leisure time as these are not contributing this study.[22] Also, it has been reported that low levels of calcium and acidic condition leads to suppression of the taste responses.[23] Normal calcium levels were reported in all crew members indicating

Table 1: Scores of mood state before and after mental and physical workload

Parameters	Computer workload				Physical workload			
	First day		End of mission*		First day		End of mission*	
	Before	After**	Before	After**	Before	After**	Before	After**
Tension	6.23 (1.22)	24.68 (4.67)	7.89 (2.33)	30.67 (3.78)	4.67 (1.04)	1.89 (1.02)	5.56 (1.23)	2.34 (12.4)
Vigor	20.68 (4.67)	12.67 (5.34)	21.02 (3.56)	13.02 (4.56)	24.67 (4.65)	32.78 (3.78)	28.78 (4.67)	32.45 (5.36)
Fatigue	11.45 (2.67)	46.54 (3.46)	13.78 (3.45)	52.67 (3.67)	14.78 (3.45)	45.67 (6.45)	15.89 (4.04)	48.67 (5.89)
Vague	12.67 (3.02)	23.56 (5.78)	14.56 (4.67)	32.67 (3.57)	10.96 (2.68)	8.03 (2.04)	9.12 (3.03)	6.95 (3.05)

Scores are a percentage (%) out of a possible 100 points possible for each factor; *P < 0.05 vs. first day; **P < 0.01 vs. before

Table 2: Taste perception following a period of physical stress

Parameters	Sweetness				Bitterness				Sourness			
	First day		End of mission *		First day		End of mission*		First day		End of mission*	
	Before	After**	Before**	After**	Before	After**	Before	After**	Before	After**	Before	After**
Total amount* (area)	567 (45)	468 (44)	534 (67)	460 (68)	732 (64)	453 (67)	723 (62)	420 (73)	554 (54)	420 (56)	534 (64)	402 (65)
Maximum intensity	76 (4)	74 (5)	75 (6)	72 (3)	79 (5)	65 (3)	77 (6)	62 (7)	72 (5)	70 (6)	70 (7)	67 (5)
Duration time (s)	74 (12)	54 (11)	70 (12)	52 (11)	88 (8)	55 (7)	86 (7)	52 (8)	70 (6)	46 (6)	67 (5)	43 (6)

Total amount was calculated by summation every 5 s. *P < 0.05 vs. first day; **P < 0.01 vs. before

Table 3: Taste perception following a period of mental stress

Parameters	Sweetness				Bitterness				Sourness			
	First day		End of mission*		First day		End of mission*		First day		End of mission*	
	Before	After**	Before	After**	Before	After**	Before	After**	Before	After**	Before	After**
Total amount$ (area)	523 (47)	409 (43)	511 (56)	398 (54)	702 (54)	446 (52)	678 (61)	340 (64)	489 (52)	399 (52)	478 (51)	402 (65)
Maximum intensity	68 (5)	62 (7)	65 (8)	57 (4)	70 (7)	60 (5)	68 (5)	56 (6)	64 (6)	52 (7)	63 (8)	58 (6)
Duration time (s)	67 (10)	48 (12)	64 (14)	43 (10)	70 (2)	50 (3)	67 (8)	40 (9)	63 (7)	40 (8)	61 (6)	38 (7)

$total amount was calculated by summation every 5 s.; *$P < 0.01$ vs. first day; **$P < 0.05$ vs. before

Table 4: Scores of CST and salivary biomarkers levels before and after mental and physical workload

Parameters	Mental workload				Physical workload			
	First day		End of mission *		First day		End of mission *	
	Before	After**	Before	After**	Before	After**	Before	After**
CST	2.56 (0.23)	3.02 (0.56)	2.89 (0.45)	3.45 (0.67)	2.78 (0.89)	3.24 (0.78)	2.84 (0.68)	3.35 (0.89)
Salivary alpha amylase (U/mL)	59.6 (24.2)	67.5 (23.2)	60.5 (23.2)	78.9 (23.6)	65.9 (23.5)	78.9 (24.6)	67.8 (34.2)	85.6 (23.5)
Salivary Cortisol (µg/dL)	0.267 (0.112)	0.289 (0.115)	0.280 (0.117)	0.304 (0.113)	0.274 (0.114)	0.296 (0.115)	0.278 (0.115)	0.312 (0.116)

*$P < 0.05$ vs. first day ss; **$P < 0.01$ vs.before; CST: Current stress test

this is not contributing factor. Decreased energy consumption is not linked to taste and smell loss and related complaints.[24]

Microgravity induces physiological changes including an upward shift of body fluids toward the head, which may lead to an attenuation of the olfactory component in the flavor of foods. Chemosensory changes may also relate to space sickness, shuttle atmosphere, stress, radiation, and psychological factors.[8] High workload during performance of experiments and extravehicular activities, multicultural and international environments and working in spacesuits leads to stress.[25-26] in simulated and real microgravity conditions.[20,27] So, stress produced due to microgravity, physical, and mental tasks and extreme environment condition could affect the taste sensations as well.

Mental stress interrupts sympathetic baroreflex sensitivity during the initial short period time of stress when expressed as diastolic arterial blood pressure - muscle sympathetic nerve activity burst incidence.[28-29] The mental arithmetic task in astronauts obtains sympathovagal shifts toward improved sympathetic modulation and reduced vagal modulation.[30] The sympathetic nervous system and the hypothalamic-pituitary-adrenal (HPA) axis are the main mediators of the stress response through hormones[20] as supported by increased levels of salivary hormones.

There were good correlation between CST scores, salivary alpha amylase, and cortisol as reported in our previous studies.[20] Salivary markers for mentoring of stress parameters can be used for stress during selection of astronauts, during mission and after mission because it is a noninvasive, cost-effective, less time consuming, easy to use, and non-infectious tool.

Consumption of food is one of the basic needs of humans and any disturbance in the pleasure of taking different meals due to taste alterations can have an effect on the health and confidence of astronauts in long-term space missions, in a similar manner to what occurred with individuals on Antarctic missions[8] and in this study. Further study is required on large sample size, taking into account all physiological and physiological factors to prove the effects of simulated and real microgravity and extreme conditions on the taste sensation. Thus, this is one of important issue to address for future human explorations.

Acknowledgments

We would like to express our gratitude toward the Mars Society, ILEWG, ESA/ESTEC, l'Ecole de l'Air, VU Amsterdam, Dr. Guy Pignolet from the SALM institute, Dr Carol Stoker (NASA Ames), Mission Support, Mr. Don Lusko, and all other related people for their daily assistance, and our remote supporters from America, Europe, Canada, and India. We are very thankful to our crew members such as Quentin Bourges (Bob), Matthieu Ansart, Crystal Latham, and Rachel Dompnier for taking part in this project, without which this project would have not possible.

References

1. Antonutto G, di Prampero PE. Cardiovascular deconditioning in microgravity: Some possible countermeasures. Eur J Appl Physiol 2003;90:283-91.

2. Kerstman EL, Scheuring RA, Barnes MG, DeKorse TB, Saile LG. Space adaptation back pain: A retrospective study. Aviat Space Environ Med 2012;83:2-7.
3. Fraser KS, Greaves DK, Shoemaker JK, Blaber AP, Hughson RL. Heart rate and daily physical activity with long-duration habitation of the International Space Station. Aviat Space Environ Med 2012;83:577-84.
4. Davis JR, Vanderploeg JM, Santy PM, Jennings RT, Stewart DF. Space motion sickness during 24 flights of the space shuttle. Aviat Space Environ Med 1989;59:1185-9.
5. Herault S, Fomina G, Alferova I, Kotovskaya A, Poliakov V, Arbeille P. Cardiac, arterial and venous adaptation to weightlessness during 6-month MIR spaceflights with and without thigh cuffs (bracelets). Eur J Appl Physiol 2000;81:384-90.
6. Willey JS, Lloyd SA, Nelson GA, Bateman TA. Space Radiation and Bone Loss. Gravit Space Biol Bull 2011;25:14-21.
7. Trappe S, Costill D, Gallagher P, Creer A, Peters JR, Evans H, *et al*. Exercise in space: Human skeletal muscle after 6 months aboard the International Space Station. J Appl Physiol 2009;106:1159-68.
8. Olabi AA, Lawless HT, Hunter JB, Levitsky DA, Halpern BP. The effect of microgravity and space flight on the chemical senses. J Food Sci 2002;67:468-78.
9. Rai B, Kaur J. Odorant identification based on solid phase in EVA Participants of ScienceReport (Biomedical). (Accessed June 23, 2012, at http://mdrs.marssociety.org/home/field-reports/crew100b/day12).
10. Rai B. Human Oral Cavity in Simulated Microgravity: New Prospects. AMDS 2009;3:35-9.
11. Rai B, Kaur J, Foing BH. Evaluation by an aeronautic dentist on the adverse effects of a six-week period of microgravity on the oral cavity. Int J Dent 2011;2011:548068.
12. Grounds D, Vargas PR, Penley N, Charles J. Human Research Program Integrated Research Plan; 2009. p. HRP-47065.
13. Hoffman SJ, Kaplan DI editors. Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team. Lyndon B. Johnson Space Center, Houston, Texas: NASA Special Publication; 1997.
14. Mars Desert Research Station. (Accessed March 23, 2012, at http://mdrs.marssociety.org/).
15. Baecker N, Frings-Meuthen P, Smith SM, Heer M. Short-term high dietary calcium intake during bedrest has no effect on markers of bone turnover in healthy men. Nutrition 2010;26:522-7.
16. McNaire DM, Lorr M. An analysis of mood in neurotics. J Abnorm Psychol 1964;69:620-7.
17. Bergdahl M, Bergdahl J. Perceived taste disturbance in adults: prevalence and association with oral psychological factors and medication. Clin Oral Investig 2002;6:145-9.
18. Nakagawa M, Mizuma K, Inui T. Changes in taste perception following mental or physical stress. Chem Senses 1996;21:195-200.
19. Dess NK, Edelheit D. The bitter with the sweet: The taste/stress/temperament nexus. Biol Psychol 1998;48:103-19.
20. Rai B, Kaur J. Salivary stress markers and psychological stress in simulated microgravity: 21 days in 6° head-down tilt. J Oral Sci 2011;53:103-7.
21. Namba K, Tuda Y, Nakagawa M. Taste preference of bitterness. Proc. 25th Jap. Symp. Taste Smell 1999;25:149-52.
22. Nasermoaddeli A, Sekine M, Kumari M, Chandola T, Marmot M, Kagamimori S. Association of sleep quality and free time leisure activities in Japanese and British Civil Servants. J Occup Health 2005;47:384-90.
23. Kamo N, Kashiwagura T, Kobatake Y, Kurihara K. Role of membrane-bound calcium in taste reception of the frog. J Physiol 1978;282:115-29.
24. Schiffman SS, Graham BG. Taste and smell perception affect appetite and immunity in the elderly. Eur J Clin Nutr 2000;54:S54-63.
25. Rai B, Kaur J, Foing BH. Salivary amylase and stress during stressful environment: Three Mars analog mission crews study. Neurosci Lett 2012;518:23-6.
26. Rai B, Foing BH, Kaur J. Working hours, sleep, salivary cortisol, fatigue and neuro-behavior during Mars analog mission: Five crews study. Neurosci Lett 2012;516:177-81.
27. Endler NS. The joint effects of person and situation factors on stress in spaceflight. Aviat Space Environ Med 2004;75 (7 Suppl):C22-7.
28. Durocher JJ, Klein JC, Carter JR. Attenuation of sympathetic baroreflex sensitivity during the onset of acute mental stress in humans. Am J Physiol Heart Circ Physiol 2011;300:H1788-93.
29. Keller DM, Cui J, Davis SL, Low DA, Crandall CG. Heat stress enhances arterial baroreflex control of muscle sympathetic nerve activity via increased sensitivity of burst gating, not burst area, in humans. J Physiol 2006;573:445-51.
30. Aubert AE, Verheyden B, d'Ydewalle C, Beckers F, Van den Bergh O. Effects of mental stress on autonomic cardiac modulation during weightlessness. Am J Physiol Heart Circ Physiol 2010;298:H202-9.

How to cite this article: Rai B, Kaur J. Mental and physical workload, salivary stress biomarkers and taste perception: mars desert research station expedition. North Am J Med Sci 2012;4:577-81.

Source of Support: Nil. **Conflict of Interest:** None declared.