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HUMAN MOON AND MARS EXPLORATION MISSION CHALLENGES & TOOLS FOR PSYCHOLOGICAL SUPPORT

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ABSTRACT

This paper provides a summary of a European Space Agency (ESA) study that lead to definition of a range of tools aimed at providing psychological support to the crew during long-duration exploration missions. The investigation started from identifying the type of psychological issues the crew will need to deal with. Subsequently, the issues where broken down into groups of interacting factors that trigger the issues. The factors then were systematically grouped into the Psychological Issues Matrix (i.e. Psy-Matrix). A workshop was run to identify solutions to the issues identified in the Psy-Matrix. During the workshop, specifically invited experts examined presented papers on tools that could potentially be applied to Moon and Mars missions. Experts also examined a structured set of factors and issues that can have an impact on astronauts' psychological well-being and proposed preventive measures. They brainstormed for solutions to overcome potential problems the crew may encounter on a mission to another planet. The study was completed with extending the existing astronaut psychological support model and defining the toolset, the Embedded Psychological Support Integrated for LONg-duration missions (EPSILON). Individual EPSILON components were defined and 24 high priority components were recommended for development. Lastly, design recommendations and an EPSILON development strategy were proposed.

INTRODUCTION

The need for a study of technologies and techniques for psychological support during long-duration exploration missions comes from a human desire for space exploration, which can be realised in the near future. This undertaking is honourable and exciting but is challenging even for the most mentally prepared and trained astronauts and cosmonauts. Hence, the challenge extends to scientists and industry to devise techniques and technologies that can support and help the crew on exploration missions.

Exploration Mission Constrains

Long-duration exploration mission success will largely depend on the psychological and physiological well-being of the crew (Kanas & Manzey 2003), which will be difficult to support merely through external resources, such as communication with the mission control on Earth. The crew, which may consist of between three and six members (Mission to the Moon) or six members (Mission to Mars), will have to be dependent on each other for the entire duration of the mission. A Moon mission can last 190 days and a return trip to Mars up to a 1000 days. The evacuation of the crew in case of an emergency is not possible during a mission to Mars, but can be done from the Moon surface. The communication during a mission to Mars has delays of up to 40 minutes and depends on the relative position of the Sun, Earth and Mars. Under these conditions, where external immediate support is unavailable, the crew will have to problem-solve and deal with events themselves.

CATEGORISING INTERACTING FACTORS INTO GROUPS

Research was performed to systematically define the types of issues the crew are likely to face. Existing categories of psychological issues, derived from interviews, anecdotal evidence and experiments were ambiguous. They accounted for roughly a quarter of the issues identified in this study, leaving three quarters to be identified and addressed (Solodilova-Whiteley, 2007a). Through a review of the latest available literature and studies (HUMEX, 2003; Kanas & Manzey 2003; Stuster, 1996) an initial list of factors has been established. The categories of factors emerged through understanding the nature of problems experienced in Low-Earth-Orbit, expeditions in Antarctica and in underwater and on-land studies designed to resemble isolated and harsh living and working conditions in space.

A total of sixty-seven factors were identified that were categorised into seven protective 'shells' and the environment. The crew will be faced with factors from these shells throughout the mission (see Figure 1). The external environment, being the most important threat of life for astronauts, will force the conditions of isolation and confinement. The crew will have to work and live surrounded by it, which in turn can be considered as the main source of psychological stressors (or an opportunity

for personal growth and improvement of interpersonal relationships).
The protective power of each shell decreases from the most inner to the most outer shell, with the inner primal biological shell being the hardest to be effected by psychological stressors. Progressing outwards, each shell becomes easer to penetrate, until the last protective layer of the habitat, which protects against the hostile environment. The external environment and outer layers have a more constant and continuous effect on the well-being of the crew. These factors are impossible (or harder) to change, where the inner shell factors are in comparison easier and quicker to manipulate.

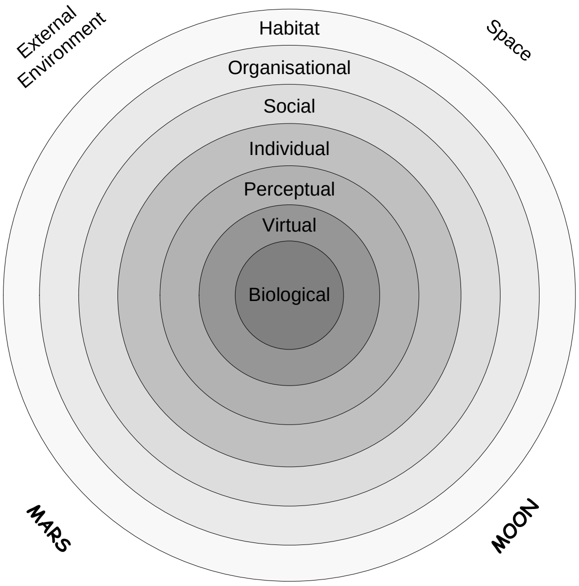

Figure 1: Protective Shells and the Environment.

External Environment
The surrounding space represents the environment that the crew will work and live in throughout the trip. It includes factors that characterise the environment, e.g. absence or unsuitability of atmosphere for a human, varied weather and lighting conditions, changes in gravitational forces, radiation levels and available resources.

Habitat Shell
The habitat is the first shell that provides the crew protection from the environment, whether it is on the Moon, Mars or open Space. It is designed (or should be designed) to allow effective crew performance and comfortable rest. This shell carries a lot of weight in influencing how well the crewmembers work, rest and interact with each other. The factors that define the habitat range from the appropriate supply of life-sustaining atmosphere, food and conditions suitable for work and relaxation, to the design of equipment layout, decor and personal space arrangement.

Organisational Shell
Organisational layers refer to systems that monitor and support the crew throughout the mission, and facilitate the crew's optimum level of performance to provide them with their best chance for mission success. Broadly, all these numerous systems can be thought of as an organisation protecting the crew and the entire mission. Included in this shell are also workload level, task distribution and organisation, and information access.

Social Shell
The social shell pertains to the maintenance of a healthy interaction balance among the crew. It contains factors ranging from crew gender, social and command hierarchy to aspects of social interaction (e.g. inclusiveness and frequency of crew interactions). This shell and the organisation shell are closely linked and have an effect on each other.

Individual shell
This shell contains the description of each individual crewmember, their needs, virtuosity and limitations. It contains a definition of their personality types and their characteristics, their need for personal space, energy level, their preferred rhythm of activity and their need for various types of information. Every person has a preferred balance in each of the shell factors. For example, in terms of rhythm of activity, some prefer to work and move on from one task to another quickly, and others prefer a slower pace; respectively one would feel bored if things do not move at a higher pace and the other might feel stress under pressure.

Virtual shell
The virtual shell can be thought of as the inner world of each individual crewmember. The definitions and information within this category may provide insight into crewmembers actions, and how they view and interpret the world, for example through the definition of a crewmember's system of values and their attitudes. Crew motivation and content with themselves is also covered under this category.

Perceptual shell
This shell contains a description of each individual's perspective on their living and working environment, based on factors that are also described within this shell. The perceptual shell is closely related to the body or biological shell. However, the inclusion of a perceptual shell as a separate category is due to its influence on how the crew perceive their surroundings. This in turn has a strong repercussion on whether they interpret their surroundings as stressful or comfortable. Also, perception is effected strongly by extreme

environmental and habitat conditions, such as isolation and/or partial or total sensory deprivation (Vernon, 1966; Comer, 2007). Additionally, alterations in perception can impair an individual crewmember's judgment and actions, impact crew interactions and as a result jeopardise the entire mission.

Both perceptual and virtual shells can be compared to a tint on a pair of glasses, which can alter our understanding of our surrounding environment, our interpretation of it, and our reading of other people's actions.

Biological shell

This shell concerns all physiological aspects of crew health. Under this category all human biological systems are listed (e.g. the system of bones and muscles, respiratory system and reproductive system). Although the description and effects of this shell are not intended to be covered under this study, deterioration and poor health has a direct effect on psychological well-being and vice versa. Also, description of this shell is an illustration of how the proposed conceptual framework can be applied to examine the effects of factors of individual shells on the crew's physical health. Using this framework may potentially elucidate health-threatening scenarios that the crew will face during long-term exploratory missions.

Each layer of the complete shell system represents a set of factors that will influence the situation and have an effect on how the situation is perceived by an individual. The diversity and completeness of situations depends on the diversity and exhaustiveness of the factors listed.

Shell Dimensions

General categories of factors can be broken down further to classify the variety of factors in each shell (Figure 2). They may be categorised against six dimensions, e.g. *time*, which are the same across all shells and the environment. The dimensions would correspond to six context-defining dimensions and can be identified through the following questions:

- *Substance* – What is it consist or made of?
- *Structure* – How is it structured? What are its components?
- *Space* – Where is it? What space does it occupy? How does it utilise space?
- *Time* – When, how often and how does it change over time?
- *Energy* – What energy does it use? How does energy affect the shell?
- *Information* – How does it work? How is information processed and controlled?

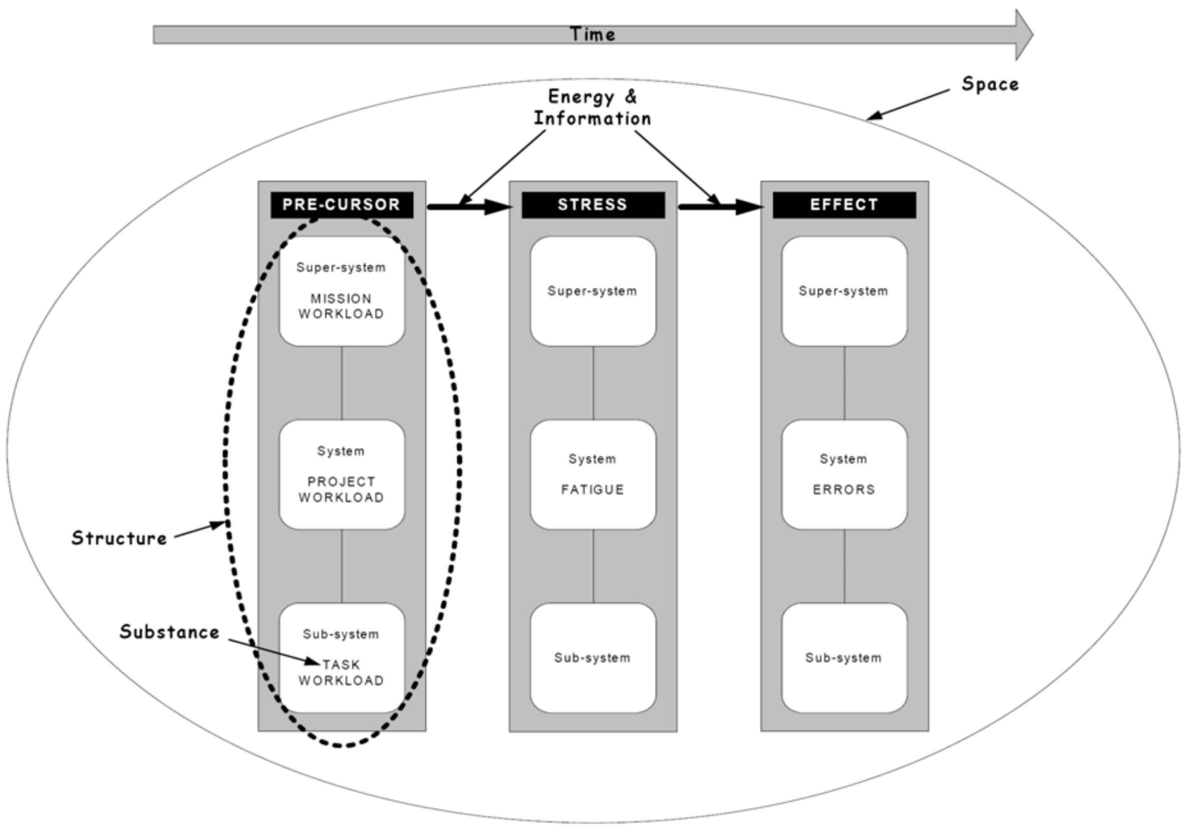

Figure 2: Shell Dimensions.

This further classification also allows the comparison of distinctly different factors across all shells. They can also be thought of as context defining factors (Bogatyreva & McMahon, 2006).

These dimensions provide the necessary elements to model any potential situation, for example individual workload (i.e. *substance*), which is part of a larger hierarchical *structure* that happens in a specific place (i.e. *space*), and changes over *time* with *information* and *energy* input (Figure 2). These six dimensions are suitable for describing both the essence of issues the crew will face and possible solutions.

This classification system allows forecasting potential problematic situations and establishing how to resolve them through interaction of classified factors in each shell and the environment, which define the situations.

Scales for Factors

Every factor can be measured on a scale representing two extreme ends of that factor. For example, the factors *Habitat size* within the *Habitat shell*, can be represented as restricted on one end and abundant on the other side of the scale. Variability along the factor's scale represents various surroundings and situations under which the crew live and interact. Each crewmember has a preferred side of the scale for each of the sixty-seven factors, which can vary over time. When any of the shell factors become out of balance, an issue or a problem arises that needs to be rectified. If the shell balance is not restored in time, it escalates to being a stress to the crew with potentially detrimental outcomes. For example, a perceived restricted habitat space can lead to a feeling of being deprived of privacy, which in turn can cause territorial behaviour, with further negative impact on interpersonal relationships and as a result can affect the mission progress and outcome.

INFORMING THE DESIGN

The effects of long-duration exploration missions cannot be predicted, but need to be explored to inform the design of psychological support. This study has been conducted to systematically define and classify the issue to inform the requirements process.

From an initial list of sixty-seven factors, seven protective shells and the environment shell, were formed. As a result, thirty-six clusters (i.e. eight shells multiplied by eight and multiplied by two to avoid duplication of clusters) of potential issues were defined producing a Psy-Matrix (Table 1). A total of 2278 individual issues and potentially even more situations the crew may face can be defined in the Psy-Matrix (Solodilova-Whiteley, 2007a). A Literature review showed that roughly only a quarter of the issues are currently identified (see the blacked out cells in Table 2).

This framework allows traceability of all identified issues and the interacting factors, which cause them to appear, in sufficient detail. It helps in identifying situations the crew can face, and the type of impact they can have on the psychological well-being of the crew. For design purposes, the comprehensive list of factors together with the Psy-Matrix can be used for the requirements definition process. The goal of the design then is to maintain the integrity of the protective shells and design out, or minimize, negative effects of factors by introducing factors that can have a positive effect on the crew well-being.

Identifying Existing Solutions

Using the thirty-six clusters of potential issues, corresponding existing solutions to these issues were identified and classified in a table format. This was based on a literature review of tools that are currently used for providing psychological support to people living and working in similar conditions to exploration mission scenarios. The use of concepts, presented at the Tools for Psychological Support workshop at ESTEC (26-27 March 2007), was also discussed as a part of literature review.

Lastly, the criteria for selecting an appropriate psychological support tool are described, which are based on mission constraints, such as the absence of live communication with Earth (for a mission to Mars), and the need for privacy when using a tool. The parameters that can establish the potential effectiveness of the tools are also discussed.

BRAINSTORMING WITH EXPERTS

One of the chief motivations for the Tools for the Psychological Support (TPS) during exploration missions workshop was to provide a forum whereby the latest psychological support tools could be presented and evaluated by experts in the space psychology domain (Solodilova-Whiteley, 2007b). The workshop format was designed to facilitate the sharing of ideas and the free-flow of discussion. In addition, in the criticisms and evaluations made upon the presented tools, it was seen as essential to introduce notions of the final requirements for a practical psychological support tool for use during exploration missions. Such practical concerns include: Is the tool already successfully used on earth? Does it need validation? Does the tool have any specific limitations that would prevent it from being used in long-term space missions? The other parts of the workshop focused on brainstorming ideas on how to prevent psychological issues arising, using the combined experience of the assembled experts. The brainstorming session systematically worked through the 36 categories of issues (i.e. Psy-Matrix, see Table 1 and Table 2).

	Environmental	Habitat	Organisational	Social	Individual	Virtual	Perceptual	Body
Environmental	1. Living & working in two conflicting environments (e.g. inside a habit protected from radiation vs. working outside the spaceship)	2. All issues related to being dependent on life support systems)	3. Remote regulation and monitoring of crew performance and adjustment during long-duration expedition	4. Issues of sharing or dividing resources available on the planet	5. Motivation, attention, memory, activity rhythm issues	6. Religious, cultural and/or moral issues, 'value shifts'	7. Issues related to how the crew perceives the environment and what impact it has on their perceptions (e.g. sensory deprivation)	8. Physiological problems related to different environmental conditions and adaptation to them (e.g. transition from zero gravity to Mars gravity)
Habitat		9. Habit design issues; (e.g. rigidity vs. flexibility of layout and design); safety issues; wear and tear	10. Social issues related to habitat use during work and rest; its functionality (e.g. habitat size vs. allocation of work and rest areas)	11. Issues over use of space (e.g. lack of privacy, territorial behaviour)	12. Confinement issues; privacy and the use of personal space; territorial behaviour issues	13. Personal preferences; cultural issues; food issues; habitat aesthetics	14. Sensitivity to habitat related stressors (e.g. discomfort and irritability due to noise, lack in food variation)	15. Habitat architecture issues; ergonomics
Organisa-tional			16. Management related issues (e.g. task distribution, workload, work-rest schedule)	17. Conflicting situation between mission-control and crew; leadership and decision-making related issues	18. Disagreements related to work programme; conflicts between mission control & crew	19. Conflict between personal & organisational priorities/values (e.g., poor motivation to perform work)	20. High/low workload problems; attention and concentration issues	21. Health & safety issues; work-rest schedule issues
Social				22. Problems of crew separating into groups & conflict between them	23. Interpersonal tension; behavioural norms; slip in morale (e.g. conflicts between personal activities schedule); dress code issues; scapegoat issues	24. Social conflicts based on belief and value systems; cultural misunderstandings; need for personal space (e.g. on some occasions be able to withdraw into own mental space)	25. Social issues related to hygiene & clothing (e.g. some crewmembers may have a strong body odour that can affect how some crew interact with that member); general issues related to any of human sensory receptors and misunderstanding based on misinterpretation (e.g. reduced or enhanced hearing ability)	26. Gender & age related social conflicts (e.g. gender related social responsibilities stereotype; a Russian Crew once made a female cosmonaut perform cooking and cleaning tasks); dress code preferences
Individual					27. Interpersonal conflicts (e.g. leadership, gender, issues)	28. Interpersonal conflict issues (e.g. differences in values or individual experience)	29. Self-image issues; issues related to changes in perception of the surroundings (e.g. altered perception due change in gravity, lighting conditions and noise levels or the need for extra rest due to over stimulation)	30. Individual hygiene and clothing issues; body image issues; individual performance issues
Virtual						31. Close friendship related issues (e.g. the need for someone to understand and appreciate crewmembers' personal values and view on life); individual motivational issues; age related crisis (e.g. 'mid-life crisis')	32. Potential changes in values, belief system due to impaired/altered perception (e.g. long exposure to alien environment)	33. Health problems and aging issues can influence changes in attitudes & values
Percept-ual							34. Conflicting inputs of information through different senses (e.g. visual vs. vestibular)	35. Sensory deprivation issues; physical coordination issues; food variety issues (e.g. lack of variety in type/texture of food)
Bo-dy								36. Health problems; physical comfort or discomfort

Table 1: Psy-Matrix – Categories of Issues during exploration missions to the Moon and Mars.

No.	Interfering factor	Group
1	Physical/chemical property (min density -max density)	Environmental
2	Landscape diversity (low---high)	Environmental
3	Resource distribution (rare-dense)	Environmental
4	Weather cycles (Mars/Moon/Transfer) (short ---long)	Environmental
5	Light cycles (Mars/Moon/Transfer) (short ---long)	Environmental
6	Gravitation level (micro ---- hypo)	Environmental
7	Light; spectrum, luminosity level (low --- high)	Environmental
8	Radiation level (low ---high)	Environmental
9	Information load level (low ---high)	Environmental
10	Humidity level (low ---high)	Habitat
11	Air composition (clear -- saturated)	Habitat
12	Nutrition/food (less ---more)	Habitat
13	Tidiness (min ---max)	Habitat
14	Equipment layout (convenient - inconvenient)	Habitat
15	Personal space arrangement (rigid - adjustable)	Habitat
16	Habitat size (restricted --- abandon)	Habitat
17	Tire and ware of the habitat (new---- old)	Habitat
18	Light; spectrum, luminosity level (low --- high)	Habitat
19	Pressure level (low --- high)	Habitat
20	Temperature level (low --- high)	Habitat
21	Artificial gravity level (low --- high)	Habitat
22	Noise/Vibration level (low --- high)	Habitat
23	Décor (permanent --- adjustable)	Habitat
24	Workload level (low --- high)	Organisational
25	Task distribution/organisation/order (free --- strict)	Organisational
26	Functional zones layout (free---fixed)	Organisational
27	Work-rest schedule (free --- strict)	Organisational
28	Resource/award distribution (available --- unavailable)	Organisational
29	Control of information (low --- high)	Organisational
30	Crew/person awareness(local --- global)	Organisational
31	Crew staff gender issue (diverse --- uniform)	Social
32	Professional skills (nonexpert --- expert)	Social
33	Hierarchy (rigid ---- flexible)	Social
34	Social inclusiveness (low --- high)	Social
35	Social exposure tolerance (low --- high)	Social
36	Social activity level (low --- high)	Social
37	Comminication level (low --- high)	Social
38	Body Image/Hygiene (unclear --- distinct)	Individual
39	Type of personality	Individual
40	Personal space/distance (small --- large)	Individual
41	Rhythms of activity (rigid --- free)	Individual
42	Energy level (low --- high)	Individual
43	Information load level (boredom --- saturation)	Individual
44	Values and attitudes (negative -----positive)	Virtual
45	Thought pattern/structure (structured --- unstructured)	Virtual
46	Inner space/mental (occupied --- unoccupied)	Virtual
47	Focus on past, present or future (past --- future)	Virtual
48	Level of motivation (low --- high)	Virtual
49	Inner 'entertainment' (low --- high)	Virtual
50	Taste (weak --- strong)	Perceptual
51	Propreoreceptors (weak --- strong)	Perceptual
52	Vestibular (balanced --- unbalanced)	Perceptual
53	Circadian rhythm (normal --- disturbed)	Perceptual
54	Touch (weak --- strong)	Perceptual
55	Hearing (weak --- strong)	Perceptual
56	Vision (weak --- strong)	Perceptual
57	Information understanding (clear --- unclear)	Perceptual
58	Skin	Body
59	System of bones and muscles	Body
60	Cardiovascular	Body
61	Respiratotry system	Body
62	Nervous& hormone system	Body
63	Excrete system	Body
64	Reproductive system	Body
65	Digestive system	Body
66	Nervous & hormone system	Body
67	Immune system	Body

PROTECTIVE SHELLS	PARAMETERS OF EACH SHELL	EXISTING FACTORS	No.	Environmental (1–9)	Habitat (10–23)	Organisational (24–30)	Social (31–37)	Individual (38–43)	Virtual (44–49)	Perceptual (50–57)	Body (58–67)
Environmental	Substance	Physical/chemical property (min density -max densit	1								
	Structure	Landscape diversity (low---high)	2								
	Space	Resource distribution (rare-dense)	3								
	Time	Weather cycles (Mars/Moon/Transfer) (short ---long)	4	1	2	3	4	5	6	7	8
		Light cycles (Mars/Moon/Transfer) (short ---long)	5								
	Energy	Gravitation level (micro ---- hypo)	6								
		Light; spectrum, luminosity level (low --- high)	7								
		Radiation level (low ---high)	8								
	Information	Information load level (low ---high)	9								
Habitat	Substance	Humidity level (low ---high)	10								
		Air composition (clear -- saturated)	11								
		Nutrition/food (less ---more)	12								
	Structure	Tidiness (min ---max)	13								
		Equipment layout (convenient - inconvenient)	14								
	Space	Personal space arrangement (rigid - adjustable)	15	2	9	10	11	12	13	14	15
		Habitat size (restricted --- abandon)	16								
	Time	Tire and ware of the habitat (new--- old)	17								
	Energy	Light; spectrum, luminosity level (low --- high)	18								
		Pressure level (low --- high)	19								
		Temperature level (low --- high)	20								
		Artificial gravity level (low --- high)	21								
	Information	Noise/Vibration level (low --- high)	22								
		Décor (permanent --- adjustable)	23								
Organisational	Substance	Workload level (low --- high)	24								
	Structure	Task distribution/organisation/order (free --- strict)	25								
	Space	Functional zones layout (free---fixed)	26								
	Time	Work-rest schedule (free --- strict)	27	3	10	16	17	18	19	20	21
	Energy	Resource/award distribution (available --- unavailable)	28								
	Information	Control of information (low --- high)	29								
		Crew/person awareness(local --- global)	30								

Table 2 (Part 1): Psy-Matrix – Interacting Factors in Protective Shells and Environment.

PROTECTIVE SHELLS	PARAMETERS OF EACH SHELL	EXISTING FACTORS	
Social	Substance	Crew gender (diverse --- uniform)	31
		Professional skills (nonexpert --- expert)	32
	Structure	Hierarchy (rigid --- flexible)	33
	Space	Social inclusiveness (low --- high)	34
	Time	Social exposure tolerance (low --- high)	35
	Energy	Social activity level (low --- high)	36
	Information	Comminication level (low --- high)	37
Individual	Substance	Body Image/Hygiene (unclear --- distinct)	38
	Structure	Type of personality	39
	Space	Personal space/distance (small --- large)	40
	Time	Rhythms of activity (rigid --- free)	41
	Energy	Energy level (low --- high)	42
	Information	Information load level (boredom --- saturation)	43
Virtual	Substance	Values and attitudes (negative --- positive)	44
	Structure	Thought pattern/structure (structured --- unstructured)	45
	Space	Inner space/mental (occupied --- unoccupied)	46
	Time	Focus on past, present or future (past --- future)	47
	Energy	Level of motivation (low --- high)	48
	Information	Inner 'entertainment' (low --- high)	49
Perceptual	Substance	Taste (weak --- strong)	50
	Structure	Propreoreceptors (weak --- strong)	51
	Space	Vestibular (balanced --- unbalanced)	52
	Time	Circadian rhythm (normal --- disturbed)	53
	Energy	Touch (weak --- strong)	54
		Hearing (weak --- strong)	55
		Vision (weak --- strong)	56
	Information	Information understanding (clear --- unclear)	57
Body - Skin	Substance	TBD	58
	Structure	TBD	
	Space	TBD	
	Time	TBD	
	Energy	TBD	
	Information	TBD	
Body - System of bones and mus[cles]		TBD	59
Body - Cardiovascular		TBD	60
Body - Respiratotry system		TBD	61
Body - Nervous & hormone systen		TBD	62
Body - Excrete system		TBD	63
Body - Reproductive system		TBD	64
Body - Digestive system		TBD	65
Body - Sensorimotor		TBD	66
Body - Immune system		TBD	67

INTERFERING FACTORS

Environmental	Physical/chemical property (min density -max density); Landscape diversity (low---high); Resource distribution (rare-dense); Weather cycles (Mars/Moon/Transfer) (short ---long); Light cycles (Mars/Moon/Transfer) (short ---long); Gravitation level (micro --- hypo); Light; spectrum, luminosity level (low --- high); Radiation level (low ---high); Information load level (low ---high)
Habitat	Humidity level (low ---high); Air composition (clear -- saturated); Nutrition/food (less ---more); Tidiness (min ---max); Equipment layout (convenient - inconvenient); Personal space arrangement (rigid - adjustable); Habitat size (restricted --- abandon); Tire and ware of the habitat (new--- old); Light; spectrum, luminosity level (low --- high); Pressure level (low --- high); Temperature level (low --- high); Artificial gravity level (low --- high); Noise/Vibration level (low --- high); Décor (permanent --- adjustable)
Organisational	Workload level (low --- high); Task distribution/organisation/order (free --- strict); Functional zones layout (free---fixed); Work-rest schedule (free --- strict); Resource/award distribution (available --- unavailable); Control of information (low --- high); Crew/person awareness(local --- global)
Social	Crew staff gender issue (diverse --- uniform); Professional skills (nonexpert --- expert); Hierarchy (rigid --- flexible); Social inclusiveness (low --- high); Social exposure tolerance (low --- high); Social activity level (low --- high); Comminication level (low --- high)
Individual	Body Image/Hygiene (unclear --- distinct); Type of personality; Personal space/distance (small --- large); Rhythms of activity (rigid --- free); Energy level (low --- high); Information load level (boredom --- saturation)
Virtual	Values and attitudes (negative ----positive); Thought pattern/structure (structured --- unstructured); Inner space/mental (occupied --- unoccupied); Focus on past, present or future (past --- future); Level of motivation (low --- high); Inner 'entertainment' (low --- high)
Perceptual	Taste (weak --- strong); Propreoreceptors (weak --- strong); Vestibular (balanced --- unbalanced); Circadian rhythm (normal --- disturbed); Touch (weak --- strong); Hearing (weak --- strong); Vision (weak --- strong); Information understanding (clear --- unclear)
Body	Skin; System of bones and muscles; Cardiovascular; Respiratotry system; Nervous & hormone system; Excrete system; Reproductive system; Digestive system; Nervous & hormone system; Immune system

	Environmental	Habitat	Organisational	Social	Individual	Virtual	Perceptual	Body
Social (31–37)	4	11	17	22	23	24	25	26
Individual (38–43)	5	12	18	23	27	28	29	30
Virtual (44–49)	6	13	19	24	28	31	32	33
Perceptual (50–57)	7	14	20	25	29	32	34	35
Body (59–67)	8	15	21	26	30	33	35	36

Table 2 (Part 2): Psy-Matrix – Interacting Factors in Protective Shells and Environment.

Workshop Participants

The workshop brought together 65 participants from around the world, out of which there were 19 presenters and 19 Workshop Committee Members. Their participation was agreed with ESA based on the required expertise, ranging from design, to training, to in-flight support. These top scientists and practitioners participated in the workshop. Some Committee Members had experience gained from working in the most extreme environments on Earth, such as a submariner, a fireman, and an Antarctic Station Commander, whilst other Committee Member's experience was gained from supporting those people living and working far away from family for extended periods of time and those that operate in extreme environments on a daily basis, such as space psychologists, a military psychiatrist, a safety expert and accident investigator, and a clinical psychologist specialising in conflict resolution and in supporting multicultural organisations. Additionally, one of the participants specialises in the fast growing research area of Positive Psychology, a domain that focuses on the development of personal strength and positive thinking qualities. It focuses on enhancing quality of life and prevention of psychological issues, rather than only addressing the aftermath. It was considered appropriate to include such expertise since prevention of conflict or event is more desirable in all safety critical domains.

Workshop Organisation

The workshop consisted of two days. On the first day, invited participants, whose papers had been reviewed by the Workshop Committee Members, presented their ideas on potentially appropriate tools for psychological support in space. The Workshop Committee Members were tasked to critically review the presented techniques and technologies against the specified criteria. The criteria are aimed to help determine whether the tool is suitable for use during an extended space mission. It identifies its strengths and weaknesses, highlighting the areas that need to be developed further. During the workshop, the Committee Members had an opportunity to ask questions directly to the designers of the tools, in order for them to determine for themselves what they considered was the level of readiness of the tool presented. The discussion and comments were documented and incorporated into the description of the psychological support toolset.

The first day of the programme was broken down into five sessions. First, the existing measures for psychological support were presented. Secondly, the lessons learned from other domains that could be compared to the extreme living and working conditions on a long duration space mission were presented. This was followed by two sessions that presented the latest concepts for psychological support that can be applicable to space exploration. The last session focused on the design of the habitat, where possibly the crew will spend the majority of their time throughout the duration of the mission. Each session was led by a group of Workshop Committee Members who facilitated the discussion after each presented concept. The expertise of the Workshop Members was complementary to the concepts presented in their respective session. As a result, each concept presented on the day had comments and criticisms from the Committee Members.

On the second day, the workshop was open only to the Workshop Committee Members. The day consisted of four parts:

1. During a brainstorming session for preventive measures for each of the 36 categories of issues related to the psychological well-being of the crew, valuable data was collected in the form of psychological interventions, categorised and criticised, outlining further concepts that need to be developed. The Workshop Committee Members' recommendations were aiming for practical measures that often do not require large technological implementation. The recommendations ranged from suggestions of design for the habitat and design of the spacecraft, and training recommendations, prior and during the mission, recommendations for both ground crew and spacecraft crew and activities for the crew during the mission.
2. A group forum discussing the papers presented on the previous day took place. This permitted open exchange of opinions. The Workshop Committee Members compared and contrasted the tool and provided recommendations on further improvement of the tools.
3. The second part of the day was facilitated by a specialist in a Theory of Inventive Problem Solving (TRIZ). The use of this method promotes innovative thinking when discussing the potential solutions to the problems astronauts will require support or resolution for. Interventions ranging from habitat design to conflict resolution were developed based on 40 TRIZ inventive principles (Altshuller, 1999) that later were described as a part of a future concept for a psychological support toolset.
4. The last hour was spent as an open discussion identifying areas that were not yet captured on day one and those that had arisen throughout the workshop. Further suggestions were made for design requirements and development approaches that can be used for future TPS.

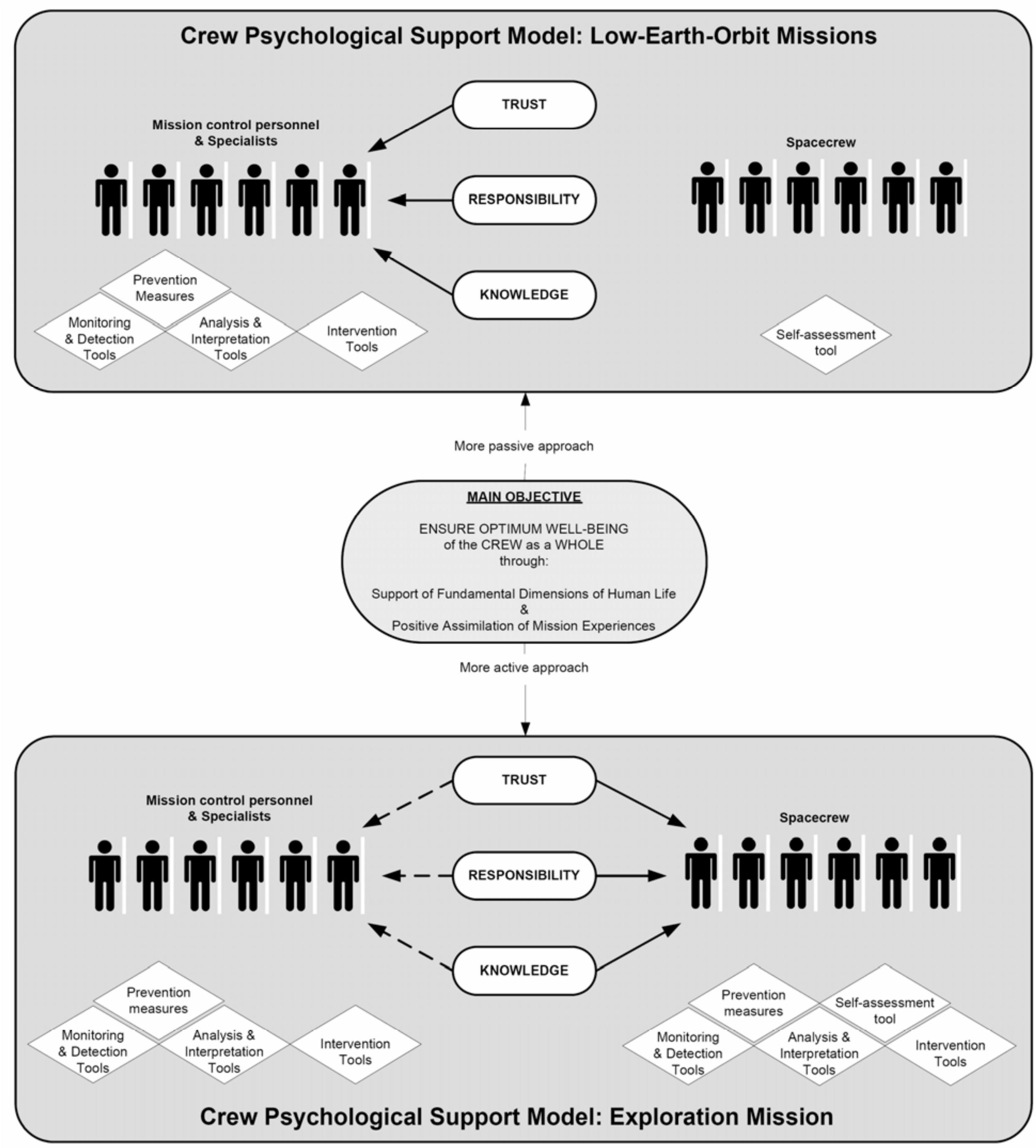

Figure 3: Psychological Support Model.

PSYCHOLOGICAL SUPPORT MODEL – EPSILON

The baseline concept for future psychological support takes into account exploration mission constraints. The future global (i.e. comprehensive) baseline concept, the Embedded Psychological Support Integrated for LONg-duration missions (EPSILON), is envisaged to be a collection of different measures, ranging from prevention, via monitoring, to resolution measures (Solodilova-Whiteley, 2007c). The EPSILON method is intended for use by the space and ground crew to identify the factors that are causing issues to arise, to consider potential avenues toward resolution of issues, and to appropriately identify the means to resolve them. The formulation of the EPSILON global baseline concept takes into account:

a) Currently used psychological measures that still might be applicable in an exploration mission, adjusted to future mission constraints; a review of applicable technology review.
b) New promising solutions and concepts gathered and evaluated during the workshop, in addition to further brainstorming with expert on identifying solutions for 36 Psy-Matrix categories of issues.
c) The use of the Psy-Matrix (Table 1 and Table 2) to situate currently used psychological measures and identify where new solutions with respect to their interacting factors need to be developed.

Formulation of Psychological Support Concept

Travelling and staying on other planets and moons will be extremely challenging for humans, to the extent that there is a need to revise attitudes toward the crew in these missions, and the nature of the psychological support that can be provided for them. No one wants the mission to be compromised, but it is a fact that the crew will become more autonomous and disconnected from Earth and may not want to be monitored, criticised or told what to do and how to make themselves feel 'better'. This can jeopardise everything everyone worked towards. The proposal is to transfer the responsibility for psychological well-being of the crew to the crew themselves, thus making the study of the effects of exploration mission on the crew's psychological well-being one of the mission objectives. The crew can be equipped with the knowledge, skills and responsibility to monitor their own psychological well-being. The crew can be trained to identify their trigger points and indeed, what they can do in response. The findings on this study may seem to fly in the face of conventional psychological support model, but through the course of the study it has became clear this is a way forward.

The nature of current psychological support relies on a live communication link with Earth where the majority of the responsibility remains with specialists on the ground (Figure 3). The nature of the psychological support during long-duration missions, extending beyond Earth's orbit, will primarily rely on the available resources on board the spacecraft due to delayed or potential loss of communication with Earth and the independent tendencies that have already been shown to arise in long duration space missions and Antarctic expeditions. Consequently, at these times, the responsibility for the optimal functioning of the crew all the way through the mission will need to reside with the crew on the spacecraft and the ground will need to trust this crew to be able to detect their own psychological symptoms early through monitoring each other and through the promotion of positive group interaction and continuous self-development.

The crew will need to posses the knowledge (i.e. what to look for; how to detect it; how to prevent it from escalating; how to mitigate it), have the responsibility (i.e. to recognise the need to monitor psychological states, to carry out required steps for the psychological support) and the trust (i.e. the ground personnel needs to trust the crew to carry out the steps, trust that they can do it effectively and ask for help when required) to address the issue concerned with their well-being in a more independent manner. Previously, these three aspects rested mainly with the ground personnel, the new model of psychological support for exploration missions proposes to empower the spacecraft crew to carry out the psychological support programme with the help of available techniques, technology and the ground crew. For example, the introduction of a reliable monitoring and detection system can assist the crew and a mission control to detect and trace developing issues early.

The most comprehensive and active approach to the implementation of preventive measures for a space mission may be to have this implemented by the crew themselves. Based on research in this study on the experiences of astronauts and reviews of currently available preventive measures, it is proposed to have the spacecraft crew themselves monitoring the changes in their psychological state, their psychological responses, and other unforeseen adaptations that may happen on a long-duration mission. Implementing this approach can be done in a form of an ongoing experiment or an exploration study conducted by the crew as part of their mission objectives. It may also fill some of the flaws of most existing psychological interventions. The flaws in existing preventive measures include:

- Reluctance of the crew to be monitored and continuing providing data for monitoring; psychological closing.
- Not being able to conduct direct and continuous observations by a specialist.
- Not being able to intervene 'live' if it becomes necessary, as it will not be possible to engage in a 'live' dialogue due to delayed communication.
- Subjective interpretation of the psychological state of the crew by the ground personnel without the ground personnel being able to fully comprehend the environment, living and working conditions, and the experiences and current situation of the crew on board the spacecraft.

For the proposed exploration study to be conducted the crew needs to be trained in the types of positive and negative psychological experiences they may face and the symptoms they may display and how to detect them. Whereas above are listed negative aspects of current preventive measures, below are given the positive aspects of the proposed approach:

- The reluctance of the crew to be monitored can be mitigated because it will be part of the core mission objectives, where the astronauts themselves will be in control of monitoring and data collection, and will have the responsibility to conduct the study.
- The understanding and self knowledge of the psychological states that will come from training for this study may help the astronauts on the mission to better articulate their sensations and psychological state and in turn this may assist the ground support team in their interpretation of each crewmembers psychological state and consequent advice.
- The psychological training of the crew may make the crew vigilant to early signs of changes to the psychological states of other members of the crew that then can be addressed early.
- Bringing vigilance of the psychological issues experienced by the crew, into the common language of the crewmembers, may enable the open discussion of these changes among the crew themselves and ground crew.
- Introducing the discussion of psychological issues among the crew may remove a common bias towards any debate surrounding personal psychological issues. Additionally, placing the astronaut's psychological issues as part of a study may remove associations with them talking about their 'strange psychological experiences' with being mentally unfit. In placing the crew's psychological state as part of a study, value judgments are not placed on what will be considered 'normal' vs. 'abnormal' during a long journey from Earth. The study conducted by the crew, on their experiences of their psychological states, will then be able to inform the body of knowledge available on the changes in human psychological well-being while voyaging into open Space.
- Psychological training will provide the crew with a scientific language that may help them to describe any unexplained psychological phenomenon they may experience.
- Through the crew conducting this ongoing study they may find the ability to systematically trace their psychological changes and associate these with perhaps environmental changes, or other protective shells factors, potentially identifying other factors that were unknown prior the mission.

Another positive effect the proposed psychological support model can have is to become a strong motivator for the crew on several levels. As shown through numerous accounts of extreme situations during a war or a crisis, or in the hostile environment of an expedition to Everest, Antarctica and during military operations, the crew's survivability greatly depends on having the responsibility for someone's life, on assisting and supporting a friend, a colleague, or even a total stranger. It acted as a strong motivator, negated minute annoyances and put problems and issues into perspective. Both, mutual trust and responsibility for the well-being of each other are essential motivators in our daily lives and can be emphasised and reinforced through training and throughout the mission among and between the ground and space crew.

Positive Assimilation of Mission Experiences

The challenge for the astronauts, the ground crew, the psychologists and the designers of the psychological support toolset is the appreciation of the depth of emotions and range of personal and interpersonal experience the crew may live through in preparation for and during the mission. How can astronauts be supported? How can personal and team challenges be turned into positive mission experiences that will help each individual grow throughout the journey. The crew may have a desperate need to express personal experience, to be understood, to feel connected to their children who are growing up and a partner who is living a separate life on Earth. Meanwhile, living and working in a small compartment with several crewmembers, depended on a life support system, anticipating, but not knowing the challenges lying ahead.

It is important to recognize that the toolset needs to focus predominantly on preventive measures and improvement of crew personal development, social interaction and mission experiences, in order to avoid mission critical psychological and interpersonal issues to occur. A crew in a degraded mental health can be impossible to deal with or provided with effective treatment from Earth, given the communication and intervention constraints. Removing the crew from a duty can have adverse effects, to the extent of a persistent feeling of failure, loss of motivation and a wish to terminate one's own life. In extreme cases, restraining the crew may become necessary, where, apart from the distress to the rest of the crew, it can severely impact crew cohesion and cause loss of motivation to carry out the mission. It will increase workload of other crewmembers, and lead to loss of essential expertise.

EPSILON Overall Description

Based on the work described above, the Psychological Support Toolset was developed that consists of three main parts, Preventive Measures, Monitoring/Detecting and Resolution tools. It needs to be embedded throughout the spaceship and integrated with the equipment and the tools the crew will use in order to provide a comprehensive psychological support. Consequently, this was captured in the name of the toolset, Embedded Psychological Support Integrated for LONg-duration missions.

To provide the traceability of the EPSILON components to the type of issues the crew can experience during the missions, the description of components was arranged according to Psy-Matrix categories (Table 1 and Table 2) and grouped into related topics that can be addressed by a similar technique or a technology. Each category of issues and a list of interacting factors within the category were associated with by one or two example solutions, which were later described in terms of proposed techniques or through the use of technology. To illustrate the EPSILON concept, a short summary of each of three main parts is provided below.

Prevention

The preventive measures will focus on providing the means to fulfil some of the Fundamental Dimensions of Life, and support the digestion and sharing of the crew's mission experiences with ground crew, family and friends. The majority of this support will be provided through electronic delayed communication and immersive technology. It can range from simple emails to sharing of video and audio recordings, and being extended through the use of haptic technology and potentially to provide sensory immersion simulations of weather effects related to recorded imagery. It is foreseen that this technology will enable a two-way communication link between the crewmembers and their family and friends on the ground, where recordings made by either the crew or persons on the ground might be exchanged. These recordings might be personal to a single crewmember, or recordings that are shared between the crew. By extending this through haptic technology, the crew might be able to experience, through immersion, the places that their family have recently visited, e.g. share in a bumpy rapids ride, or a mountain bike ride imitated while exercising on the rowing or cycle machine. This can also allow the crew to ask their family to travel to a particular location, for example a favourite location. At a later date the recording and haptic data might be experienced by the crewmember or crew in general.

Preventive measures will also include personal growth and development exercises for the crew, practiced on a daily/weekly basis. The exercises will also be aimed at improving crew cohesion. These exercises might include group exercises, such as microgravity games already developed by astronauts, cycling competitions (simulations) or even mystery games.

In addition, it is suggested the crew might be included as part of an on-line community and be able to send uploads to the Earth-based internet and be updated daily (or as technology allows). With this facility, the crew's selection of movies, e-books, audio books, music and games initially taken onboard might be supplemented by downloaded material on demand. This could provide support for hobbies or training and educational programmes. Learning could also take place in a similar way through uploaded tutorials, or through crew interaction, whereby one crewmember might obtain new skills during the mission. The skills the crew can learn can range from a new language to a professional skill learned from another crewmember by the end of the mission.

Monitoring

Monitoring and detection measures can be based on pattern recognition techniques that will record the facial expressions of individual crewmembers and analyse these in relation to surrounding conditions and actions of other crewmembers (e.g. proceeding and subsequent).

The technology will also be able to interpret the body language of individual crew. For example, if a crewmember is performing a mission task alone, this technology might be used to ascertain if the crewmember is becoming unduly, or dangerously, fatigued. The technology might determine this through interpreting the crewmember's posture, type of crew interaction and their facial expressions. Through collation and analysis of facial and body language data, it may be able to detect positive and negative interaction patterns between crewmembers.

This technology will also be able to identify the location of each crewmember, their proximity to other crew, their frequency of interaction with other crewmembers, and possibly, through analysis recognise the nature of the interaction and patterns of interaction amongst the crew. Should this technology be realised and it would be able detect all types of data described above, it would be able to extract emerging patterns of interaction within the crew, and perhaps warn the crew of developing unhealthy or hazardous situations.

Resolution

Resolution technology will focus on providing the crew with assistance, when preventive measures, training and warning measures, have not overcome the development of a situation or an issue. The technology will have a database of all the information collected during prevention and monitoring phase (i.e. data provided and usage of data during preventive measures). For example, it may contain information on whether the frequency of exercise has decreased, and whether this is due to less data arriving from family doing sport activities on Earth. Perhaps, this can also be due to fewer feelings and emotions are being shared by this crewmember with their family and friends, or the crewmember is watching more sad or depressing movies. Information in this database will also come from phase two of EPSILON (i.e. from monitoring and detection technology). For example, this data will inform on whether the crewmember is avoiding contact with perhaps another specific crewmember; or whether the crew as a whole is alienating this crewmember; or whether, from body language and facial expression cues, there is a slight hostility toward this crewmember from other crewmembers. Together this data will provide a start for this crewmember in identifying why he or she feels uncomfortable around another crewmember. Ideally, this would encourage them to talk to the person they are uncomfortable with. A great challenge for this technology will be its presentation. For example, how constructively information can be communicated back to each crewmember (note: it is anticipated that it will be tailored to each crewmember), in a manner whereby this information will regulate the situation rather than inflame it. Thus, it needs to be carefully considered how the information collected by the Psychological Support Toolset is presented to the crew.

Additionally, a software tool is proposed that will act as a database to allow the crew to systematically search and identify applicable resolution tool/s. This software tool can also be used by the crew to help brainstorm as to the causal nature of the issue at hand. In those cases where there is no tool available to address the issue, or the crew cannot identify a suitable the tool, this software tool may help the crew in articulating their problems as accurately as possible, for example in an email format, to the specialists on the ground. Then the specialist can propose a solution, or engage in a constructive discussion with the crew on how to resolve the problem.

THE WAY AHEAD: DEVELOPMENT PLAN

The strategy and priority for development of EPSILON components was developed (Solodilova-Whiteley, 2007d). In total twenty-four high-priority EPSILON components were identified that require the development programme to begin within the next year to achieve a Human Mission to the Moon by 2020 and the First Human Mars Mission by 2033 (ESA Aurora Mission Roadmap, 2007):

Preventive Tools

- Means of exchanging information with children.
- Means of providing emotional support via digital technology.
- Means of mood regulation.
- Means of encouraging a humorous dynamic among the crew & experience sharing.
- Means of encouraging & maintaining social interaction, open discussion & experience sharing on specialised topics.
- Positive Psychology Intervention.
- Means of adjusting habitat space by the crew.
- Email Personal Consultancy.
- Means of simulating sensory environment.
- Means of providing a skills development programme to be conducted throughout the mission for redundancy and motivation of the crew.

Monitoring Tools

- Self-training, cognitive and perceptual-motor assessment tools.
- Emotion Recognition Technology.
- Means of Affective Support.
- Individual & crew behavioural pattern recognition technology:
  - Pattern recognition Technology;
  - Means of picking-up, distinguishing and tracking minor changes in individual human behaviour;
  - Means of tracking crew interaction;
  - Means of detecting and registering prior and post events.
- Means of non-intrusive stress & workload detection technology.
- Means of merging, synthesising & analysing data.
- Means of extracting & presenting analysed data in a meaningful way to individuals & to groups.

Resolution tools

- Issue Clarification Tool.
- Means of helping the crew to express themselves.
- Virtual Reality Therapy.
- Email Personal Consultancy

SUMMARY OF OVERALL RECOMMENDATION FOR EPSILON

The development and invention of new techniques and technology will progress significantly prior to the return Moon missions and progress even further before the first manned missions to Mars. The techniques and technology watch studies have to be conducted prior to the commencement of the development programmes of EPSILON components. This can help identify potential collaboration partners in the development of components and provide possibilities of exchange of experience and lessons learned across related domains. It can also lead to cost saving and application of tools developed for space to be used on Earth and vice versa.

The tools described above are shown as components, however in the approach to design and develop them needs to follow a comprehensive approach where all elements of EPSILON are integrated and are interwoven to provide the following:

- *EPSILON for the crew with no background or minimal training in psychology*. Preventive, monitoring and resolutions measures and associate techniques and technology should be designed for use by the crew with no background in psychology and minimal training. Proposed TPS will be aimed at helping the crew to effectively and efficiently reach mission objectives. They are aimed at specifically studying psychological responses to long-duration exploration missions.
- *Integrated data analysis from various data collection sources*. For example, this may include data from sensors and cameras on location of the crew, interaction frequency, proximity, time spent in specific location, time spent on work and leisure, correlated with performance and emotional state of individual crew and crew cohesion. Furthermore, together with data collected from facial and voice recognition, cognitive performance and biosensors, can provide an insight on patterns of interaction over time, individual preferences, and factors that affect the crew in a positive and in a negative way. It can also provide an insight on the crews' coping and resolving strategies as individuals and as a whole crew.
- *Integrated data presentation*. Data collected and analysed from various sources is required to be presented in a meaningful way and in a form requested by the crew. For example, the crew may need to understand how the EPSILON monitoring and detection system arrived to a particular conclusion. The crew may request to see the source of data and the analysis performed. This can allow the crew to understand the system, assess if the results are meaningful, and grow to trust the system's output. They can learn how their actions affect other and themselves. Collected and analysed data will also act as a resource for the crew to achieve one of the mission objectives, specifically understanding how long duration exploration missions affect the wellbeing of individual crew and crew interaction.
- *Common interface across all tools used by the crew and ground personnel*. Data presented across all parts of the EPSILON require common interaction components and means of information presentation for efficient and effective use, especially if it consists of several separate components. It is recommended to have a single point of access EPSILON (e.g. software that can be accessed from various locations), for ease of search and analysis of data.
- *Commonality of hardware used for EPSILON and other activities on the mission*. It is recommended to implement EPSILON with a minimum hardware or hardware that can be used for other tasks on the mission to accommodate mission constraints, such as weight and space constraints.

To efficiently integrate EPSILON components, it is recommended to establish an EPSILON working group prior to commencement of the development programme. The group will focus on establishing consistent overall design requirements, implementing the design philosophy throughout the components, testing, tracing and monitoring design changes. The group will consist of potential users, designers, psychologist and Human Computer Interaction experts to insure effectiveness and efficiency of the final designed and implemented product. The setup and running of the group has been known to help avoid late changes in design and development process. It provides better acceptance by the users and potentially results in shorter training times due to improved usability of the tools.

The development of both the components and the overall EPSILON tool set requirements should follow best practices in the iterative design process, in accord with traditional and current Human Computer Interaction design approaches. One of the distinctions of iterative design approach is that each step in design and development can be reviewed by an independent human factors and human computer interaction expert together with potential users of the tool. The recommendations provided during each review are considered and implemented to improve the usability of the tool.

In addition, the psychological support tools, and their development, are necessary for the use by both the space and ground crews. It is offered that the shared experience of concurrent training and use of tools by both crews may be beneficial, and can lead to each crew having insights into experiences of the other crew.

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