FACULTY OF PSYCHOLOGY
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BATTLING HOMESICKNESS ON MARS

THE RELATIONSHIP BETWEEN RELATEDNESS, WELL-BEING, PERFORMANCE, AND DISPLACEMENT IN A MARS SIMULATION STUDY

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Abstract

During a Mars mission, crew will simultaneously be confined to small shared living quarters, and will experience extreme geographical and temporal isolation from all other people. Under these circumstances, group tensions have been known to cause communication issues with mission support; a phenomenon called displacement. To gain further insight in these challenges, this study investigated the effects of the psychological need for relatedness as described by the Self-Determination theory, a macro theory on human motivation. During a yearlong Mars simulation, HI-SEAS IV, six crewmembers filled out weekly self-report questionnaires measuring their level of relatedness with friends and family at home as well as fellow crewmembers living inside the Mars simulation. Crew further filled out questionnaires measuring their well-being, performance, and displacement with mission support staff outside the station. Using hierarchical modelling, the results indicated that relatedness was a predictor of crewmembers' well-being, performance and displacement. Relatedness with fellow crewmembers was a positive predictor of crewmembers' well-being and performance, and was a negative predictor of displacement. Relatedness with friends and family at home was a positive predictor of well-being and a negative predictor of displacement. Overall, the results provide evidence for the presence of the psychological need for relatedness as affecting crewmembers' well-being, work performance, and displacement toward mission support, successfully applying the Self-Determination theory to a spaceflight setting.

Key words: Space Psychology, Self-Determination Theory, Mars Simulation, Relatedness, Displacement.

Foreword

Two years ago, I spent a six month winter season working on a husky farm in the High North of Sweden. Officially, we were a village. Särkimukka, population: 4. There, beyond the Arctic Circle, I met a Dutch firefighter. Yes, it does seem that isolation in the true sense of the word doesn't exist anymore. Not on our globalized world at least. Even as we were gliding through the plains and swamps covered in ice and snow, life was all around us. But that's not the point here, the point is the story of this firefighter.

You see, he was one of those rare people who are born knowing exactly what they want from life. When he was five, he participated in a drawing contest, which, of course, he won. His grand prize was a visit to the fire department and right there and then, he decided to become a firefighter. He joined the youth corps as soon as he was eligible, started volunteering before his graduation, took the necessary tests, and soon became a full-fledged firefighter. Captain, even. "Perfect holiday destination," he says from the passenger seat in my sled, "there's nothing here to burn. It's as if we're on a different planet!"

I nod my head and yell "Haww!" We make a turn, left. The dogs know the commands. They're smart. Pulling us through the tundra, breathing out the hot air, and covering the trail we made last night with paw prints. I check behind us, groups of tourists are still following. Good, I hope they're enjoying their desolate wilderness. As for me, I wonder, do I envy the firefighter? I still don't know. Maybe I do. And I'm not saying this is the start of my own firefighter story, but who knows, maybe it could be.

Maybe this is my drawing contest.

Acknowledgements

I'd like to thank my supervisors, Professor Beyers and Sophie Goemaere, whose practical applications of SDT on my writing process have definitely hit home. My thanks to the six participants of the HI-SEAS IV experiment. You may not know me, but I certainly feel like I know you. That actually sounds a bit creepy, doesn't it? Additionally, I'd like to point out that the ideas in this study are influenced by the many researchers who came before me, and on whose shoulders I now stand. It seems appropriate to acknowledge their contribution, which has been much larger than the occasional quote or reference in the text. I also want to thank my friends who have cheerfully encouraged me, and even more those who did not. Your silent trust means a lot to me. Lastly, special thanks to my friend Erin for proofreading the final version of this document.

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ESA	European Space Agency
EVA	Extra Vehicular Activity
FSO	Family Support Office
FTS	First Tier Support
Hab	Habitat module
HI-SEAS	Hawaii Space Exploration Analog and Simulation
HLM	Hierarchical Linear Modelling
ICE	Isolated and Confined Environment
IMI	Intrinsic Motivation Inventory
ISS	International Space Station
MS	Mission Support
NASA	National Aeronautics and Space Administration
SDT	Self-Determination Theory
STS	Second Tier Support

Literature review

Future Mars Missions

Introduction: Humans in space. Four months before his scheduled departure to the International Space Station (ISS), Russian cosmonaut Yuri Malenchko proposed to his fiancée Ekaterina Dmitrieva. The wedding was planned to take place in August, after Yuri's return to Earth. However, while on board of the ISS, the crew received a notice from Mission Support (MS) that their space trip was to be extended until late October. The couple decided not to delay the marriage, and on August 10, 2003, some 400 kilometres over New Zealand, Yuri married his fiancée who was in Texas via satellite. Guests on planet Earth were greeted by a cardboard cut-out of the Russian cosmonaut. The bride wore white, while the groom added a bowtie to his spacesuit ensemble. The couple took their vows via video-link and put on their own wedding rings.

This unlikely story and many other infamous anecdotes from space history fall under the responsibility of NASA's Astronaut Family Support Office. The FSO's primary objective is to 'assure no loss of mission goals due to deterioration in family functioning' and runs on funds of the ISS Program Office (Curtis, Beven, Holland, Sipes, & Vander Ark, 2014).

At any given time, six people are orbiting the Earth aboard the ISS. They do so at the dazzling speed of 28,000 km/hour. That is 16 sunrises and 16 sunsets 'per day'. No wonder photography is a popular leisure time activity among astronauts. Crew have often been known to describe the view as breath-taking, and some even say live changing. Many decide to share their experience with others. Canadian astronaut Chris Hadfield for example became a social media celebrity by tweeting from space, and even went as far as to perform David Bowie's Space Oddity, from space.

This comfortable feeling of having a support system on standby, it will eventually be left behind when we leave the safety of Earth's orbit. And we will. Because humankind is going to Mars.

And when that day comes we will have selected the best of the best. We will wish them well and their friends and family will wish them a safe trip. Because their trip will be a long one, leaving a small crew in a very tiny tin can for a very long time. A very human crew that is. Most likely six people, maybe fewer, about to spend almost three years away from home, heading for a destination orbiting at a distance between 55 and 400 million kilometres away from planet Earth. Six humans in space. Alone.

Structure of this chapter. This study will investigate the effects of isolation for a prolonged duration of time in a confined setting, particularly an interplanetary spacecraft.

We will research how the perceived relationship with home and fellow crewmembers influences the well-being as well as performance of astronauts, and how it affects their style of communication with the ground. To fully comprehend the effects that deep space exploration missions pose upon mental health, it may be beneficial for the reader to first attain a better understanding of what Mars missions will theoretically look like. This is something we will address in this section, *Future Mars Missions.* Here, we will also present the different kinds of research methods used to make predictions about Mars missions. The next section, *Psychological Challenges of Long-Term Spaceflight*, will further discuss some of the most pertinent issues in space psychology that are relevant to this study. Section three, *Current Countermeasures,* will explain how some of these psychological challenges are currently dealt with, as well as how many of these countermeasures will be less effective, if at all possible, during a Mars mission. *SDT Underscoring Relatedness as an Effective Countermeasure* will introduce the Self-Determination Theory, a macro theory on motivation, and how it may contribute to the field. Finally, in *Aims of This Study*, we will present our hypotheses on the relationship between relatedness, displacement, well-being and performance in a Mars mission.

Description of a Mars mission. As a species, we have plenty of reasons to go to Mars. Humans have always been pioneers and explorers, keen to discover the unknown. Interplanetary travel is a new challenge, and one that offers high rewards with its completion. Mars is the most scientifically interesting location in our solar system that humans may be able to reach in the foreseeable future. NASA is currently on a quest to find water and life on Mars, but with only satellites orbiting the planet, and rovers exploring the surface, the limited data they are receiving is sometimes paradoxal (Webster, Cantillo, & Tabor, 2017). Many other scientific investigations are also not possible with robots alone; adding humans to the assets would greatly improve our flexibility. Additionally, research conducted on Mars may further benefit the quality of life on Earth, as has been the case many times before with previous research conducted in space. Several scientists have also expressed their hope to eventually install a permanent settlement on the planet, serving not only as a new ISS on the cutting edge of science but also as both a safeguard for humankind and a springboard to further space exploration.

However, it is important to understand the stress that is produced by living and working in space. Astronauts going to Mars will undoubtedly be spending a long time confined in a spacecraft and living in an environment that is filled with potential danger. Deep space exploration amounts to a significant technical challenge (it is rocket science, after all), and is subject to equipment malfunctions. Crew members must adapt to a certain level of danger and stress to survive, and therefore space is understood to be an extreme work environment. Elon Musk, CEO of the private aerospace company SpaceX, has repeatedly compared future Mars crewmembers to America's early colonists. "Basically, are you prepared to die?" he asks. "If that's okay, you know, you're a candidate for going." Once you get over the fear of death, of course, "it'd be, like, really fun to go!" (Dooley, 2016).

But when are we going? American president Obama has set a goal of sending humans to Mars by the 2030's (Obama, 2016), mirroring his predecessor John Kennedy, who once called for the famous moonshot (putting a man on the moon by the end of the decade, which succeeded in 1969). And recently, president Trump has jokingly asked NASA to speed things up a little since he would like to see it happen during his first term, or at worst his second, leaving NASA staff somewhat uncomfortable (Yuhas, 2017). It is hard to predict, however, how achievable these goals are. As it is, different organisations have already put forward multiple deadlines. NASA is planning to send humans to an asteroid by 2025 and to Mars in the 2030's. Note that they are even obligated to do so by American federal law as outlined in the U.S. National Space Policy (Gains, 2015). However, NASA is not alone in this race. Their main competitor, SpaceX, has recently outlined their highly ambitious vision for manned missions to Mars, which could begin as soon as 2022, only five years from now (Woolf, 2016). Meanwhile, India has managed to send the cheapest Mars satellite so far into orbit (Amos, 2014), and China has stated they intend to beat NASA to the Red Planet (Jiang, 2017). Game on.

The planet Mars itself is in many ways similar to our Earth. Its average distance to the sun is 230 million km, only 50% further than we are. One sol (that's Martian for day) is 24 hours, 39 minutes and 35 seconds, almost exactly as long as one day on Earth. There are seasons and there's gravity. Albeit less than ours, the Martian surface has a gravitational force of 1/3 g. What makes the planet inhabitable is that there is almost no atmosphere as we know it. Compared to ours, the Martian atmosphere is about one percent as dense and consists mainly of carbon dioxide (95%). Scientists have already theorized to use this overabundance of CO2 as a valuable source of rocket fuel (Muscatello et al., 2016), however, lack of atmosphere creates very hard environmental conditions on the surface. Temperatures vary from 20 to -150 °C, with -55°C being a common value, turning the whole planet into a gigantic, frozen desert plagued by dust storms.

Choosing the right candidates to undertake such a mission is not an easy task. Earlier this year, NASA handpicked a class of 12 new astronauts from a pool of 18,300 applicants, twice as many candidates as ever before (Northon, 2017). NASA conducts the selection process in two phases. First there's the select-out procedure, a psychiatric screening based on DSM and ICD classification systems which aims to select-out candidates who are, compared to an established psychiatric standard, more prone to psychopathology (Endo, Ohbayashi, Yumikura, & Sekiguchi, 1994; Santy, Endicott et al., 1993). Then there's the select-in process, individuals are chosen for their good teamwork or interpersonal skills. Surprisingly, most of the current interviews are based primarily on expert judgments (Kanas & Manzey, 2008). "Once, I was evaluating astronaut applicants," says Kanas. "I asked them to give me some examples of things that might cause stress. One applicant, a test pilot, recalled the time he was flying an experimental aircraft and it spun out of control. As the plane spiralled down, he took out his manual, calmly thumbed through it, and figured out how to pull the plane to safety. His ability to temporarily control his emotions was very striking" (NASA, 2012).

Good teamwork and interpersonal skills are important as well because most organisations are planning to send a three to six person crew to Mars. NASA's original reference mission recommends a nominal crew size of six people as they believe it to be the most reasonable based on past experiences and several studies (e.g., Hoffman & Kaplan, 1997). They would have one commander in charge of a team of scientists. According to a second study, the crew would consist of a mechanical engineer, an electrical and electronics engineer, a geologist, a life scientist, a physician psychologist and a backup crew (Drake, 1998). Working and living quarters will be severely limited and privacy will not be evident, which may lead to group tensions. With regard to psychological issues, Nicholas (1989) has already proposed training all crewmembers in general social support skills. Furthermore, as modern spaceflight is now a global undertaking, nowadays all manned missions have astronauts from different countries and different cultural backgrounds, which sometimes leads to misunderstandings or a perceived lack of empathy.

Spaceflight crew members must adapt to being confined to extremely small living and working quarters for the duration of the journey. Astronauts live on the job and are always surrounded by their co-workers. NASA's Human Research Program recommends a minimal acceptable net habitable volume of 25m^3 per person in spacecraft for future space exploration missions such as a Mars mission (Whitmire, Leveton, & Broughton, 2015). In comparison, the ISS has a habitable volume of 425m^3 (with an internal pressurized volume equal that of a Boeing 747 aircraft) for six people, that is 71m^3 per person. The Soyuz spacecraft on the other hand, which is the only spacecraft currently available for transporting people to and from the ISS, is notoriously known for its small size. It has a habitable volume of 5m^3 for a three person crew, roughly 1.5m^3 per person. The Soyuz spacecraft is pictured in Figure 1 (Schierholz & Huot, 2015). Astronaut Ron Garan (2012) described it as “a small vehicle that you *wear*. In the Soyuz you feel/hear every pump that turns on, every valve that opens and every explosive bolt that fires and there is no doubt when you "land".

Figure 1. Crew of ISS Expedition 45 Inside the Soyuz Spacecraft. Left to right: Kjell Lindgren of NASA, Oleg Kononenko of the Russian Federal Space Agency (Roscosmos) and Kimiya Yui of the Japan Aerospace Exploration Agency (JAXA). Reprinted from *NASA Astronaut Kjell Lindgren Completes Space Station Mission, Safely Returns to Earth* (2015), by S. Schierholz and D. Huot. Copyright 2015 by NASA. Retrieved from https://www.nasa.gov/press-release/nasa-astronaut-kjell-lindgren-completes-space-station-mission-safely-returns-to-earth

With current technology, it would take the astronauts about eight months to travel to Mars (Jenner, 2017). Since both planets follow different elliptical trajectories around the sun, the distance between us and the Red Planet varies greatly, from roughly 55 to 400 million km. Both planets’ orbits around the sun allow for an opportunity to embark to Mars every 26 months, when the planets are closest to each other. Because of this limited launch window there are two scenarios for going to Mars and returning to Earth. The first requires astronauts to remain on Mars for only a few weeks before returning, while the second scenario will see astronauts spending over a year on the Red Planet. Therefore, the overall mission duration ranges from about a year and a half to close to three years (Lind, 2012). Incidentally, the current record of longest time spent in space commutatively is held by cosmonaut Gennady Padalka, who spent 879 days (roughly 2.5 years) in space over the course of five missions.

During the flight, astronauts will conduct research similar to astronauts aboard the ISS, and their daily life is expected to be scheduled accordingly. Appendix 1 shows an example of a flight plan timeline used by the crew on board of the ISS. More specifically, this exact timeline was used on November 12, 2014. Almost every hour is scheduled, with crew members' tasks carefully choreographed by experts on the ground making sure no one gets in anyone's way in the crowded spacecraft. Aboard the ISS, the day starts at six o' clock (universal time). The crew meets for breakfast, gets briefed on the day's jobs and then scatters, breaking only for lunch and dinner. Most of their time is dedicated to research and maintenance, but exercise is also an important part of the daily routine. On average astronauts exercise two hours per day to prevent bone and muscle loss. Deviating from the schedule needs approval from MS, which requires a considerable amount of time and effort from ground personnel. As such, astronauts are pressured to stick to the imposed workload and tasks and are constantly supervised through audio and video channels (Goemaere, Vansteenkiste, & Van Petegem, 2016). This of course restricts and sometimes frustrates these highly trained astronauts. Cosmonaut Alexander Kalery even went as far as calling the ISS “a space station assembly line” (Kalery, Sorokin, & Tyurin, 2010, p. 926).

A Mars mission however will see a uniquely low level of support from ground control due to their immense physical distance from planet Earth. Resupplies and evacuation will be impossible. And crew will not be able to rely on swift help from MS in case of emergency because of a communication delay. Sending data to and from Mars takes several minutes, making live two-way communication impossible. Astronauts will no longer be able to video call their friends and family, staff at MS, nor psychological ground based counsel. Truly, they will be on their own.

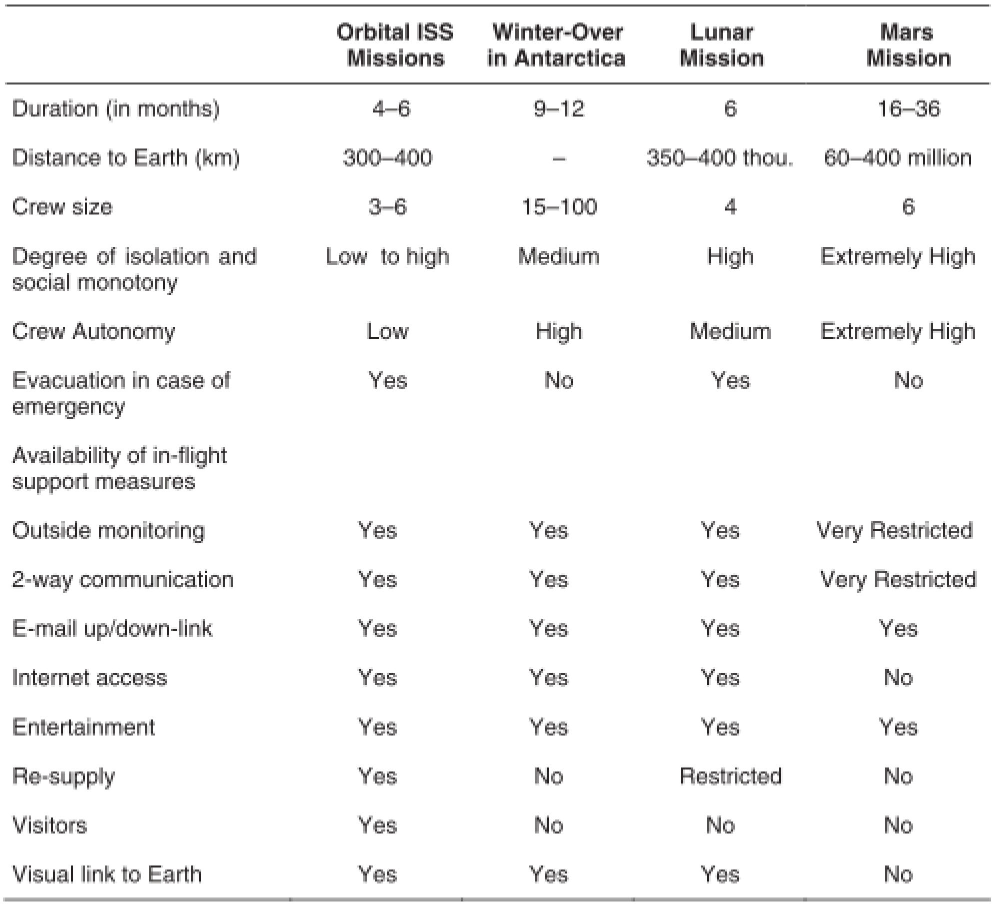
Sources of information. An exploration mission to Mars hasn’t been done before of course, thus researchers must turn to other sources of empirical evidence. Gathering empirical data in this field, however, is not a simple task because of the financial costs and the unique setting. In general there are four reliable sources of evidence (Kanas, 2015): 1) anecdotal reports from experts and people who have been to space, 2) research performed during space missions, 3) studies from natural space analog environments, and 4) artificially created simulations conducted on earth.

Anecdotal reports include for example space agency documents of debriefing, surveys of astronauts, and diaries kept while in space; but also interviews from newspapers and books written by astronauts after their return to planet Earth. Their stories are of course inspiring, they are the reason why some many children dream to become astronauts. And they can also inspire researchers, which can lead to new experimental studies such as this one. These sources can furthermore be helpful to understand the humanity of space travel and can be used to empathize with the crew to gain greater understanding on an emotional level. However, anecdotal reports are by nature subjective and should be interpreted with caution. Even though individuals are found to have better memory recall for autobiographical events, attribution research has shown that these works may be subject to self-serving attributional bias (Watson, Dritschel, & Obonsawin, 2007). When the Challenger, a NASA space shuttle, exploded in 1986, a study of Neisser and Harsch (1989) later found errors in self-reports of the disaster. Another shortcoming of anecdotal evidence is the small sample size of the date ($n = 1$). Albeit very useful to illustrate life in space and to serve as a source of inspiration, these limitations combined make for unscientific evidence.

In many ways, of course, actual space missions seem to be the most preferable source of information. The ISS has played a very valuable role in this since astronauts often spend several months in orbit aboard the station. Indeed, the space station offers a cluster of features unique to spaceflight such as microgravity and the changes it brings to daily life, and constant reliance on life support due to lack of atmosphere outside which creates true danger. Hence many scientists have called for more experimental data from the ISS. The station only has a maximum crew capacity of six however, which makes astronaut's time very limited. This leaves scientists all over the world competing for their valuable time, which in turn makes it very expensive. Until recently little has been done in the psychological and psychiatric field. In part, this has been due to the short-term nature of most space missions, prioritizing other research fields. During long-term missions however, psychological factors are expected to be more problematic (Kanas & Manzey, 2008). Consequently, we can expect that more research will be conducted in the future.

When considering Mars missions, however, the ISS has a number of limitations to simulate a long-term interplanetary flight of that level. The circumstances will be different than aboard the low orbit, Earth bound station as presented in Figure 2 (Kanas & Manzey, 2008). Social monotony and isolation in the ISS do not come close to what can be expected during a Mars mission. A typical stay at the ISS lasts only a few months, hardly enough time for the novelty to wear off. The crew on board the station also rotates on different schedules, so group dynamics often change. Astronauts are allowed and encouraged to make phone calls and video calls to their friends and family. Astronaut Tim Peake, in fact, likes to joke about how he once dialled a wrong number and "prank called" someone from space (Peake, 2016). Additionally, on board the station, there's constantly a direct visual link with planet

Earth, something a Mars crew will have to do without. During a Mars mission, evacuation will also be impossible**,** and while it is certainly costly and strenuous from low orbit, it is not impossible and has been done before (Summers, Johnston, Marshubrun, & Williams, 2005). “Policy is to pack seriously sick or injured astronauts into a Soyuz spacecraft and get them home as quickly as possible. Within hours we can have someone in a care centre back on Earth” (Hollingham, 2015).



	Orbital ISS Missions	**Winter-Over in Antarctica**	**Lunar Mission**	**Mars Mission**
Duration (in months)	4–6	9–12	6	16–36
Distance to Earth (km)	300–400	–	350–400 thou.	60–400 million
Crew size	3–6	15–100	4	6
Degree of isolation and social monotony	Low to high	Medium	High	Extremely High
Crew Autonomy	Low	High	Medium	Extremely High
Evacuation in case of emergency	Yes	No	Yes	No
Availability of in-flight support measures				
Outside monitoring	Yes	Yes	Yes	Very Restricted
2-way communication	Yes	Yes	Yes	Very Restricted
E-mail up/down-link	Yes	Yes	Yes	Yes
Internet access	Yes	Yes	Yes	No
Entertainment	Yes	Yes	Yes	Yes
Re-supply	Yes	No	Restricted	No
Visitors	Yes	No	No	No
Visual link to Earth	Yes	Yes	Yes	No

Figure 2. Comparison of Different Space Missions and Winter-over in Antarctica. Reprinted from *Space Psychology and Psychiatry* (p. 217), by N. Kanas and D. Manzey, 2008, El Segundo, California: Microcosm Press and Springer. Copyright 2008 by Springer Science+Business Media B.V.

The bulk of the evidence comes from non-space domains, such as space analogs. Space analogs are natural environments on Earth with extremely hard living conditions, which makes them suitable as a comparison to Mars. Analogs are often called Isolated and Confined Environments (ICE) and can be found all over the world, they include offshore oil rigs, submarines, and arctic expeditions. Analogs are frequently used as a comparison to spaceflight because they are simply more accessible than spaceflight. Because of the lower expenses, participants can remain in isolation for longer periods of time. Winter-over expeditions in Antarctica often last almost a year. Several studies have found evidence that it is in fact the psychological meaning of a space analog that is important (Sandal, Vaernes, Bergan, Warncke, & Ursin, 1996; Suedfeld, 1991). And analogs have the dubious advantage of being truly dangerous. Geographically, the Antarctic is the coldest, driest, windiest extremity of the world, providing both a physical and psychological challenge. But natural analog studies are also frequently criticized. Because of the extreme environment, not all variables can be controlled. Participants always have access to two-way communication for example. And albeit dangerous, just like on the ISS, evacuation is always an option. Additionally, there are often much more individuals in natural analog settings than the amount of crew members that is to be expected in current and future long-duration spaceflight missions (Mcphee & Charles, 2009).

Because of the recent interest in undertaking a manned Mars mission, ICE-settings have been created artificially to simulate actual space missions as closely as possible. Similarities include heterogeneous crews, crew size, similar scientific research objectives, and comparable physical and psychological challenges. Crew members are expected to live and work together for extended periods in confined settings, away from their social networks (McPhee & Charles, 2009). A huge advantage of Mars simulations is that all variables can be manipulated. The Mars 500 experiment for example had six individuals living in a 550m^3 confined area simulating a 520 day long trip to Mars (Tafforin, 2013), during which two-way communication was shut down for a prolonged period of time. Simulations are the only setting in which researchers can observe the effects of social monotony. Other advantages include again the lower expenses and also the availability. While there is only one space station, several Mars simulation experiments can be running at the same time on Earth. The only true limitation is a lack of perceived danger, as it would be unethical to add severe risks to an experimental setting. Because of its many advantages, Mars simulations are currently the most popular research setting of many studies researching the psychological effects of such a trip. Therefore, for the purpose of this study, we also made use of data gathered during a Mars simulation.

Psychological Challenges of Long-Term Spaceflight

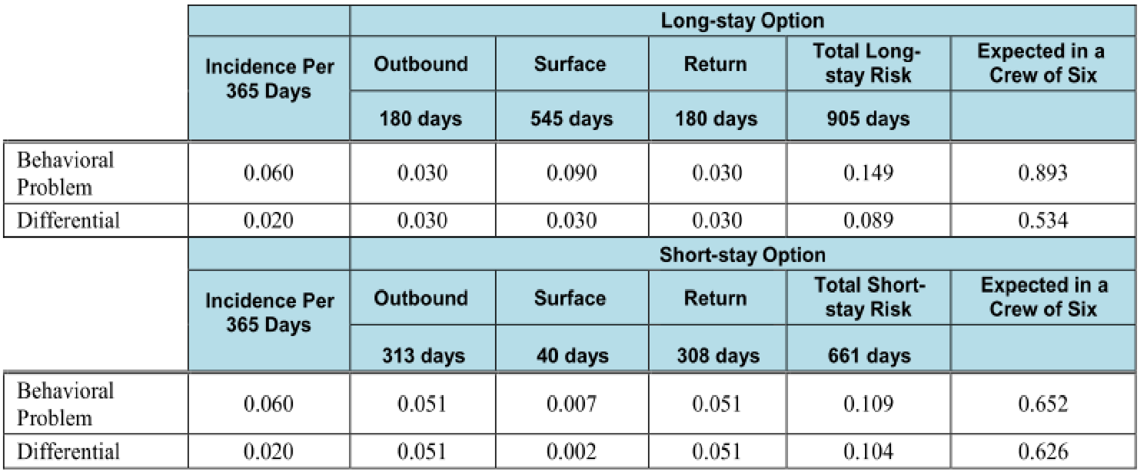
Psychological challenges regarding well-being. ***Isolation.*** Life in space is accompanied by several psychological stressors that are known to decrease well-being. For instance, future long-duration Mars exploration missions will increase astronauts' exposure to extreme isolation. After only a few days into their three year mission, the crew will already be the most geographically isolated humans in history. The effects will be twofold: social isolation from home resulting in loneliness and also social monotony as crewmembers will only have each other to interact with.

Contact with others (aside from the immediate crew) will be very limited and inconsistent at times, depending on the position of the Earth, Mars and the sun. This will isolate astronauts from their friends and family for the duration of several years. Ground based epidemiology research, for instance, shows that socially isolated patients have higher mortality rates in general (House, 2001). Further studies conducted where conditions similar to a Mars mission apply (ICE-settings such as submarines, offshore oil rigs and polar stations), show that isolation and confinement are generally harmful to mental health and well-being during long periods of time (Britt & Bliese, 2003; NASA, 1987; Sells, n.d.) and impact mood and social aspects (Heuer, Manzey, Lorenz, & Sangals, 2003; Johannes, Salnitski, Polyakov, & Kirsch, 2006; Manzey, Lorenz, Heuers, & Sangals, 2000; Pattyn et al., 2005; Whitmore, McQuilkin, & Woolford, 1998).

Whereas in other settings, such as the ISS, these findings can be reduced by effective support measures like visiting crews and crew rotation schedules, these options will not be available during missions to Mars. The astronauts will be on their own for the whole duration of the mission. A crew of three to six people (Bessone & Vennemann, 2004; Salotti, Heidman, & Suhir, 2014) puts a major restriction on the number of dyadic interactions available. As crewmembers get to know each other, this limited amount of conversational partners may over time lead to a sense of interpersonal boredom. People become predictable, jokes get old, and crewmembers get more easily irritated by each other. Astronauts must live and work together in close quarters 24 hours per day, which means they can feel both lonely and crowded at the same time. The effects of social monotony have been observed in prison inmates in solitary confinement (Haney, 2003) and a lack of variety in social interactions can result in boredom, a loss of concentration, loss of energy, and even interpersonal conflict (NRC, Space Studies Board, 1998; Otto, 2007).

Another challenge that will amplify the effects of isolation is the communication delay of data transmission. It will take radio signals quite a long time to reach Earth from the spacecraft. As mentioned earlier, the distance between our planets fluctuates, translating in a communication delay between a minimum of four minutes and a maximum of around 24 minutes (one way) depending on the position of the planets (Ormston, 2012). An important consequence of this rather technical issue is that live two-way communication will become impossible. Thus, the mental health threats of social monotony and perceived isolation may increase as the crew will be completely cut off from any real time interactions with people outside the spaceship. Sadly, the delay cannot be improved by radio or computer upgrades because the data is already travelling at the speed of light. This illustrates how far away Mars actually is and how isolated these astronauts will be.

Risk of psychiatric disorders. In analog studies, Lugg (1977, 2005) found that physicians have described more issues with depression and somatic illnesses during long periods of relative social monotony and isolation among people overwintering in Antarctica. Even though only a few incidents of psychiatric problems have been reported from orbital spaceflight so far, we can assume that the risk of developing symptoms of mental illness will increase during missions as long and isolated as future Mars mission. Research supports this idea: as the length of space missions increases, the incidence of behavioural conditions and psychiatric disorders is also expected to increase (Ball & Evans, 2001; McPhee & Charles, 2009; Otto, 2007). In a Russian study, Myasnikov and Zamaletdinov (1996) reported that the risk for severe adjustment disorders is directly related to the duration of the spaceflight and can be assumed to rise significantly for missions lasting longer than four months in isolation.



		Long-stay Option				
	Incidence Per 365 Days	Outbound	Surface	Return	Total Long-stay Risk	Expected in a Crew of Six
		180 days	545 days	180 days	905 days	
Behavioral Problem	0.060	0.030	0.090	0.030	0.149	0.893
Differential	0.020	0.030	0.030	0.030	0.089	0.534
		Short-stay Option				
	Incidence Per 365 Days	Outbound	Surface	Return	Total Short-stay Risk	Expected in a Crew of Six
		313 days	40 days	308 days	661 days	
Behavioral Problem	0.060	0.051	0.007	0.051	0.109	0.652
Differential	0.020	0.051	0.002	0.051	0.104	0.626

Figure 3. Risk of a Behavioural Problem Occurring During Mars Missions. Reprinted from *Human health and performance risks of space exploration missions* (p. 30), by J. McPhee and J. Charles, 2009, Houston, Texas: NASA. Copyright 2009 by NASA.

Figure 3 (McPhee & Charles, 2009) shows the risk of a behavioural problem occurring during Mars missions based on data from Antarctica. The calculations consider two possible mission scenarios, a long stay leaving the crew on the planet for a year and a half (waiting for the next launch window) and a short stay utilizing only one launch window, which results in a longer flight time. The row labelled ‘Behavioural Problem’ assumes a stable 6% incidence rate per person-year during flight and on the surface of Mars. While the

‘Differential’ row allows for a smaller incidence rate on the surface, where stressors may be reduced by the novelty of the environment, a change in task performance, and a larger habitable volume. This study predicts a high risk of a psychiatric disorder occurring during the mission, 53% to 89% chance per person.

Billica (cited in McPhee & Charles, 2009, p. 9) found similar results analysing real life data of 89 space shuttle missions from 1981 until 1989. Based on data from 208 crewmembers, they found an incidence rate of 0.11 for a 14-day space shuttle mission. In other words, behavioural signs and symptoms occurred at a rate of approximately one per every 2.86 person-years, which is the approximate length of a future Mars mission. Two of the symptoms most commonly reported in these missions were anxiety and mood issues. Kanas and Manzey (2008) further report adjustment disorders, somatoform disorders, and mood and thought disorders. The actual incidence rate however, is likely to be understated because astronauts have been known to be reluctant to report psychiatric symptoms (Ball & Evans, 2001; Shepanek, 2005).

Boredom (Houston, are we there yet?). Research further shows that the in- and outbound flight stages may be the most taxing on crew members’ mental health. A Mars mission will be characterised by longer, comparably uneventful periods of low workload, coupled with confinement and unchanging surroundings. Because many procedures are automatically operated or controlled from the ground, astronauts are often left with the same monotonous workload. In fact, monotony or boredom is routinely listed as one of the main psychological stressors in extended space missions (Kanas & Manzey, 2008; Suedfeld & Steel, 2000; Otto, 2007). The effects however are most likely less severe in current spaceflight since short-term missions provide high workloads and variety, whereas in longer exploration missions a major concern is the possibility of too much spare time, novelty wearing off, and astronauts’ workload lessening, thus resulting in higher levels of boredom. As space missions become longer, the question won’t be how much work astronauts can safely perform, but how little (McPhee & Charles, 2009). In the words of astronaut Norman Thagard: “The single most important psychological factor on a long-duration flight is to be meaningfully busy. And, if you are, a lot of the other things sort of take care of themselves” (Herring, 1997, p. 44).

Klapp describes what he calls the perfect boring situation (Klapp, 1986) as a threefold model of sameness: monotonous of environment, people and their conversations, and seeing and doing the same things every day. These three elements reinforce each other, resulting in a triad of boredom. A recent study applied this model to spaceflight and concluded that astronauts are especially at risk (Peldszus, Dalke, Pretlove, & Welch, 2014).

Crew is confined to neutral living quarters, isolated from social interactions, and deprived from usual Earthly stimuli. This results in a triad of spatial, social, and sensory monotony and boredom as shown in Figure 4 (Peldszus et al., 2014). In addition, based on qualitative diary input from six orbital and simulation missions, they found that monotony may worsen other psychological stressors and negatively affect behaviour and crew performance.

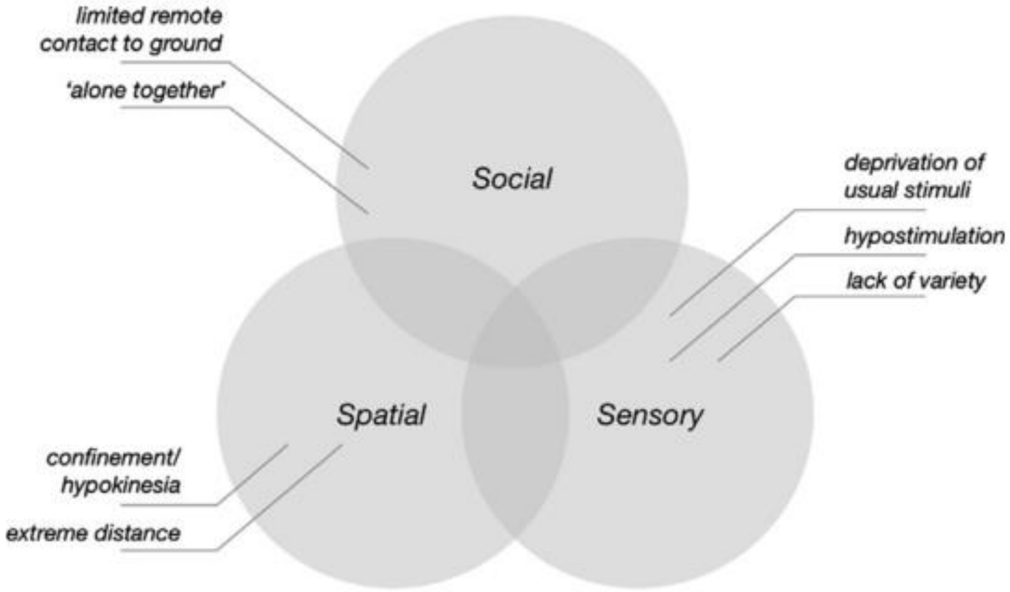


Figure 4. Triad of Monotony Applied to Spaceflight. Reprinted from "The perfect boring situation - Addressing the experience of monotony during crewed deep space missions through habitability design," by R. Peldszus, H. Dalke, S. Pretlove, and C. Welch, 2014, *Acta Astronautica*, 94, p. 264. Copyright 2013 by Elsevier Ltd.

A Mars crew might be even more at risk. Several studies found that participants for ICE-experiments often show an affinity for thrills and novelty and a high motivation and need for change. They thrive towards adventure and mastering difficult tasks (Sandal, 2000; Suedfeld & Steel, 2000). In reality however, they often find themselves confined to a monotonous environment in an unvarying group with a routine schedule. It could be wiser to recruit volunteers with a medium motivation and creativity who have a high readiness to withstand boredom since they are more likely to cope positively with the more monotonous phases of the mission (Ursin, Comet, & Soulez-Larivière, 1991). This results in a paradox however, as space agencies obviously want a highly motivated crew, yet for those people especially forced inactivity and deprivation of stimuli and social interactions may result in acute distress and frustration (Bennet, 1983).

Earth out of view. The absence of Earthly conveniences and daily routines further also intensifies the feeling of isolation and loneliness in space (Ball & Evans, 2001). Perhaps this is the reason why astronauts enjoy gazing at the Earth that much. Especially when they have just arrived, crew in the ISS likes to fill their leisure time in a meaningful way by looking at the Earth and identifying various sites and personally relevant places (Johnson, 2010).

This is where a deep space exploration mission to Mars will challenge the crew in a new and interesting way. The distance between our planets is so immense that the Earth will no longer be visible. Considering the positive effects of Earth observation for astronauts' well-being, it seems almost certain that seeing the Earth reduced to a distant dot through a telescope will impact negatively on the mental health of the crew (Manzey, 2004). No one in the history of humankind has ever been so isolated from our planet that they had no visual link to Earth. We cannot study how this will influence the crew's behaviour and mental state because it's a situation that is simply impossible to simulate on Earth. We can only guess what the effects will be. The best evidence we have are anecdotal reports from astronauts who travelled to the moon and to the ISS and they report that having a direct visual link with the Earth is soothing and of psychological importance for their well-being (Kanas & Manzey, 2008).

We can assume, that at a minimum, this will increase the feelings of isolation and loneliness within crew (Kanas, 2015). Suedfeld (2005) proposes that break-off may occur, concluding in a feeling of personal detachment from our world. According to Kanas and Manzey (2008) we should prepare for a higher possibility of psychological, interpersonal, or psychiatric problems, and crew will need to be monitored for anxiety and depressive reactions. Pre-emptive measure can be taken in an attempt to lower the impact of this unknown phenomenon. Films or images of the Earth, or even a telescope might lessen the feeling of homesickness. But it's likely none of these options will be a sufficient substitute for a direct link with our home planet.

Psychological challenges regarding performance. The aforementioned stressors on well-being will certainly also influence astronauts' work performance. Moreover, as discussed earlier, space is a highly stressful work environment, and research has shown that human cognitive performance and perceptual motor skills can worsen under stress (Albery, Armstrong, Roe, Goodyear, & McCloskey, 1988; Hockey, 1983; Lieberman, Tharion, Shukkit-Hale, Speckman, & Tulley, 2002)**.** It is assumable such a decrease in performance will also occur in the stressful environment of a long-term spaceflight. Indeed, evidence has been found to support this, showing that cognitive performance and various psychomotor functions decline during space missions (Bock, Fowler, & Comfort, 2001; Heuer et al., 2003; Semjen, Leone, & Lipshits, 1998; Watt, 1997; Whitmore et al., 1998).

Team performance. Astronaut performance is largely team dependent. Because of the international nature of modern space travel, most crews now consist of members of different nationalities. Crewmembers also have different scientific backgrounds and cultural upbringings. These and other factors make for heterogenetic and diverse teams. Interpersonal conflicts and a lack of cohesion have been suggested as a negative influence on the ability of crew teams to perform tasks accurately, efficiently, or in a coordinated manner during long-duration missions (McPhee & Charles, 2009; NASA, 1987; Vinograd et al., 1974).

However, some crew teams commit almost no observable errors but still fail to accomplish performance objectives, while others do commit several errors but yet manage to perform spectacularly. Failure can be a part of the progress. Successful performance therefore, should not be viewed as simply the absence of errors or the avoidance of failure; the goal should be to optimize team performance during long-duration missions despite errors, which are inherent to human nature (McPhee & Charles, 2009).

A distinction to consider on the subject of team processes is one between interpersonal conflict and task conflict (De Dreu & Weingart, 2003). Research shows that interpersonal conflict is generally destructive to team performance and cohesion, whereas moderate task conflict may benefit team performance as team members openly discuss and challenge each other's arguments, figuring out how to solve a problem together (Jehn & Mannix, 2001; Pelled, Eisenhardt, & Xin, 1999; Porter & Lilly, 1996).

This is important because several studies have shown that space crew is prone to groupthink (Kanas & Manzey, 2008; Sandal, 2012). Groupthink is a phenomenon that can be described as the tendency to strive for consensus at the cost of considering alternative courses of action and has been known to emerge in small groups clearly separated from others. Which is the case for a small space crew isolated from not only their friends and family, but also clearly separated from earth bound personnel such as MS. Thus, groupthink may lead to a lack of critical thinking (and task conflict), resulting in errors simply because signs of failure were overlooked.

Because of the high diversity of space crews, interpersonal conflict can be a risk as well. Harrison, Price and Bell (1998) differentiated between two types of diversity in team cohesion. Surface-level diversity includes heterogeneity in gender, ethnicity and age. Whereas heterogeneity at deep-level stands for differences among the crew's attitudes, values, beliefs, and cultural norms. They found the effects of surface-level diversity weakening over time, while the effect of deep-level diversity strengthens as group members spend more time together. Several other studies have also reported that similarity on a deep-level is one of the best predictors of team cohesion (Byrne, 1971; McGrath, 1984) and long-term performance (Edwards, Day, Arthur, & Bell, 2006; Hirschfeld, Jordan, Field, Giles, & Armenakis, 2006). Nonetheless, issues related to language and cultural differences have been reported in both simulations and space environments (Kelly & Kanas, 1992, 1994; Santy, Holland, Looper, & Marcondes-North, 1993).

Some of the better studied performance errors in spaceflight history include the space shuttle disasters. Studies that have investigated the Challenger and the Columbia explosions mention breakdowns in team coordination, informational exchanges, and role conflicts, all indicators of poor group cohesion (Columbia Accident Investigation Board, 2003; Launius, 2004) and groupthink has been mentioned as one of the main reasons leading up to the Challenger disaster (Esser & Lindoerfer, 1989; Moorhead, Ference, & Neck, 1991). The accidents led to a setback in the shuttle program as a special investigation commission found NASA's organizational culture and decision-making processes had been key contributing factors to the accident of the Challenger. The whole shuttle fleet was grounded for 32 months while improvements were made to the management structure (Rogers et al., 1986).

Psychological challenges regarding communication. ***Displacement.*** Sometimes problems related to interpersonal conflict or lack of empathy can lead to miscommunications between space crew and ground personnel. During a Russian Salyut space station mission for example, cosmonaut Valentin Lebedev (1988) and his crewmate did not report a fire on board to ground control because "it would have just caused more panic" (p. 309). In his logs, Lebedev also notes that during his mission he felt increasing frustration with people on the ground. Sometimes his anger with MS was related to a change in the voice quality of people on Earth, or other relatively smaller inconveniences. At the same time, Lebedev reports onboard tension between himself and his fellow cosmonaut, something the two of them did not openly express or discuss. Indeed, research suggests that his irrational frustration towards MS may have been a displacement of his emotions towards his crewmate.

Displacement is a very common way to deal with stress. Many people experience displacement when they get angry but cannot display their emotions in public, they then later vent their frustrations on innocent bystanders, such as a spouse or a shop assistant (Kanas, 2014). Displacement provides the short-term benefit of relieving tension, but does little to resolve the problem since the source of the problems is not dealt with, it can furthermore produce conflicts with outsiders. Research has shown that people who are in isolation for a prolonged time may displace or transfer their intra-crew tension and negative emotions to safer, more remote individuals on the outside, such as MS.

Such a displacement of affect has been repeatedly reported from space simulation studies on Earth (Gushin et al., 1997; Kanas, 1998; Kanas & Manzey, 2008; Kanas, Weiss, & Marmar, 1996; Sandal, Vaernes, & Ursin, 1995)**.** During the Biosphere 2 experiment the crew even divided into two fractions with one group viewing outside personnel more negatively and the experiment had to be stopped prematurely (Walford, Bechtel, MacCallum, Paglia, & Weber, 1996). Otto (2007) found further evidence in Antarctic analog settings where crew reported having avoided communication with their external support team or even deliberately misleading them. Displacement has also been observed during space missions, finding displacement of negative mood from crew members to MS and from MS personnel to higher management (Gushin, Shved, Ehmann, Balazss, & Komarevtsev, 2012; Kanas & Manzey 2008; Kanas et al., 2001; Kanas et al., 2007). Anecdotal evidence from NASA (McPhee & Charles, 2009) describes how Skylab crew once made space history when a perceived lack of support from MS led to a mutiny and the crew shut down all communication with the ground for 24 hours. Crew insisted on taking a day off and spent their time relaxing and looking at the Earth. Conflicts between space crew and MS are not only costly (a single day on Skylab then was worth about 23 million in 2017 US dollar), but could also prove to be catastrophic if they occurred during an emergency.

In their original proposal, Kanas and Feddersen (as cited in Kanas 2014) reasoned that flight crew who are experiencing high group tension (as a result from isolation and crew heterogeneity), would displace their negative emotions onto MS personnel and perceive them as unsupportive. From several studies conducted on the ISS and ground analogs we now know that psychological problems become increasingly more likely with the duration of the mission (Kanas, 2015). A Mars crew will experience a higher level of independence and isolation then any astronauts before them. Crewmembers will be less able to rely on support from MS because of the communication delay and will have to solve any problems and conflicts on their own. Other stressors, such as the prolonged dependence on technical life support, may further increase onboard tensions. A matter of speculation is whether these factors will increase the level of displacement during a long-term Mars mission.

Recent evidence from the Mars-520 experiment seems to support this. When participants were confined for over a year and given higher levels of independence, Gushin et al. (2012) found an increase in crew tension towards MS, which suggests displacement.

Sandal (2012) reported increased homogeneity within crew and more reluctance to express negative interpersonal feelings over time, which could lead towards perceiving MS as a common enemy. Based on data from the Mars-105 experiment, Sandal, Bye and Van De Vijver (2011) also found that average individual scores on benevolence decreased significantly towards the end of the experiment, when a communication delay was implemented, which may lead to higher levels of interpersonal tensions; an effect that has been found before towards the end of several ICE-experiments (Sandal et al., 1995).

Current Countermeasures

Relatedness with home. In the previous section, we discussed various psychological challenges astronauts will have to endure on a long-term Mars mission. The attentive reader probably noticed that most of these hardships are experienced in relationship to other people, or lack thereof, and so has NASA. With the first manned Skylab mission for instance, it was decided that astronauts' private conversations with their families would be monitored and that the transcripts would become a matter of public record. The astronauts in question, however, decided the best way to handle the lack of privacy was to agree that they would 'though it out' and not have any communication with their families during the 28-day mission (Johnson, 2010). Since then space agencies and researchers all over the world have developed countermeasures to respond to the effects of loneliness and interpersonal issues during spaceflight. They have helped astronauts to remain connected to life on Earth and to deal better with time away from home and family. The Family Support Office which was mentioned earlier is one of the departments charged with this task.

Since the creation of the station, there exists a protocol for in-flight support of ISS residents, and astronauts are now allowed private conversations with their family and friends. They have report that these weekend video conferences and regular phone calls help them to get through the separation period (Kanas, 2015). This way, astronauts in space can still be an integral part of the family back home. Crew members furthermore report that having contact with their loved ones has a positive influence on their mission performance (Kelly & Kanas, 1993). The importance of family support was also found in analog studies in Antarctica. There, evidence was found that support provided by contact with family and friends is more important for stabilizing mood and performance than potential support available from crewmates (Palinkas, Gunderson, Holland, Miller, & Johnson, 2000). Meanwhile, recreational contact with Earth from space has become surprisingly normal. Astronauts can send e-mail and make telephone calls with an internet phone to call friends and family anytime they like (NASA, n.d.-a), and a part of astronaut training is an optional amateur radio licensing class, which astronauts can use to communicate with people on Earth (Kanas & Manzey, 2008). Astronaut Scot Kelly for example, has hosted a two hour radio show called "The Scott Kelly out of this world tour: Rocking the one-year mission" (Ziv, 2016).

Every few months family members can send care packages up to the ISS. These care packages arrive with the usual re-supplying of the station and most contain treats, letters and other gifts that remind the crew of home (Kanas, 2015). Food is very popular since it's not dehydrated like most, if not all, food on board the station (Johnson, 2010). And since their weight limit nowadays is a royal five kilograms, some family members have gotten creative. Astronaut Thomas Pequet received a Saxophone for his birthday (Dunn, 2017), and other musical instruments such as a keyboard, but also bagpipes and a didgeridoo have been sent up to space.

Additionally, astronauts are kept up to date with daily news and world events. The ISS has a fairly strong internet connection, and protocol further specifies that astronauts receive news summaries and audio news in their native language (Kanas & Manzey, 2008). It helps the crew to feel connected to the ground and prepares them for possible chances when they return home. In 1991, the Mir space station crew launched from the Soviet Union and later landed back on Earth in the Russian Federation (Russian Spaceweb, 2008). After being informed of the Twin Towers attack in 2001, astronaut Frank Culbertson writes he "zipped around the station" until he found a window that could give him a view of New York City (Culbertson, 2001). Although far from home, spaceflight crew is not untouched by political turbulence and world events.

Relatedness with crew. A different approach to improve the psychological well-being of astronauts is to create a daily life in space that resembles life on Earth. This approach has been observed before in Antarctic expeditions. Crew members in the Arctic cope with isolation and danger by recreating a home-like environment, with special foods and celebrations; all of which provides them with continuity and a feeling of being connected with family back home (Suedfeld, 2005). In a study based on journals written by astronauts in the ISS, Skylab and Mir, Johnson (2010) concludes that in space too astronauts cope with isolation by creating a home in low orbit. They enjoy meals together, celebrate special events like on Earth, and even have their own space celebrations. Not only do they have a Christmas tree in the ISS, they also celebrate Cosmonautics day. Personal milestones such as breaking a previous records for longest time in space are also celebrated and typically include a great meal, conversation, and music. The ISS further has its own traditions. There's a ship's bell attached to the wall (which is rang when a spacecraft arrives at the station), a traditional New Year's poem, and a handover ceremony of command on the last docking day.

The Soyuz spacecraft embarks the ISS about four times per year and brings three new crew members to the station. Crew usually rotates over several expeditions, with different crewmates. This rotation system provides a welcome relief from the social monotony otherwise experienced in the station (Kanas & Manzey, 2008). The arrival of new crew is always highly anticipated, with preparations not unlike cleaning house (Johnson, 2010). As described by astronaut Clay Anderson (Anderson, 2007, Ch. 5): "I find that it is reminiscent of the same type of work you might do when you have guests scheduled to arrive in your home! […] they are my friends! Time to put out the guest towels!"

It's true that astronauts in the space station are no strangers to each other. During pre-flight training, future crewmates take many lectures and workshops together. Kanas and Manzey (2008) state that each group has to go through several stages and that the goal of joint training is to cycle through these stages before the crew launches off to space. During this time, astronauts also receive psychological training and are taught how to interact with their crewmates. A group of experts (e.g., former astronauts and psychologists) developed a model of 25 specific behavioural competencies that astronauts should train in. These specific competencies are clustered in larger categories such as teamwork, conflict management, and communication. The category self-care contains competencies that are needed to cope with the demands and stress of spaceflight on an individual level. And due to the multi-cultural aspect of the ISS, the model also includes a category of cross-cultural competencies, thus reducing possible interpersonal conflicts and miscommunications.

Limitations. However, due to the great distance from Mars to Earth, real time communication between flight crew and MS and their family will be restricted by time delays. Re-supply, care packages, and visits from rotating crew will be impossible. Psychological monitoring will become difficult and counselling sessions will no longer be available. All in-flight support measures will have to rely on emails and video recordings to communicate and a direct link with planet Earth will be lost. In conclusion, the implementation of many of the aforementioned support tools will become dramatically hard during a Mars mission. Thus, space agencies and researchers will have to develop alternate support measures based on these restrictions.

To develop new deep space counter measures, first more research is needed on the subject. Mars simulation experiments and the ISS missions are valuable sources of evidence for these new studies and new hypotheses and models are continuously tested. This is one of these studies and in the following section, we would like to propose a theoretical model that seems to be a good fit for the previously discussed issues.

Underscoring Relatedness as an Effective Countermeasure

Relatedness within SDT. Interpersonal contact shows to be an underlying cluster factor that will prove to be a major challenge during long-term space missions. Indeed, the need to feel belongingness and connectedness with others is centrally important for the human well-being (e.g., Baumeister & Leary, 1995; Crary, 2016). As this central need for relatedness comes under risk during interplanetary travel, several symptoms seem to surface: loneliness in isolation, interpersonal conflicts, and miscommunication with MS, to name a few. Space psychology is in dire need of a theoretical framework which can provide explanatory utility for this large number of seemingly disparate phenomena.

The Self-Determination Theory (SDT) is an influential theory of motivation that focuses on the social-contextual conditions that facilitate versus forestall positive behaviour, well-being, and human motivation. It defines people's psychological needs that are at the basis of a healthy psychological development or foster pathological problems and maladaptive behaviour when obstructed. When these needs are fulfilled, SDT predicts improved well-being and a more internalized form of motivation, resulting in better performance (Ryan & Deci, 2000).

Through a bottom-up approach, Ryan and Deci (2000) distilled three psychological needs from empirical evidence: autonomy, competence, and relatedness. These needs are said to be inherent and universal across culture, gender, and time and lay at the basis of a nurturing social environment which provides for opportunities of growth. In this study, based on the previously discussed evidence, we decided to focus on the psychological need for relatedness.

The need for relatedness reflects the need to belong and feel connected with other people, to feel securely attached to others in satisfying, supportive relationships. It's the very human longing of feeling cared for and to experience care for others. The importance of interpersonal relationships appears in some form as early as 1943 in Maslow's hierarchy of needs. When the need for relatedness is fulfilled, people feel emotionally (and act physically) close to others and have meaningful relationships with them. Relatedness is important to SDT because it provides the affective foundation for natural growth tendencies to develop and for motivational cues to internalize (Ryan & Connell, 1989).

However, the need for relatedness will leave much to be desired for astronauts traveling to Mars. Based on SDT, it is very likely that social isolation and monotony will prove to be some of the major risks of the mission. Direct contact with loved ones will no longer be possible and the psychical distance to every other human being than onboard crew will be enormous. This will impact the crew in unknown ways that are currently being researched through simulation studies on Earth. Some of the first results and earlier ISS and analog studies suggest that several psychological issues are indeed related to a lack of relatedness. These findings are correspondent with predictions based on the SDT framework, and will therefore be tested in this study.

Evidence supporting the need for relatedness. SDT has been researched across multiple life domains and a wealth of data has shown that satisfaction of all three needs is critical to optimal functioning for everything from healthcare (e.g., Williams, Frankel, Campbell, & Deci, 2000) to mental health (e.g., Sheldon, Williams, & Joiner, 2008) to interpersonal relationships (e.g., LaGuardia & Patrick, 2008) and prosocial behaviour (e.g., Grant, 2008). Results have also been found in professional settings (e.g., Greguras & Diefendorff, 2009), education (e.g., Diseth, Danielsen, & Samdal, 2012), and in the sport domain (e.g., Gillet, Berjot, & Gobance, 2009). Countless studies document the importance of the fulfilment of all three needs and by proxy the importance of the need for relatedness. These findings provide evidence that supports the notion that perceived relatedness contributes to well-being and performance among others and that thwarting this need may lead to passivity, alienation or opposition. To strengthen our theory that the same results can be expected in a spaceflight setting, the following section will discuss the current evidence supporting the need for relatedness.

In organizational psychology, the role of social support (Viswesvaran, Sanchez, & Fisher, 1999) and the effects of loneliness at work (Wright, Burt, & Strongman, 2006) have since long been acknowledged. And more recently, several studies in professional settings have further investigated the practical utility of SDT in the work domain. They found that the need satisfaction of relatedness is essential for the well-being of workers, reporting less burnouts and stress (Fernet, Austin, Trepanier, & Dussault, 2013; Van den Broeck, Vansteenkiste, De Witte, & Lens, 2008), lower anxiety and somatization (Baard, Deci, & Ryan, 2000), and improved well-being (Deci, Olafsen, & Ryan, 2017; Gillet et al., 2011). These results were found in work settings across countries (Deci et al., 2001; Nie, Chua, Yeung, Ryan, & Chan, 2015). Considering the enormous amount of studies on the subject of well-being at work, it seems appropriate to mention a recent meta-analysis (Van Den Broeck, Ferris, Chang, & Rosen, 2016). They included data from 116 samples from professional settings, with effect sizes from over 45,000 subjects. The results showed that relatedness accounted for unique variance in positive affect, general well-being, and life and job satisfaction. They furthermore reported a negative correlation with negative affect, strain, and burnout. Thus, we may conclude that there is evidence supporting the effects of relatedness on well-being in the work domain.

Realisation of the psychological needs is also known to elevate performance. In a professional setting, need fulfilment resulted in higher affective commitment (Greguras & Diefendorff, 2009) and an increase in task performance (Chianara & Bentein, 2016; Marcus & Sanders-Reio, 2001). Further research found that witnessing acts of rudeness by an authority figure or peer, reduced workers' performance levels (Porath & Erez, 2007, 2009). Again, the amount of research is plentiful. Cerasoli, Nicklin and Nassrelgrgawi (2016) conducted a meta-analysis on the effects of need satisfaction on performance. Their research included the results of 96 scientific publications, reporting the effects from over 30,000 respondents. They specifically found evidence supporting that perceived relatedness predicts performance at work. Van den Broeck et al. (2016) also focused on the effects of relatedness on job performance. They found a significant, unique positive relationship of relatedness with task performance, creative performance, effort, and organizational citizenship behaviour. Furthermore, a negative relationship with turnover intention and amotivation was reported. These numerous results clearly indicate that relatedness influences performance levels in the work domain.

Similarly, the effects of need satisfaction have been studied in the sports domain. Sheldon, Zhaoyang and Williams (2013) found a positive relationship between need satisfaction and performance in basketball teams. An application of STD has also led to a positive effect on autonomous exercise motivation, performance and long-term persistence in exercising (Vansteenkiste, Simons, Soenens, & Lens, 2004). Additionally, relatedness specifically was found to increase the engagement and intrinsic motivation during PE classes (Sparks, Dimmock, Whipp, Lonsdale, & Jackson, 2015).

In school settings, SDT has been researched studying the effects of need satisfaction on learning. Standage and Emm (2014) stated that teachers and other individuals who play a role in shaping students' attitudes and values, should engage in caring and warm interactions with their students. They further suggested that more research is needed to identify specific techniques and behaviours to target relatedness. Certainly, in this field particularly, the effects of relatedness have yielded strong results. Students who feel they have teachers who care for them, reported lower levels of symptoms of depression and anxiety (Pössel, Rudasill, Sawyer, Spennce, & Bjerg, 2013; Rueger, Malecki, & Demaray, 2010). A sense of relatedness with teachers leads to higher perseverance, consistency, and passion for long term goals (Datu, 2017). Students who perceived more teacher rapport and relatedness with their school were found to have a stronger academic performance and showed greater overall extracurricular participation (King, 2015; Wormington, Corpus, & Anderson, 2012). Moreover, also those students who had positive relationships with their peers displayed higher levels of school engagement and academic achievement (Chen, Hughes, Liew, & Kwok, 2010; Léon & Liew, 2017; Wentzel & Muenks, 2016).

Studies have also found effects of need thwarting on interpersonal communication. For instance, several types of social activity have been identified that people engage in to increase their sense of relatedness with their peers (Reis, Sheldon, Gable, Roscoe, & Ryan, 2000). One of these is avoiding arguments and conflict that create distance and feelings of disengagement (Gottman, 1994; Notarius & Markman, 1993). Further research by Uysal, Lin and Knee (2010) found that concealing personal distressing information is obstructive to the satisfaction of basic psychological needs, which in turn predicts negative well-being. Thwarting the need for relatedness was also reported to lead to higher levels of bullying in high school students (Hein, Koka, & Hagger, 2015).

Since a lot of the evidence originates from self-reports, Sheldon and Filak (2008) conducted a randomly controlled trial experiment in which the needs for autonomy, competence, and relatedness were manipulated during a game-learning experience. Relatedness support helped participants to improve their performance during the game. All three psychological needs had main effects on a range of outcomes, including positive mood, willingness to recommend the game to others and objective game performance, providing further evidence for the effects of relatedness in an experimental setting.

Aims of This Study

These findings show that SDT as a theory and the effects of its psychological needs are indeed inherent and universal across culture, gender, and time as Ryan and Deci (2000) once claimed. As space agencies are reaching out for Mars, social isolation and social monotony will be some of the hardest psychological challenges astronauts will have to face during their three year mission. Current research shows that these challenges will be accompanied by a number of psychological issues that may affect crewmembers' well-being, performance, and communication with MS. SDT could offer a framework attain a better theoretical understanding and synthesize some of these issues. A better understanding of the effects of relatedness could be applicable to maintain well-being and performance levels, and prevent displacement with MS. And the theory as a whole may furthermore prove its practical utility in supporting future crews in many other ways.

As plentiful the possible advantages may be, to our knowledge, no research has been conducted on the subject of relatedness as a psychological need in space yet. Some space psychology research on SDT has already been conducted, focussing mostly on the possible effects of autonomy in spaceflight (Goemaere et al., 2016). SDT research in general has traditionally focussed more on the role of autonomy. Based on this theory however, one can predict that social isolation from close relationships and the limited number of direct human interactions may also form a major risk for Mars missions. Therefore, more research should be performed to take on the issue of relatedness as a psychological need in space. This study aims to contribute to the field by researching the effects of the need for relatedness on well-being, performance, and displacement in a spaceflight setting. Based on the literature review, three hypotheses were tested.

Hypotheses. *Hypothesis 1: perceived relatedness is positively related to well-being.* The need for relatedness will most likely be thwarted during an interplanetary space mission, and SDT states that all three psychological needs are required for a natural state of well-being. Recent research has supported this theory across multiple domains, reporting more burnouts, school dropouts, and lower life satisfaction when the need for relatedness was thwarted. Therefore we expect that in a space setting too, a lack of relatedness will result in a decrease of personal well-being.

Hypothesis 2: perceived relatedness is positively related to performance. Studies conducted in a professional setting showed an increase in motivation and performance when participants reported higher levels of relatedness and vice versa. Space is an extreme work environment, but it's still a work environment nonetheless. Thus, we expect that a lack of relatedness will also lead to a decrease of performance.

Hypothesis 3: perceived relatedness is negatively related to displacement. During several space missions crew-ground miscommunications were reported when tensions within crew were high. Studies showed that people cope with a decrease in relatedness by avoiding conflict with their peers, and based on previous research on displacement we are led to believe that astronauts displace their negative feelings on more distant individuals such as MS personnel. A lack of relatedness may therefore result in more displacement and thus a higher level of irritation and miscommunication with MS.

Methods

Earlier, we discussed the ISS' limitations to simulate Mars missions and the strengths of simulations, being the only ICE-setting in which we could control all variables to create an experience as similar to a real Mars mission as possible. Therefore, to investigate our research questions, this study focused on a yearlong, ground based Mars simulation funded by NASA's Behavioural Health and Performance program: HI-SEAS IV.

Participants

Meet the crew! The HI-SEAS IV crew was composed of three male and three female subjects (N = 6) and comprised an international mix of scientists from Europe and North-America. Their ages at the start of the experiment ranged from 25 to 36 years old (M = 30, SD = 4). All had a university academic degree and were paid to take part in the experiment. The group consisted of:

- Carmel Johnston, soil scientist and crew commander (USA)
- Tristan Bassingthwaighte, space architect (USA)
- Christiane Heinicke, physicist (Germany)
- Cyprien Verseux, astrobiologist (France)
- Andrzej Stewart, aerospace engineer (UK/USA)
- Sheyna Gifford, crew medical officer and journalist (USA)

Further information about all crewmembers is available on the internet (https://hi-seas.org/?page_id=6157). The crew had six hand-held cameras to record each day and a documentary of the experiment is in the making. The trailer of the film 'Red Heaven' can also be found online (https://vimeo.com/168119640).

Selection and training. Applicants had to be between 21 and 65 years of age and had to meet the basic requirements of the NASA astronaut program. This includes but is not limited to: ability to pass a Class 2 flight physical examination, fluency in verbal and written English, tobacco-free for at least 24 months, a bachelor's degree in a science or engineering discipline, three years of experience or graduate study, and a willingness and ability to eat a wide range of foods. In addition, candidates were evaluated for experience considered valuable to the program, such as work experience in other complex operational environments (e.g., submarine, ambulance, airplane cockpit). For a complete list see Appendix 2.

The first step was an online written application in which applicants were asked about their motivation and relevant skills for the mission. They were also asked to write out a research proposal for the duration of the experiment. The second test was a series of online questionnaires which included cognitive and psychological tests. Pre-screening was carried out by a panel of experts who were familiar with the astronaut selection process. Successful applicants were asked to partake in an interview with two of the managers of the HI-SEAS project.

For the remaining eight, the next selection phase consisted of a week of survival and leadership training in a national park in the US' Rocky Mountains (Grand Teton). The group was dropped in the park and given five days to reach an exit while finding water sources along the way. They were followed by two instructors from NOLS (National Outdoor Leadership School), who provided training and evaluated them. Participants were taught a wide range of skills from conflict-resolution techniques to cooking with shelf-stable ingredients. Every day, two of them were designated leaders. Afterwards the participants were asked to vote anonymously for their preferred mission commander and the final six crewmembers were chosen.

Finally, just as if it were a real Mars mission, on August 29, 2015, the six crewmembers said their goodbyes. And their husbands, colleagues, friends and family whished them well. Leaving them in a hermetically sealed dome for a full year. As soon as the hatch locked behind them, they were six people on Mars. Alone.

Design

Enter the dome. HI-SEAS stands for Hawaii Space Exploration Analog and Simulation. This was the fourth experiment. It was implemented to simulate a yearlong stay on Mars to prepare for future deep space exploration and lasted 365 days, from August 29, 2015, to August 28, 2016. To date, it is the longest NASA funded space travel simulation in history (Gifford, 2016). The experiment facility was located on the island of Hawaii in an isolated position on the slopes of the Mauna Loa volcano at an elevation of 2.500m above sea level. The area has Mars-like features, there's nearly no vegetation, nor animal life, hardly any rain, and the terrain is all bare lava rock. During the experiment, the crew lived in a habitat module (Hab) powered by solar cells. Similar to a real future Mars mission, the building was hermitically sealed. Leaving the Hab was only allowed during Extra Vehicular Activity (EVA), known as 'spacewalks'. Participants had to wear a spacesuit and follow strict protocol when going outside, as shown in Figure 5 (Gifford, 2015).

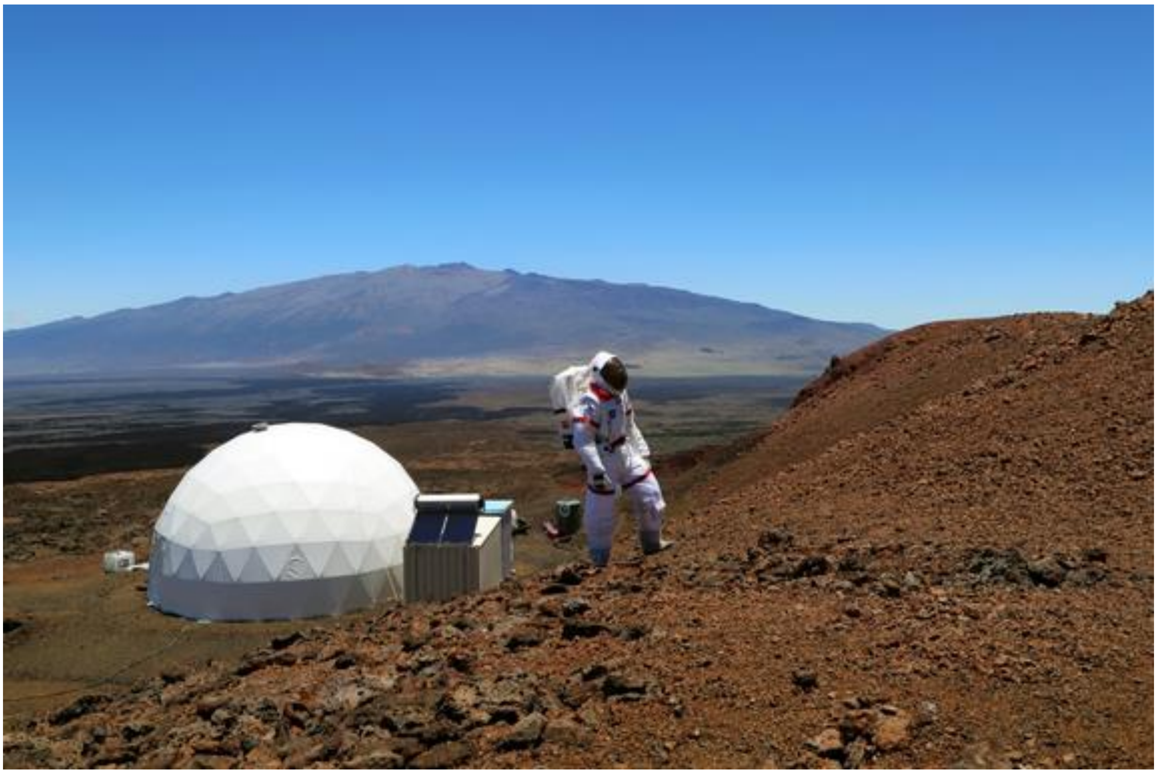


Figure 5. HI-SEAS IV Crew Performing an EVA Outside the Hab*.* Reprinted from *My Blog – Live from Mars* (2015), by S. Gifford. Copyright 2015 by S. Gifford. Retrieved from http://sheynagifford.com/index.php/2015/07/12/my-blog-live-from-mars

The Hab was a dome with a diameter of 11 meters enclosing a volume of 384m^3, comparable to the ISS which has a pressurized volume of 475m^3. Crewmembers entered the Hab through a 15m^2 container that served as an airlock and storage room. The ground floor of the Hab had a kitchen, bathroom, dining area, common work space, exercise area, and a lab. The layout of the interior was open-plan, which was beneficial in that it makes a relatively limited volume appear larger than it actually is. However, this also severely limited privacy as almost all areas were visible from the common workspace, including the second floor sleeping quarters. The plan for the first floor is provided in Figure 6 (Proctor, 2013). The second floor of the Hab included six small separate bedrooms and a washroom. Crew sleeping quarters each had a floor surface of approximate 4m^2 and are depicted in Figure 7 (Proctor, 2013).

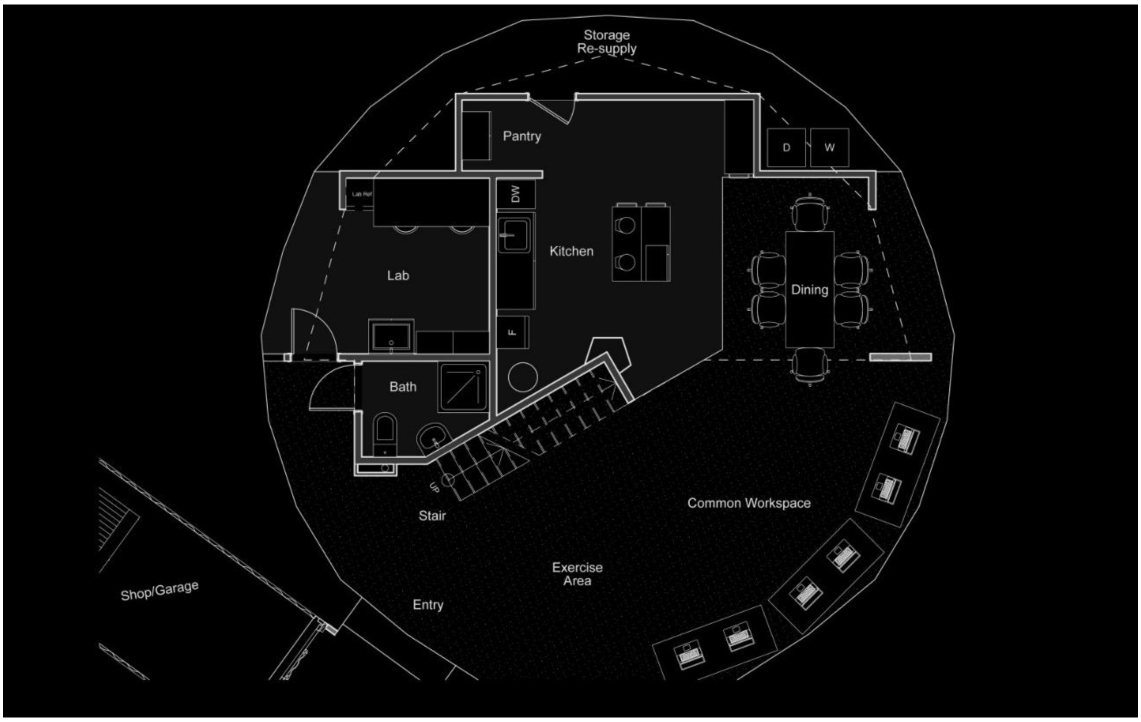


Figure 6. Plan of the Ground Floor of the Hab. Reprinted from *The HI-SEAS Habitat* (2013), by S. Proctor. Copyright 2013 by HI-SEAS, Envision Design LLC, and S. Proctor. Retrieved from https://hi-seas.org/?p=1278

Figure 7. Crew Sleeping Quarters in the Hab. Reprinted from *The HI-SEAS Habitat* (2013), by S. Proctor. Copyright 2013 by HI-SEAS and S. Proctor. Retrieved from https://hi-seas.org/?p=1278

Life on Mars. During their stay in the Hab, participants simulated a yearlong stay on Mars. The setup of HI-SEAS was meant to help with that: supplies were replenished only every few months (food every four months, water every two), they relied on solar power, ate only shelf-stable food, and had to request permission for an EVA and wear spacesuits to go outside. They were geographically and temporally isolated from everyone else on Earth. Stewart (2015): "I'm going to miss the birthday of absolutely everyone on Earth this year, except for my crewmates'". The simulation aimed to make their stay on Mars as similar to what can be expected during a real Mars mission, namely concerning crews' work schedule, daily life, and social interactions.

Participants' work schedules consisted mostly of research. In addition to the many psychological studies they were partaking in as part of the main research, the HI-SEAS researchers also carried out personal studies on a variety of other topics. Crewmembers were running several plant-growth experiments, performed research on drones and bacteria, and tested medical procedures. Aside from research inside the Hab, crewmembers also conducted EVA's twice a week, which took roughly half a day each. In addition to research, their schedule also included a lot of time for exercising. As participants barely had to move outside of EVA's, exercise was not only part of the simulation but also critical for their own physical and mental health, and was therefore mandatory. "Crew has nothing to fear but Carmel [crew commander] on abs day… which is every day" (Johnston, 2015).

This did not leave the crew with much leisure time during their daily life on Mars. When they had time off, they tried to fill it meaningfully with either some private activities away from the group (e.g., reading, playing music, and drawing) or group activities to increase cohesion. Crew installed a rotation system for cooking and had a board game night and a movie night on most weeks. Nonetheless, during their yearlong mission, eventually, boredom struck. "I think that the main reason for this hazy perception of time is the lack of variation. We are always in the dome, or in the lava fields around. Always with the same people. We take, always at the same times of the day and the same days of the week, the same tests. In spite of some of my crewmates' efforts, our food always has this typical, salty note of shelf-stable food." (Verseux, 2016). Some crewmembers tried to relief boredom by starting a band together, learning a new language, or dancing salsa. Three of them even ran a marathon on the treadmill inside the Hab. "Fortunately, in spite of a daily monotony, unusual events happen that mark the passage of time. [...] Here, rather than in weeks or months, time is measured in earthquakes, celebrations, technical failures." (Verseux, 2016). Similar to astronauts in space, the HI-SEAS crew also celebrated birthdays and holidays. Usually with a nice meal, a card, and gifts. Some of the crew members brought a few generic presents beforehand to offer as birthday gifts, others handcrafted presents themselves. The crew also celebrated their own special occasions, such as the halfway point, and the 300th mark day of their mission.

Communication with "Earth" was very restricted. As this was a Mars simulation mission, an important part of the experiment was isolation. During their yearlong stay in confinement, the crew was socially isolated from all other humans on Earth. There was no visiting crew and because of an artificial 20 minute one-way communication delay, no live video conferences or phone calls were possible, exactly as one would expect during a Mars mission. Contact with their friends and family was only possible via e-mail "when they remember to write back, the neglectful devils" (Bassingthwaighte, 2016) and the occasional one way video message during the holidays. Internet access was also severely restricted. Crewmembers had access to an extremely limited set of websites necessary to the mission (e.g., websites hosting surveys) and for safety purposes (e.g., weather.gov), all without live interaction. This also means crew had no access to their social media profiles (contrary to astronauts in the ISS). If they wanted to retrieve journals for their research or post on their social media accounts, they had to rely on MS to do so. Interestingly, all six crew members chose to run a personal blog instead. The crew journalist even had two blogs, a personal and an official one. However, their blogs too were buffered by MS.

Participants were further constantly confined with their fellow crewmates. The six crewmembers spent the whole year together, never more than a few metres apart. They shared the same bathroom, communal kitchen, communal workspace, etc. There was no way to escape each other's constant presence but they also only had each other to rely on. During their stay, the crew was challenged in many ways. Three months into the experiment for example, the Paris attacks occurred (November 13, 2015). One of the crew members lived in Paris at that time, but could not reach his friends and family due to the artificial time delay. Some crew members had to deal with bad news from their families, the crew medical officer had to do a small wart removal surgery, and the team had to cope with an unplanned communications blackout and a failing water pump. Crew members further went through several periods of group tensions and interpersonal conflict. Luckily, similar to real spaceflight missions, they could count on MS.

Mission support. "Good morning crew! How are you doing? I am available to you for the next 4 hours, let me know how I can help you. FTS Lucie signing on!"(Heinicke, 2016a). MS for HI-SEAS IV consisted of four separated units. The First Tier Support (FTS) was available from 8am until 8pm in three four hour shifts. This group consisted of 20 volunteers from all over the world. FTS monitored the Hab's life support and crew could contact them with various requests such as retrieving journal papers, a movie, or updates on the news. Sometimes they just had a friendly "chat" together through delayed e-mails. Crew further had to submit EVA requests to FTS if they had to go outside. When there was a pause of more than two hours without hearing from the crew, FTS asked for a communication check.

Second Tier Support (STS) consisted of primary members of the HI-SEAS project. STS had more decision-making authority regarding the mission and had to be consulted for any non-routine issues. STS was on call 24 hours per day and seven days per week if the crew or FTS felt that their intervention was necessary.

Also part of MS were medical support and engineering support. Medical support consisted of an emergency medicine physician and a psychologist, with backup physicians and first responders located in Hawaii. Engineering support was a group of technical experts who helped design and construct the Hab. They were available to troubleshoot problems and furthermore coordinated resupply drops.

Ethical questions. All crewmembers learned the content and procedure of this study and gave their written informed consent before isolation. Of course, during their confinement, crewmembers were allowed to step out of the experiment at any time. Afterwards, private counselling sessions were scheduled in the first week after the experiment.

During the mission, crew could rely on sincere support from MS, and social interactions were not manipulated for the sake of the experiment. Medical support had a psychologist on standby, who provided the crew with teambuilding exercises when interpersonal conflicts occurred. Engineering support members provided advice and solutions when the Hab suffered from technical problems. MS further developed a protocol in case of unresponsiveness from the crewmembers, which could eventually lead to a mission shutdown. In case of emergency, crew was given emergency communications – a simple phone. Albeit isolated in a lava desert, Hawaiian ambulances and the crew's personal medical support team were just a phone call away.

Measures

Strengths and limitations of surveys. As discussed earlier, this research aimed to study the relationship between crewmembers' perceived relatedness (social isolation), well-being, performance and displacement (blaming mission support). To do so, during their yearlong confinement, we asked participants to fill in several questionnaires inquiring their mental health, the quality of their contact with MS, perceived relatedness with crewmates, etc.

Questionnaires are often praised because of their cost-effectiveness, reliability and anonymity (Kumar, 2011). During this experiment, subjects participated in several psychological studies from 12 different institutions, thus surveys were also convenient and time-efficient, and participants enjoyed some freedom to choose when and where to answer the questionnaire. In this study, the use of surveys was particularly valuable since they could be conducted remotely. Surveys are not limited to geographical and temporal proximity, making it possible to reach out to these subjects who were isolated from the rest of the world.

However, questionnaires are also often criticized. In general, surveys have a low response rate. This was countered for, we believe, because of the extremely high motivation of the subjects and the fact that the subjects were paid to partake in the experiment (and confined to a 100m^2 plastic dome). Another weakness is that questionnaires consisting of only Likert scales can be rigid and lack the opportunity to clarify issues or supplement responses with further information. Therefore, a qualitative, open answer field was included at the end of each weekly survey, inquiring respondents about their experiences with co-workers outside the station. This provided some more flexibility. For instance, when intra-group tensions were high, some participants used this field to express their emotions about their co-workers inside the station instead.

A disadvantage of self-report scales in particular is that respondents may not feel comfortable presenting themselves in an unfavorable way (Fisher, 1993). This effect is mostly countered by the great anonymity surveys allow for, however as closely as these subjects were observed and accounting for their high aspirations (several crewmembers applied for the astronaut training program), the effects of social desirability may have influenced our results. To further minimalize social desirability effects, we cross-validated some of the answers given by the crew with the more objective assessment of the crew commander.

Variables and measurements. Since we didn't manipulate our variables directly (we didn't artificially stimulate conflict or fabricated distant emails from home), we cannot make causal statements about the relationships between them. Therefore we will use the terms predictor variable and outcome variable. Unless stated otherwise, all items measuring these variables were scored on a weekly basis, using a 5-point Likert scale ranging from 1 *strongly disagree* to 5 *strongly agree* (Likert, 1932).

Relatedness. Relatedness is considered a predictor in this study and was conceptualised by two variables. 'Relatedness with crew' measured the level of perceived relatedness towards fellow crewmembers in the Hab. 'Relatedness with home' measured the level of perceived relatedness towards friends and family at home.

Relatedness with crew was measured using the Intrinsic Motivation Inventory (IMI). The IMI (Ryan, 1982) is a multidimensional measurement grounded on SDT used for assessing the subjective experiences of participants when partaking in an activity. The original test contained 27 items and of these we only used the seventh subscale with 4 items measuring the experience of relatedness. Due to their generic substance, the individual items can be modified slightly to fit specific activities (McAuley, Wraith, & Duncan, 1991). A recent study, for instance, adapted the IMI to a context of first language and mathematics learning and also found satisfactory reliability scores (Monteiro, Mata, & Peixoto, 2015). Similarly, we adapted several items from the relatedness subscale of the IMI. "I felt really distant to this person" for example, was changed to "I felt my fellow crew-members acting distant toward me". The full list of adapted IMI items can be found in Appendix 3. We found an internal consistency (Cronbach's alpha) of .89 for the four items measuring relatedness with crew.

Relatedness with home was also measured with the IMI. Again, crew was asked to answer four adapted items. An example of these items is: "I felt my friends and family at home acting distant towards me" and the full list of IMI adapted items used in this study can be found in Appendix 3. An internal consistency of .90 (Cronbach's alpha) was found for relatedness with home.

Well-being. To conceptualise well-being, two outcome variables were measured. 'Happiness assessed by commander' measured crewmembers' happiness as perceived by the crew commander. And 'Stress and frustration assessed by commander' measured crews' stress and frustration levels, also evaluated by the commander.

Happiness was measured by asking the commander to appraise crew-members' happiness using the following item: "My fellow crew-member seemed happy or satisfied". Once again, by cross validating the self-report scales of the crewmembers with an external observations by the commander, we aimed to increase objectivity and reduce the effects of social desirability.

Stress and frustration was assessed by asking the commander to evaluate crewmembers' stress/frustration levels, using the following item: "My fellow crew-member seemed stressed-out or frustrated".

Performance. Performance was conceptualised by the outcome variable 'performance assessed by commander'. This variable measured crewmembers' performance levels appraised by the commander.

Performance was again measured by the commander. She objectively evaluated each crew-member's performance level using the following item: "My fellow crew-member performed well in the fulfilment of his or her duties".

Displacement. We conceptualised displacement by three outcome variables. The variable 'irritation with MS' measured crew's irritation level towards ground control personnel such as FTS and STS. The outcome variables 'cooperation with MS' and 'cooperation with MS assessed by commander' measured nearly the opposite, namely how well crewmembers cooperated with their fellow HI-SEAS colleagues outside the Hab.

Irritation with MS was measured using the resentment scale. The original version of this scale was developed by Assor, Roth and Deci (2004) to measure respondents' resentment towards their parents. In this study we adapted our irritation items from the resentment scale. For example, "As a child or adolescent, I often felt very angry with my mother (father)" was adapted to "I felt angry with my co-workers' [outside the station] working methods". Our adapted scale contained four items for which we found an internal consistency (Cronbach's alpha) of .92. A complete list of all adapted items can be found in Appendix 4.

Cooperation with MS was measured with a self-developed self-report scale consisting of four items. We found an internal consistency (Cronbach's alpha) of .88 for this. One example of the items is: "I felt the cooperation with my co-workers [outside the station] went smoothly". For a complete list, see Appendix 4.

Cooperation with MS assessed by commander was measured by asking the commander to evaluate each crewmember's level of cooperation with MS using the following item: "My fellow crew-member got along well with co-workers outside the station".

Procedure

During their yearlong confinement to the Hab, crewmembers were asked to fill out the questionnaires independently as a part of the HI-SEAS experiment. They did so every week, preferably on Sunday evenings. Questionnaires were part of a longer survey and were provided through Qualtrics, a website without live interaction that participants were allowed to use because of the necessity for the mission. Completion of the extensive questionnaire took between 10 and 20 minutes, and was to be filled out by all crewmembers (including the commander). A second survey was aimed only at the crew commander and took about five minutes to complete. It contained questions measuring the variables assessed by the commander, as discussed previously.

Statistical Analysis

The entire HI-SEAS IV experiment lasted 365 days, during which we received data from 48 weeks. In longitudinal research, data collected at different times is nested within each study subject (Osborne, 2000; Raudenbush & Bryk, 2002). This means that because our data consisted of observations from several measure points (weeks) from the same six participants, the data were not independent from each other.

Only one participant however filled out the whole questionnaire for the duration of the entire 48 weeks. Three participants filled out 47 weeks of surveys and two of them considerably less (42 and 43 weeks). This resulted in a total of 274 measure points between all six crewmembers. Additionally, variables that consisted of items assessed by the commander (concerning well-being and performance), did not include the commander's own data. Therefore, these variables were analysed based on the results of only 230 observations. This provided us with several statistical challenges: longitudinal data nested in subjects, assumption of independence violated, and missing data.

Therefore, the implementation of hierarchical linear modelling (HLM) was required. HLM demands fewer assumptions to be met than other statistical methods and can easily account for non-dependence in hierarchically structured data, such as the subjects in which our data are nested. It further provides an elegant solution for missing data, which allowed us to include as many of the observations as possible. The term HLM may be somewhat confusing since this statistical method has come to be known by several names, including multilevel-, mixed level- and random effects-modelling (Raudenbush & Byrk, 2002). HLM is also the name of the software we used to analyse these data, we will refer to it as HLM7.

The hierarchical linear model. In HLM, each Level-1 unit (e.g., perceived level of relatedness at a certain time) is identified by its Level-2 cluster (crewmember) in which it is nested. Thus our model was specified by two levels. Level-1 consisted of the repeated measurements that were conducted weekly, and level-2 consisted of the crewmembers in which these observations were nested. Using HLM, both within- and the between-group regressions were taken into account to interpret the relationship between the variables (Woltman, Feldstain, Mackay, & Rocchi 2012).

Longitudinal hierarchical linear models are typically organized by the following equation: $Y_{ij} = \gamma_{00} + \gamma_{10}X_{ij} + \gamma_{01}G_j + \gamma_{11}G_jX_{ij} + U_{1j}X_{ij} + U_{0j} + r_{ij}$. In which Y_{ij} represents the outcome variable measured for the *i*th Level-1 observation, nested within the *j*th Level-2 subject. γ_{00} is the overall intercept. X_{ij} refers to the value of the Level-1 predictor for the *i*th observation in the *j*th subject and γ_{10} represents the regression coefficient of X_{ij}. G_j represents the value of the Level-2 predictor in the *j*th subject with γ_{01} as its regression coefficient. $\gamma_{11}G_jX_{ij}$ is a cross-level term and the tail represents the composite error of the model, which shows the discrepancy between the fitted model's predictions and the actual data points.

This study wished to investigate the effects of relatedness with crew and relatedness with home, therefore both predictor variables were included in the model as Level-1 predictors. Since we were not interested in the direct effects of any Level-2 subject predictors, we did not insert a Level-2 variable in our model. However, we did wish to account for the effects of nesting, thus u_0 stands for the random effects of the Level-2 predictors. This resulted in an equation that applies to all mixed models for each outcome variable in this study: $Outcome\ variable = \gamma_{00} + \gamma_{10}(relatedness\ with\ crew) + \gamma_{20}(relatedness\ with\ home) + u_0 + r$. The basic equation for the observation-level (Level-1) reads: $Outcome\ variable = \beta_0 + \beta_1(relatedness\ with\ crew) + \beta_2(relatedness\ with\ home) + r$ and for the subject level (Level-2): $\beta_0 = \gamma_{00} + \gamma_{01}(relatedness\ with\ crew) + \gamma_{02}(relatedness\ with\ home) + u_0$; $\beta_1 = \gamma_{10} + \gamma_{11}(relatedness\ with\ crew) + \gamma_{12}(relatedness\ with\ home) + u_1$; $\beta_2 = \gamma_{20} + \gamma_{21}(relatedness\ with\ crew) + \gamma_{22}(relatedness\ with\ home) + u_2$.

Implementation of the model. Questionnaire data were analysed using HLM software (Version 7) and initial descriptive analysis was done with SPSS (Version 23). Initial exploration of the data served to obtain descriptives of our Level-1 variables and how they correlated to one another, and was aggregated between subjects. To further study the effects of the predictor variables of relatedness on the outcome variables of well-being, performance, and displacement in HLM7, we entered these variables at Level-1. Since we also needed to account for the dependency of the observations within subjects, subject grouping was included here as ID. As Level-2 variables we again specified subject as ID and also included gender in the model. Although we were not interested in the effects of gender, the HLM7 software requires at least one Level-2 predictor to run. We further specified that our data was longitudinal and contained missing observations. In HLM7, observations with missing data are deleted using listwise deletion. By specifying to do so only when the analysis is run, this deletion was performed based on the variables included in the actual model rather than excluding entire records each time a value was missing.

Once the model was computed, we specified full maximum likelihood as the method of estimation of variances. Full maximum likelihood produces a more accurate estimate of the fixed regression parameters compared to restricted maximum likelihood (Field, 2009) because it assumes that the fixed parameters are known with certainty when estimating the variance parameters (Duchateau, Janssen, & Rowlands, 1998). Our hypotheses focused on these fixed effects of the Level-1 variables, rather than on estimating variances of the random effects. Therefore, full maximum likelihood was chosen.

To reassure ourselves that there was indeed even need for HLM, we examined whether the data were in fact hierarchically structured, i.e. whether observations within individuals were more similar than observations between individuals. This was done by estimating the variance components of the intercept only model for each outcome variable under the following equation: $outcome\ variable = \gamma_{00} + u_0 + r$. *P*-values smaller than .001 were found for all outcome variables (as shown in Table 1), indicating that each of them consisted of hierarchical data, as we suspected. Thus, the implementation of HLM was required.

Table 1
Variance Components of the Intercept Only Model for All Outcome Variables

	σ^2	*df*	χ^2	*p*
Happiness assessed by commander	.36	4	277.65	< .001
Stress and frustration assessed by commander	.50	4	266.18	< .001
Performance assessed by commander	.02	4	18.84	< .001
Irritation with MS	.05	5	26.01	< .001
Cooperation with MS	.30	5	265.01	< .001
Cooperation with MS assessed by commander	.09	4	83.13	< .001

Finally, to test our hypotheses, in each analysis a separate outcome variable was selected as the only variable on the left-hand side of the Level-1 equation, and the predictor variables relatedness with crew and home were added in the model. Predictor variables were group mean centred. In general, interpretation is more reasonable using centred predictors as compared with using uncentred predictors (Enders & Tofighi, 2007). Group mean centring was chosen because a pure Level-1 effect was desired, without considering fixed effects of Level-2 variables.

Results

Descriptive Analysis

Means, standard deviations and correlations between all variables (aggregated between subjects) are shown in Table 2. Albeit not yet accounted for nesting, these descriptives offer a first overview of the data. Relatedness with crew was significantly positive related with happiness, performance, and cooperation with MS, but negatively with stress and frustration. Relatedness with home on the contrary was negatively related with happiness and positively with stress and frustration, as well as with irritation with MS. For a more detailed inspection of our hypotheses, hierarchical analyses of the data were needed.

Table 2

Descriptives and Correlations for All Variables

	M	*SD*	*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*
1. Relatedness crew	3.48	0.96	-						
2. Relatedness home	3.59	0.98	.32***	-					
3. Happiness^a	3.67	0.82	.66***	-.24***	-				
4. Stress and frustration^a	2.55	0.97	-.58***	.26***	-.78***	-			
5. Performance^a	3.93	0.63	.44***	-.12	.55***	-.39***	-		
6. Irritation with MS	2.08	0.84	.02	.14*	-.17*	.16*	-.17*	-	
7. Cooperation with MS	3.63	0.77	.51***	-.10	.57***	-.48***	.34***	-.46***	-
8. Cooperation with MS^a	3.90	0.61	.43***	-.10	.77***	-.55***	.51***	-.13	.43***

^{a}Assessed by commander. All other variables were self-report by crew members.

**p* < .05, ** *p* < .01, ****p* < .001.

Well-Being

According to our first hypothesis, we expected that perceived relatedness would be positively related to well-being. In this study, the influence of relatedness on crewmembers' well-being was tested by measuring the effects of the predictor variables RCREW (relatedness with crew) and RHOME (relatedness with home) on the outcome variables HAPCOM (happiness assessed by commander) and STRESCOM (stress and frustration assessed by commander).

Outcome variable 'happiness assessed by commander'. We found that RCREW was a significant and positive predictor of HAPCOM ($b = .40$, $t(212) = 3.02$, $p < .01$), which shows that a higher perceived relatedness with fellow crewmembers is associated with higher levels of happiness. The effect of RHOME on HAPCOM however, was non-significant (*b* = .05, *t*(212) = 0.70, *ns*), providing no evidence that relatedness with home is positively related to happiness.

Outcome variable 'stress and frustration assessed by commander'. The results showed that RCREW was a significant and negative predictor of STRESCOM (*b* = -.36, *t*(212) = -10.31, *p* < .001), which shows that higher levels of relatedness with crew are related with lower levels of stress and frustration. We also found that the effect of RHOME on STRESCOM was significant and negative (*b* = -.22, *t*(212) = -5.21, *p* < .001). This indicates that a higher perceived relatedness with home also equals lower levels of stress and frustration.

Performance

Our second hypothesis stated that we expected a positive relationship of relatedness and performance. We researched the effects of relatedness on performance by studying the effects of the predictor variables RCREW (relatedness with crew) and RHOME (relatedness with home) on the outcome variable PERFCOM (performance assessed by commander).

Outcome variable 'performance assessed by commander'. The results showed that RCREW was indeed a significant, positive predictor of PERFCOM (*b* = .45, *t*(212) = 9.96, *p* < .001), which indicates that a higher level of perceived relatedness with fellow crew results in higher performance levels. The effect of RHOME on PERFCOM was non-significant (*b* = -.05, *t*(212) = .70, *ns*), providing no evidence that relatedness with friends and family at home leads to higher productivity.

Displacement

In our third hypothesis, we stated that perceived relatedness is negatively related to displacement. In this study, relatedness was conceptualised by the predictor variables RCREW (relatedness with crew) and RHOME (relatedness with home), and the concept of displacement was studied through the following three outcome variables, IRRI (irritation with mission support), COOP (cooperation with mission support) and COOPCOM (cooperation with mission support assessed by commander).

Outcome variable 'irritation with mission support'. We found that RCREW was a significant, negative predictor of IRRI (*b* = -.33, *t*(266) = -8.10, *p* < .001), which shows that perceived relatedness with crew is negatively related with irritation with MS. The effect of RHOME on IRRI was non-significant (*b* = -.13, *t*(266) = -1.00, *ns*), which indicates that the effect of relatedness with friends and family at home does not significantly influence the level of irritation with MS.

Outcome variable ‘cooperation with mission support’. The data showed a significant, positive effect of RCREW on COOP (b = .45, t(266) = 5.39, p < .001), indicating that higher levels of relatedness with fellow crewmates result in better cooperation with MS. No significant effect of RHOME on COOP was found (b = -.01, t(266) = -0.07, *ns*), which shows that relatedness with home did not influence cooperation with MS.

Outcome variable ‘cooperation with MS assessed by commander’. We found that RCREW was a significant and positive predictor of COOPCOM (b = .17, t(212) = 2.31, p < .05), which provides further evidence that a higher relatedness with crewmembers results in better cooperation with MS. The results also showed a significant, positive effect of RHOME on COOPCOM (b = .09, t(212) = 2.68, p < .01), indicating that relatedness with home leads to higher levels of cooperation with MS.

Summary

The results of our HLM analyses are summarized below in Table 3. They show that relatedness with crew was a significant and positive predictor of happiness, performance and cooperation, and was a negative predictor of stress and frustration. Relatedness with home was only a significant, positive predictor of cooperation (assessed by the commander) and a negative predictor of stress and frustration.

Table 3

Effect Sizes of RCREW and RHOME on All Outcome Variables

	HAPCOM	*STRESCOM*	*PERFCOM*	*IRRI*	*COOP*	*COOPCOM*
RCREW	.40**	-.36***	.45***	-.33***	.45***	.17*
RHOME	*ns*	-.22***	*ns*	*ns*	*ns*	.09**

*p < .05, ** p < .01, ***p < .001.

Discussion

Main Findings of This Study

Research findings. Regarding our first hypothesis, *perceived relatedness is positively related to well-being*, the results show that crewmembers are indeed happier and experience less negative emotions when they report a better relationship with their fellow crewmates. When they report to feel closer to their family and friends at home, crewmembers experience less negative emotions and aren't noticeably happier. Overall, these findings support our hypothesis. While confined to Mars-like living quarters, the crew's well-being is positively affected by their relatedness with fellow crewmembers and friends and family outside.

Considering our second hypothesis, *perceived relatedness is positively related to performance*, the results of this study show that when crewmembers feel more related to their fellow crewmates, they perform noticeably better on their work projects. Feeling close to family and friends at home, does not influence crew performance. Thus, crewmembers' performance is positively affected by relatedness with their fellow crewmembers, supporting our hypothesis.

Finally, in regard to our third hypothesis, *perceived relatedness is negatively related to displacement*, the results show that when crewmembers feel closer to each other, they are less irritated with MS. Feeling more relatedness towards friends and family at home does not change irritation towards outside personnel. This indicates that only the perceived relationship with fellow crewmates impacts crewmembers' irritation with MS. Moreover, when crewmembers report a better relationship with their fellow crewmates, they are more likely to cooperate well with MS. When they feel close to their family and friends, crew is also more likely to cooperate well with MS, but only when cooperation is evaluated by an external observer such as the crew commander. In general, these findings provide support for our hypothesis, crewmembers cooperate better with MS and show less irritation towards MS when their need for relatedness is satisfied.

Explanations in relationship to previous research. Existing research supporting the effects of relatedness on well-being and performance is manifold. In the literature review we discussed how Ryan and Deci (2000) proposed relatedness as a psychological need. Ever since then, research covering multiple domains has provided evidence to support this theory. Cerasoli et al. (2016) and Van den Broeck et al. (2016) confirmed the effects of relatedness on well-being and performance in recent meta-analyses. This study's findings, namely that crewmembers show increased well-being and better work performance when they report higher relatedness, are in line with their conclusions.

Moreover, we have extended our knowledge on the topic by replicating these results in a spaceflight setting. When socially isolated and confined to small living quarters for a prolonged period of time, crewmembers' well-being and performance are positively influenced by perceived relatedness, particularly with their fellow crewmembers and less so with their friends and family at home.

A rather unexpected outcome of this study is that the relatedness with home doesn't affect crewmembers' happiness, even though it does affect how much stress and frustration they experience. Since both happiness and stress and frustration are assessed by the crew commander in this study, this indicates that the commander was able to notice the negative effects of relatedness on her crewmembers' well-being, but not the positive effects. Research shows that this is a common occurring phenomenon, called negativity bias, or negativity dominance (Baumeister, Finkenauer, & Vohs, 2001; Rozin & Royzman, 2001). Even when of equal intensity, things of a more negative nature have a greater effect on people's psychological state. Moreover, negative information is generally more heavily weighted when participants are tasked with forming evaluations and impressions of other target individuals, exactly as was asked of the commander during this study (Ito, Larsen, Smith, & Cacioppo, 1998; Hamlin, Wynn, & Bloom, 2010). Additionally, from our data we know that several conflicts occurred. It's possible that positive news from home was less of a conversation topic between crewmembers and was overshadowed by group tensions, or crew kept this kind of intimate e-mails more private (from the commander). Further inspection of our data shows that the commander generally self-reported lower levels of relatedness with crew than her fellow crewmembers did. Perhaps, had she been socially closer to her crewmates, she would have better noticed the effect of positive relatedness with home on her crewmates' well-being.

Similarly, it can be explained why crewmembers' performance in this study isn't affected either by relatedness with family and friends at home. It is possible that negativity bias, group dynamics and social closeness again play a role here, since performance is also assessed by the crew commander. However, albeit theoretically well grounded, both explanations will require further research.

In previous work, displacement was described as a concept according to which high crew tensions were projected towards more distant groups such as MS (Kanas, 2014). Our research results are consistent with these findings. Crewmembers show less irritation with MS when they feel closer to their fellow crewmates, but their relationship with home does not influence their irritation towards MS. These results indicate that only relatedness with crew predicts irritation with MS. In other words, only group tensions are a positive predictor of irritation with ground control personnel. When perceived relatedness with fellow crewmembers is low, irritation with co-workers outside is more likely to occur. Similarly, our results illustrate the effects of relatedness on how well crewmembers cooperate with MS. A better relationship with fellow crewmembers, equals better cooperation with MS. Their relationship with family and friends however, does not or only barely affects crewmembers' cooperation with MS. These results are consistent with the definition of displacement as proposed by Kanas and Feddersen (as cited in Kanas 2014) in their original research.

Implications

Theoretical implications. Within SDT, our findings support the importance of relatedness as a psychological need. Relatedness shows to have a positive impact on well-being and performance on crewmembers in ICE-settings. Thus, we may now add that the effects of this psychological need as presented in SDT are inherent and universal across culture, gender, time, *and space* (Ryan & Deci, 2000).

Furthermore, these results provide evidence that confirms the existence of displacement in spaceflight crews. When crewmembers perceive higher levels of relatedness, they are less likely to show displacement towards MS. This is mainly the case when crewmembers report a good relationship with their fellow crewmates, perceived relatedness with friends and family nearly didn't influence displacement. This supports the idea that displacement is caused by intra-crew tensions (Kanas, 2014).

Practical applications. Our findings show that amongst others, more attention should be given in practice to improving the relationship between fellow crewmembers. During our experiment, we found that when crewmembers feel more related to their fellow crewmates, they show improved well-being, better work performance, and less displacement towards MS. Therefore, we feel that the need to employ and develop proven (counter)measures has been demonstrated once again. It is clear that the psychological need for relatedness with crew should be nurtured and actively taken care for. We would like to advocate for more focus on pre-emptive measures to maintain good intra-crew relationships. For a discussion of existing countermeasures, we refer back to our literature review.

This study also confirms the importance of relatedness with friends and family at home. Crewmembers in confinement experience less stress and frustration and cooperate better with MS when they feel closer to their loved ones at home. Albeit definitely a huge challenge because of the geographical and temporal isolation, space agencies should aim to find new ways to nurture the need for relatedness with friends and family during long-term spaceflight and employ as many of the existing counter measures as discussed previously.

Space agencies should further deploy countermeasures to deal with the effects of miscommunication such as displacement. In their research, Kanas and Manzey (2008) discuss possible ways to effectively counter displacement. They suggest astronauts and MS staff members should learn to identify causes of intra-group stress and learn strategies to cope with them directly. They also advise that both groups are given time during the mission to self-monitor their emotions and group interactions, so both MS and flight crew can pick up on early signs. Crew will need to learn to aim their critiques towards people inside the spacecraft who are the cause of their frustrations, this in a constructive manner.

Strengths and Limitations

The results of this study should be interpreted with care, since they are based on only a small number of participants. Furthermore, during the experiment, many aspects of a Mars mission were simulated, but many others were simply impossible, dangerous, or excessively expensive to simulate. For example, crew was still exposed to Earth gravity, as well as Earth levels of radiation. Ground based simulations in general aren't able to study the physiological effects of low gravity and space radiation environments on astronauts. And even though crew had to wear simulated spacesuits, they knew there was breathable air outside. Thus, during this experiment the psychological effects of the dangers of operations in vacuum couldn’t be studied either.

However, NASA has the data of 135 space shuttle missions (NASA, n.d.-b) and Roscosmos has had cosmonauts in space almost continuously since 1986. This study doesn’t focus on the physiological challenges of a Mars mission. For that, there’s missions such as Scot Kelly’s and Mikhail Kornienko’s year in space. HI-SEAS IV’s design focused on simulating the effects of social isolation of a Mars mission. This is where some of this study’s greatest strengths lie. The HI-SEAS IV experiment was one of the most realistic and longest Mars simulations ever conducted. Crewmembers were confined to the Hab, had to suffer communication delays and lived their lives as if they were on a real Mars mission. “From a psychological point of view, our living conditions were very realistic […]: We were isolated, in a restricted and extreme habitat. We were and felt far removed from everything, properly detached. We were on our own, for forty, four thousand, or four hundred million kilometres.” (Heinicke, 2016b). Because of the highly realistic design of the experiment, we can assume a high external validity of our results.

Other strengths of this study include our data collection; our results are acquired through data gathered from 48 consecutive weeks' worth of questionnaires, which covered nearly the whole duration of the mission. Many other studies in the field that use data from Mars simulations and analogs did not have this opportunity, and only collect data during a part of the mission (e.g., Van Baarsen, 2013), have fewer measure moments (e.g., Solcova, Lacev & Solcova, 2014), or are based on much shorter missions (e.g., Groemer et al., 2016). Using HLM, this kind of longitudinal data allows us to account for intra-individual effects, and thus finding more reliable results. This study could furthermore rely on a strong theoretical foundation provided by SDT. The results we found are expected based on earlier ground-based research and have a proven and well tested macro theory on human behaviour backing them. SDT further allows us to synthesize our findings into bigger constructs, offering an explanation for some earlier documented phenomena.

As discussed earlier, a last limitation may lie in the manner in which we measured some of our variables. By relying on a rather simple assessment of the commander of some outcome variables such as performance and well-being, we are left with doubts about the effects of relatedness with home. We chose to focus on the commander's evaluation to reduce the effects of social desirability but are now faced with the effects of negative bias. We also found little variance of the commander's answers for some of our variables. It is possible that the commander felt unsure about how well her crewmembers performed or perhaps a high workload prevented her from taking more time to think about the answers. Nonetheless, a wider choice of measurements might have provided us with more significant results and will prove to be an interesting development for further research.

Suggestions for Further Research

The application of SDT to spaceflight opens a plethora of possible research questions. The theory may prove to be a much needed framework, which can organize several seemingly unrelated psychological issues of long-term spaceflight under bigger constructs. In this research, we only studied the effects of the psychological need for relatedness, but one can imagine that further research may soon show significant results for the other psychological needs in SDT, such as competence and autonomy. We advocate for a richer exploration of SDT applied to spaceflight to improve our understanding of the psychological challenges of spaceflight and develop future countermeasures. It would be interesting to investigate whether some of the effects and countermeasures studied in the work, education and sports domain can be replicated in a space setting.

Previously, in the literature review, several already existing countermeasures regarding relatedness were discussed. Some of these countermeasures were applied during the HI-SEAS experiment: crewmembers celebrated Earthly holidays and mission landmarks together, they partook in training together before the start of the mission, and regularly received news from home. Nonetheless, group tensions still occurred and crew reported descending levels of relatedness with their friends and family at home. Future research should aim to develop new countermeasures improving relatedness, applicable to interplanetary spaceflight with communication delays.

Future research addressing a better understanding of relatedness could further aim to include the effects of internet blogging on relatedness with friends and family at home and planet Earth in general, but also the relationship between blogging and relatedness with crewmembers; since all six crewmembers of the HI-SEAS IV experiment decided to run a blog to compensate for live social interactions during their yearlong confinement. Another intriguing topic on this subject is whether the use of e-mail as a communication medium restricts the proper satisfaction of the need for relatedness. E-mail doesn't provide crewmembers with visual or auditory feedback and sometimes leads to miscommunication and unresponsiveness from family and friends or co-workers. Future research could aim to further understand the effects of e-mail on relatedness with home and study possible improvements and alternative communication options. Additionally, research on the subject of relatedness could further explore the effects of leadership on relatedness in space settings and how being in command effects perceived relatedness with fellow flight crew.

On the subject of displacement, we could ask ourselves what the impact of projected (and thus unjustified) irritation is on MS personnel. Could there be a pattern where displacement effectively leads to less support from ground personnel? We discussed that as onboard interpersonal crew tensions rise, they lead to a perceived lack of support from mission support, thus resulting in feelings of displacement and irrational frustration with MS. Several studies (e.g., Kanas et al., 2007) already found that MS personnel displayed signs of displacement towards outside supervisors. It does not seem unlikely that this projected irritation from space crew could also lead to ground personnel showing less empathy and less support for flight crew. Further countermeasures regarding displacement should also be developed and tested in various ICE- or space settings. It would furthermore be interesting to study whether countermeasures regarding the psychological need for relatedness also effect displacement.

Conclusion

Space is a vast and lonely place. During future interplanetary missions, astronauts will find themselves to be the most geographically isolated humans in history. Moreover, they will be confined with their fellow crewmates to extremely small living quarters for a prolonged period of time, possibly years, without live interaction with other people. These astronauts will feel lonely and crowded at the same time. According to SDT, the psychological need for relatedness with others will be severely thwarted during long-term journeys such as a Mars mission. Based on data from a yearlong Mars simulation, our results show that relatedness has a significant impact on crewmembers well-being, performance, and displacement towards MS, opening the doors for more research based on SDT in a spaceflight setting. As a species, interplanetary travel will be a multi-disciplinary challenge. It is not only rocket power that will get us there. Careful consideration and understanding of the psychological issues that are associated with this undertaking will surely prove to be beneficial. In the words of the HI-SEAS IV crew medical officer, Sheyna Gifford (2016): "a crucial lesson from sMars [the experiment] is that technology is the lowest common denominator. Mechanical solutions for getting a crew there and back alive will take shape as time and money allow. What cannot be engineered is people." It's true, we cannot engineer people, but we can aim to understand them in order to support them and design better countermeasures. We hope that our findings will encourage others to continue to work towards a better understanding of the psychological need for relatedness in space, SDT applied to spaceflight, and the psychological issues of spaceflight in general.

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Appendices

APPENDIX 1. Flight Plan Timeline ISS, November 12, 2014 (NASA, 2014)

Radiogram No. 7162u Form 24 for 11/12/2014

REBOOST USING ATV5 2 OCS THRUSTERS. REPLACEMENT OF WATER DISTRIBUTION AND HEATING UNIT (БРП-М) IN WATER SUPPLY SYSTEM [СВО]

TIME	CREW	CREW
06:00-06:05	CDR	REMINDER - Reading Reminder
06:00-06:10	**FE-1**	Morning Inspection. Laptop RS1(2) Reboot Laptop RSS2 Reboot
06:00-06:10	**FE-2**	Morning Inspection. SM ПСС (Caution & Warning Panel) Test
06:05-06:20	CDR	HRF - Sample collection and preparation for insertion
06:10-06:30	**FE-1**, **FE-2**	Post-sleep
06:20-06:25	CDR	HRF - Sample Blood MELFI Insertion
06:25-06:35	CDR	Morning Inspection
06:30-06:50	**FE-1**	Biochemical blood test. Blood Sampling
06:30-06:50	**FE-2**	Biochemical blood test. Blood Sampling – assistance
06:35-07:05	CDR	Post-sleep
06:50-07:40	**FE-1**, **FE-2**	BREAKFAST
07:05-07:40	CDR	BREAKFAST
07:40-07:55		Daily Planning Conference *(S-band)*
07:55-08:10	CDR	BREAKFAST
07:55-08:10	**FE-1**, **FE-2**	Reviewing BRI Replacement and RS Network Nominal Reconfig Procedure. *Tagup with specialists*
08:10-08:20	CDR	Work Prep
08:10-08:50	**FE-1**	Blood Biochemistry Analysis
08:10-08:30	**FE-2**	Work Prep
08:20-08:30	CDR	Saibo UDC Payload and Cable Reconfiguration
08:30-08:35	CDR	XF305 - Camcorder Setup
08:30-09:20	**FE-2**	FGB Dust Collector ПС1, ПС2 Filter Replacement ***(ТГК424ГрО zone 1 enclosure No. 3) Reflect changes in IMS***
08:35-09:20	CDR	CMS2 - MICROSCOPE- Closeout Ops Part 1
08:50-09:10	**FE-1**	Work Prep
09:20-09:40	CDR	CMS2 – MICROSCOPE - Closeout Ops Part 2
09:20-10:20	**FE-2**	Cleaning FGB ГЖТ Detachable Screens 1, 2, 3
09:25-10:35	**FE-1**	BRI R&R. *Tagup with specialists*
09:40-09:55	CDR	CMS2 – MICROSCOPE - Closeout Ops Part 3
09:55-10:55	CDR	ANISO - Hardware Installation Part 1

10:20-11:20	**FE-2**	B3 Fan Screen Cleaning in DC1
10:35-10:45	**FE-1**	**On MCC Go** Mating BRI Telemetry Connector. *Tagup with specialists*
10:45-11:35	**FE-1**	BRI Standalone C/O. *Tagup with specialists*
10:55-11:10	CDR	ANISO - Hardware Installation Part 2
11:10-13:00	CDR	Waste and Hygiene Compartment (WHS) Pre-Treat Tank and Pre-Treat Tank Hose Remove & Replace
11:20-11:35	**FE-2**	OTKLIK. Hardware Check
11:35-13:00	**FE-1**	ARED Exercise
11:35-11:50	**FE-2**	ИП-1 Flow Sensor Position Verification
11:50-12:50	**FE-2**	БД-2 Exercise, Day 4
12:50-13:05	**FE-2**	Exercise data downlink
13:00-14:00	CDR	LUNCH
13:05-14:05	**FE-1**, **FE-2**	LUNCH
14:00-15:10	CDR	LAB Carbon Dioxide Removal Assembly (CDRA) CO2 Selector Valve 104 Remove and Replace
14:05-17:05	**FE-1**	Installation of Cable- Insert into СРВ-К2М БРП-М. *Tagup with specialists*
14:05-14:45	**FE-2**	IDENTIFIKATSIYA. Copy ИМУ-Ц micro-accelerometer data to laptop
14:50-15:05	**FE-2**	Private Medical Conference *(Ku + S-band)*
15:05-15:15	**FE-2**	SM CO measurement using CMS unit
15:30-17:00	**FE-2**	ARED Exercise
15:35-15:50	CDR	Private Medical Conference
15:55-16:25	CDR	LAB Carbon Dioxide Removal Assembly (CDRA) CO2 Selector Valve 104 Remove and Replace
16:25-17:25	CDR	T2 Exercise
17:00-17:40	**FE-2**	Filling ***EDV-SV No.1002 n.37 (00053403R, ФГБ1ПГО_4_404_1) from EDV No.1104 (00063568R, ФГБ1ПГО_1_109)*** followed by separation
17:05-17:20	**FE-1**	Private Medical Conference *(Ku + S-band)*
17:25-18:55	CDR	ARED Exercise
17:40-18:20	**FE-2**	СОЖ Maintenance
17:45-18:15	**FE-1**	Evening Work Prep
18:15-19:15	**FE-1**	БД-2 Exercise, Day 1
18:20-18:40	**FE-2**	IMS Delta File Prep
18:40-18:50	**FE-2**	Closing Shutters on windows 6,8,9,12,13,14
18:50-19:15	**FE-2**	Evening Work Prep
18:55-19:05	CDR	Evening Work Prep

19:05-19:15	CDR	Pre-sleep
19:15-19:30	.	Daily Planning Conference *(S-band)*
19:30-21:05	CDR	Pre-sleep
19:30-21:30	**FE-1**, **FE-2**	Pre-sleep
21:05-21:10	CDR	REMINDER. MELFI Insertion
21:10-21:15	CDR	REMINDER - Urine Collection Reminder
21:15-21:25	CDR	Closing USOS Window Shutters
21:25-21:30	CDR	REMINDER - Reading Reminder
21:30-06:00	.	SLEEP
Task List	**FE-1**, **FE-2**	Preparation of reports for Roscosmos site
		ECON-M. Observations and Photography
		URAGAN Observations and Photography

Notes:

1. See OSTPV for references to US activities.
2. Pre-sleep ops: daily food prep, dinner, pre-sleep
3. Russian crew uses US exercise equipment strictly per F24 or OSTPV
4. No T2 exercise allowed: 00:20-00:35 (11/13/14)

APPENDIX 2. Participant Requirements for the HI-SEAS Experiment (Proctor, 2012)

Required:

- Bachelor’s degree from an accredited institution, in engineering, biological or physical sciences, mathematics, or computer science.
- Professional experience (including graduate school) of at least three years beyond the bachelor’s degree
- Ability to pass a class 2 flight physical examination
- No history of upper airway surgery, rhinoplasty, chronic rhinitis or chronic sinusitis
- No other medical or psychological condition that would preclude participation in this study
- Willingness and ability to eat a wide range of foods
- Normal sense of taste and smell
- Tobacco-free for at least 24 months
- Demonstrated ability to conduct field research
- Strong interest in human space exploration
- Fluency in verbal and written English
- Availability and willingness to take time to participate in [the workshops and training program]

Desirable:

- Experience in a complex operational system, e.g. submarine, ambulance, airplane cockpit, control room
- Background in medicine or nursing at the “first responder” level or higher
- Ability to lift 15 kg and to cover 100 m on foot in 40 seconds or less
- Experience in construction, electronics, or home repair
- Body mass index between 19 and 25.
- Not pregnant or lactating […]
- Household cooking experience
- Valid driver’s license
- Age between 21 and 65

APPENDIX 3. Complete List of Adapted Items from the IMI

"The following items concern experiences you may have had in the past week. Some of these items are in regards to your experiences with your fellow crew-members inside the station. Please evaluate these statements using the following scale. 1 = Strongly disagree, 2 = Rather disagree, 3 = Neither agree nor disagree, 4 = Rather agree, 5 = Strongly agree

During this past week..."

Regarding relatedness with crew:

- I felt excluded from my fellow crew-members. (R)
- I felt connected to my fellow crew-members, who likewise cared about me.
- I felt my fellow crew-members acting distant towards me. (R)
- I had a warm feeling about my fellow crew-members.

Regarding relatedness with home:

- I felt excluded from my friends and family at home. (R)
- I felt connected to my friends and family at home, who likewise cared about me.
- I felt my friends and family at home acting distant towards me. (R)
- I had a warm feeling about my friends and family at home.

APPENDIX 4. Co-operation/Irritation with MS, Self-Report Scale

"The following questions are in regards to your experiences with your co-workers outside the station (not your fellow crew-members). These co-workers can be Research Investigators, Mission Support personnel, people from Maintenance Support, or any other person outside the station that is providing you with instructions for a specific task. Please evaluate the statements using the following scale: 1 = Strongly disagree, 2 = Rather disagree, 3 = Neither agree nor disagree, 4 = Rather agree, 5 = Strongly agree"

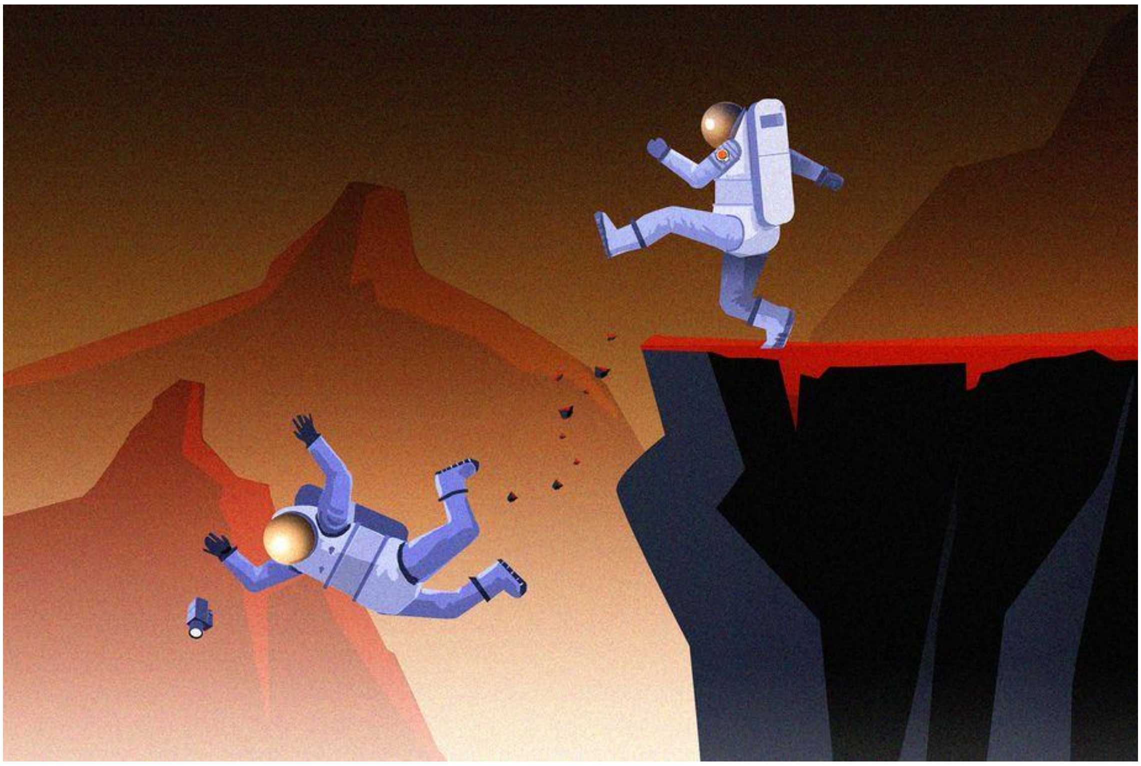
Irritation items:

- I felt irritated by the way my co-workers are handling things
- I felt annoyed with my co-workers
- I felt angry with my co-workers' working methods
- I felt bothered by my co-workers

Co-operation items:

- I got along well with my co-workers
- I was able to cooperate well with my co-workers
- I felt the cooperation with my co-workers went smoothly
- I felt my co-workers and I understood each other perfectly

APPENDIX 5. Relatedness with Crew



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