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DOI
10.1016/j.actaastro.2018.11.048

Publication date
2018

Document Version
Final published version

Published in
Acta Astronautica

Acta Astronautica 157 (2019) 9–16

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Do astronauts benefit from autonomy? Investigating perceived autonomy-supportive communication by Mission Support, crew motivation and collaboration during HI-SEAS 1

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ARTICLE INFO

Keywords:
Self-determination
Astronaut
Autonomy
HI-SEAS
Motivation
Communication

ABSTRACT

The topic of astronaut autonomy has received increasing attention in recent spaceflight literature. However, the question of whether astronauts benefit from autonomy in space, and how autonomy can be fostered by Mission Control deserves further examination. The objective of the present research was to study how the experiences of autonomy relate to crew motivation (i.e., internalization, lack of defiance) and collaboration (i.e., crew-ground cooperation and irritation) during HI-SEAS mission 1, and how crew autonomy relates to Mission Support's perceived communication style in interacting with the crew. The study sample comprised all six volunteers, three women and three men, between 33 and 43 years of age ($M = 39$, $SD = 4$), who participated in the HI-SEAS 1 mission, which simulated a four-month-long stay on Mars. During the simulation, measures of Mission Support's perceived autonomy-supportive communication, crew members' autonomy, motivation and crew-ground interactions were taken on a weekly basis during eight weeks. Data were analyzed using multilevel analyses. Results indicated systematic week-to-week variation between constructs, such that greater experiences of autonomy during a given week related to more internalization and acceptance of instructions, less oppositional defiance, and a more fruitful collaboration with ground support that week. Additionally, weekly variations in crew autonomy were positively related to weekly variations in perceived autonomy-supportive communication by Mission Support. Implications for future studies and human spaceflight are discussed.

1. Introduction

Future human space exploration will differ greatly from what astronauts have experienced thus far [1,2]. With the advent of interplanetary travel, we face major challenges at the technical, physical, financial, political, but also psychological level. One particular challenge, due to the immense distance between Earth and Mars, is the restricted crew-ground communication [3–6]. Where the traditional crew-ground relationship relies heavily on Mission Control, future more limited crew-ground communication will inevitably increase the autonomous functioning of the crew, which may yield implications for astronauts' motivation and instruction adherence (e.g. [7]). Although space agencies may fear that their more limited impact upon astronauts may come at a cost, there are theoretical reasons to believe that the increasing crew independence, when volitional in nature, may yield a range of benefits [8]. Self-Determination Theory (SDT [9,10]), an overarching psychological theory of human motivation and social development, underscores the importance of the experience of autonomy or volition for all individuals' well-being. Based on this theoretical framework, one way for the crew to experience greater volition in space is through an autonomy-supportive communication style by Mission Control. Previous literature in human spaceflight testifies to the importance of crew-ground interactions for astronaut functioning and mission success, and abundant research in SDT convincingly shows that autonomy support enhances volition and motivation in many domains.

However, to date, most research on astronaut autonomy and motivation tends to focus primarily on their importance for crew selection (e.g. [11–13]). Moreover, the few studies that did take into account the

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https://doi.org/10.1016/j.actaastro.2018.11.048
Received 12 March 2018; Received in revised form 23 October 2018; Accepted 27 November 2018
Available online 28 November 2018

changing nature of astronaut autonomy and crew motivation during the course of a mission often lack a strong theoretical basis (e.g. [14]), and do not relate such fluctuations to other important outcomes, such as crew-ground interactions (e.g. [15,16]). Grounded in SDT [17], the present research aims to provide evidence for the potential value of the crew perceiving ground support's communication style as autonomy-supportive, such that crew members' experience of volition and motivation, and crew-ground collaboration get fostered [8]. Specifically, using data collected during the last eight weeks of the first mission of the NASA-funded HI-SEAS Mars simulation, our study focused on whether week-to-week fluctuations in perceived autonomy-supportive communications between Mission Support and the crew related to week-to-week variations in crew autonomy, and whether week-to-week variations in crew autonomy related to crew motivation and crew-ground collaboration.

2. A nuanced perspective towards astronaut autonomy

The last couple of years, the notion of crew autonomy has become a popular subject among space experts (e.g. [4,6,18]). Traditionally, Western space agencies tend to be strongly ground-based, with a centralized control from ground control centers. For instance, planning at NASA involves a top-down, hierarchical approach, where Mission Control directs the majority of the missions [6]. Such strong reliance on direction from upper management and planning currently occurs with minimal, if any, input from crew members [4,19]. Because astronauts are in some cases merely considered an “extension of ground support” [6,18], their autonomy has been restricted, in spite of their high intelligence and capacities for independent decision making. At least some astronauts may interpret this tendency to limit autonomy as signaling distrust, which may further reduce their motivation and even give rise to feelings of irritation and defiant behavior towards Mission Control. This could explain why, after a couple of months into a mission, astronauts tend to rebel against their deprived autonomy [6]. As one NASA expert characterized the astronaut mentality: “Just give me the skeleton and let me do it my way.” ([6], pg. 484).

From a SDT perspective, such rebellious behavior can be expected. Together with the psychological needs for competence and relatedness, autonomy is conceived as an essential nutrient for psychological health, motivation and personality integration [9,20], regardless of cultural background, age and socio-economic levels (e.g. [21,22]). When autonomy is satisfied, people experience a sense of volition, ownership and psychological freedom when carrying out a task, while frustration of autonomy involves feeling conflicted and pressured to think, act or feel in a prescribed way. Importantly, from the SDT-perspective, autonomy does not equal *independence* [23,24]. Whereas independence refers to making decisions without external guidance, autonomy refers to the inner experience of volition and psychological freedom when engaging in an activity [25]. Such a sense of volition can be experienced when acting independently, that is, when making one's own decisions, but also in a state of dependence, that is, when relying on others for advice and guidance [26]. Hence, even if astronauts are turning to ground control for help and counseling, they do not necessarily act non-autonomously given that they concur with the guidelines offered by the ground. Thus, it is important for space agencies to understand that both a state of dependence or independence can be experienced as volitional or pressuring. Past research among adolescents has shown that (in)dependence in the parent-child relation is not the most critical predictor of their well-being and problem behavior. Instead, more important is the *ownership* associated with the state of either dependence or independence [23,27]. Extrapolating from this body of work, ground control would do well to foster crew members' sense of volition to optimize their health and mission success.

Previous research has shown that the experience of autonomy as volition is critical in a variety of life domains, such as education (e.g. [28,29]), healthcare (e.g. [30,31]), sports (e.g. [32–34]) and the workplace (see Ref. [10], for a review). In the work context, more specifically, research has shown that employees who experienced more autonomy satisfaction were more engaged [35,36], performed better [37], and evidenced greater well-being [10,38], while experiences of autonomy frustration related to greater exhaustion [39]. Importantly, there are not only between-person differences in autonomy need satisfaction, but a person's experienced autonomy may also fluctuate from week-to-week [40] and from day to day [41]. Furthermore, such within-person fluctuations in daily autonomy satisfaction were found to relate to within-person fluctuations in well-being [42], sleep quality [40], and bulimic eating patterns [43]. As such, based on previous research results, it seems important to investigate astronauts' autonomy, within-person changes in these feelings of autonomy, and the link with important study variables such as Mission Control's communication style, astronaut motivation and crew-ground collaboration.

3. Astronaut motivation and oppositional defiance

Although it is typically acknowledged that astronauts are highly motivated individuals, previous research [3,14,16,44] and anecdotal evidence [7,44,45] testify of the changing nature of astronaut motivation during past missions. According to some NASA experts [7], astronauts tend to overestimate the ease of long-duration flights and underestimate the stressors of spaceflight. Their daily schedule consists of many tasks that are not inherently interesting or enjoyable, such as cleaning and maintenance. And when crews are isolated and confined, such daily routines may become even more monotonous and boring, leading to degrading motivation [46,47]. In such circumstances, it is not uncommon for insubordination issues to arise, and several experts have expressed concern with regard to astronaut instruction adherence during future Mars missions [3,7]. It is therefore crucial to study what motivates astronaut behavior during spaceflight, and how this motivation evolves during the course of the mission.

SDT offers a thorough and differentiated vision on motivation, thereby distinguishing between different types of motivation that fall along a continuum of increasing internalization or self-endorsement. In the case of *external regulation*, an individual's behavior is driven by motives outside the person, such as the gain of a reward or appreciation, or the avoidance of punishment and criticism. Typical for this type of motivation is its contingent nature, that is, the desired behavior is emitted as long as the external regulator is operative but wanes as soon as the external factors are no longer present. To illustrate, according to one NASA expert [7], this type of regulation can be characteristic for the ISS crew, who may comply with guidelines from ground control in order to make a good impression, garner appreciation and eventually increase their chances to be accepted for another mission. Interestingly, in a Mars mission, this motivator would likely not be present, as such a long-duration mission would probably be the last flight for the crew, which increases the risk of motivational problems arising.

Further down the motivation continuum is *introjected motivation*, when an individual is driven to meet internal, rather than external pressures, such as the avoidance of guilt or shame for not adhering to work protocol, or the bolstering of one's ego and reputation by doing so. To illustrate, astronauts may comply with instructions from Mission Control to avoid feeling guilty for letting down ground control members or other crew members. Although the motive for instruction adherence has now been internalized to some degree, it has not yet been fully accepted. Instead, a fuller form of acceptance and self-endorsement is achieved when individuals identify with the self-importance of instructions, rules and procedures. In the case of *identified regulation*, one volitionally decides to engage in the activity, presumably because one fully accepts and owns one's reasons for engagement. As such, identified regulation reflects a person's abiding convictions and values and is operative when astronauts perceive the personal relevance and necessity of provided instructions and introduced rules and procedures.

Congruent with the assumption that these different types of regulation reflect an ordered pattern of increasing self-endorsed motivation, a wealth of previous studies has shown that the pattern of correlates with external variables follows a similar ordered pattern. That is, in an encompassing study, comprising 3435 workers from nine different cultures, Gagné et al. [48] observed that employees' job effort, performance, and job satisfaction yielded an increasingly positive correlation with employees' motivation as one moves along the continuum from external to identified regulation. Similarly, the pattern of correlates became decreasingly negative in the case of undesirable work outcomes, such as exhaustion and turn-over intention.

While autonomy need satisfaction serves as a precursor for self-endorsed motivation, when individuals need for autonomy gets frustrated, they may react by becoming passive or oppositional defiant [49]. Oppositional defiance involves the blunt rejection of external guidelines and instructions, presumably because these are perceived to be autonomy-threatening [20]. Indeed, oppositional defiance is said to function as a compensatory mechanism to cope with pressure and autonomy frustration [20,50]. Given its antagonistic nature, oppositional defiance is said to involve a form of anti-internalization, as individuals actively go against imposed instructions or regulations [51].

4. Autonomy-supportive crew-ground communication

One important way to support the crew's sense of volition and subsequently minimize the risk for oppositional defiance, is via autonomy-supportive interactions between the crew and Mission Control. If Mission Control is not sensitive to the specific demands and needs of the flight crew, they run the risk of being perceived as non-supportive. Previous missions have indeed shown that crew-ground interactions are a crucial factor for the crew's well-being and performance. Since the beginning of the space age, crew-ground interaction mishaps have been recorded (e.g. [1,52,53]). Due to relatively small inconveniences in Mission Support interaction (e.g., change in the voice quality of a Mission Control member), increased frustration with Mission Control personnel and decreases in the crew's performance were observed (see Salyut mission of Cosmonaut Lebedev [54]). At one time, Cosmonaut Lebedev and his crewmate for example, deliberately chose not to report a fire onboard the station to avoid panic on the ground. During the infamous Skylab 4 "space strike", the flight crew closed down communications with the ground for 24 h in response to Mission Control's interventions, which were perceived as pressuring and controlling [55]. This often observed phenomenon, in which crew-ground tensions are reflected in symptoms as decreased communication volume, reduction in the number of issues being discussed and strong preferences in the choice of communication partners, is described in the literature as "psychological closing" [53,56]. Such crew-ground miscommunications during orbital missions are expected to occur more frequently during a Mars mission due to the longer duration of high-Earth orbit missions and the greater communication delay with Mission Control. The risk for increased psychological closing has alarmed space agencies (e.g. [1,6,57]), and has led some space experts to develop potential countermeasures to ensure the ground's control over Mars crews. For instance, it has been suggested that Mission Control could make use of computer-interactive intervention programs to assess the crew′s cognitive and emotional state [1,53]. In this context, some experts have developed wearable devices that continuously record the crew's general behavior and health (e.g. [58]), while others want to use content analysis of audio recordings of crew interactions to secure continued monitoring (e.g. [59]). However, these measures, if not volitionally accepted by the Mars crew, again run the risk of being experienced as restrictive and controlling. What is critical from a psychological viewpoint is that, to preserve the crew's autonomy, one not only needs to focus on the technical feasibilities of ground-based guidance and support, but also on the acceptance and endorsement of this Mission Control guidance by the crew. If this happens to be the case, crew members may be less defiant and even be highly motivated to follow ground control's guidelines.

Fortunately, Mission Control members have a variety of means from which to choose when trying to motivate the flight crew. Only a few of those, however, can positively influence the crew's sense of willingness and self-endorsed motivation. Within SDT [60], the way Mission Control interacts with the crew can be described as either autonomy-supportive, satisfying the crew's need for autonomy, or controlling, thwarting their sense of volition. Mission Control members can foster volitional functioning by providing the crew with a desired amount of choice, for instance in the scheduling of tasks, or in the preferred working method to accomplish mission objectives. In situations where choice is constrained, autonomy can still be supported by giving a meaningful rationale for a request, by accepting, rather than countering frustration and anger that might arise during difficult moments, and by using inviting language (e.g., "you can"). A controlling approach, on the other hand, conveys pressure by using coercive language (e.g., "you must"), the use of pressuring deadlines, controlling rewards and manipulative strategies such as guilt-induction, shaming or conditional regard [61].

Numerous experimental and correlational studies (see Refs. [62,63], for a review) have shown the benefits of an autonomy-supportive communication style to improve volition and self-endorsement, and diminish oppositional defiance in various life domains, such as sports (e.g. [33,64]), parenting (e.g. [65,66]), education (e.g. [67,68]), or work (e.g. [37,69]). However, as previously noted by some space experts (e.g. [14]), such findings still need to be validated in the astronaut context.

5. This study

Although the topic of crew autonomy has received increasing theoretical [8] and some empirical (e.g. [70,71]) attention, the question whether astronauts benefit from autonomy, and how autonomy can be fostered on a day-to-day basis in space deserves further examination. The current study presents the findings of a unique dataset which was collected from the six participants during the first mission of the NASA space simulation HI-SEAS in 2013. HI-SEAS involved an experimental study, which was set up to simulate a four-month stay on Mars. During this simulation study, participants filled out weekly questionnaires tapping into their felt autonomy, their motives for adhering or defying Mission Support guidelines, collaboration with the ground and the perceived autonomy-supportive versus controlling nature of communication by Mission Support. The repeated, weekly assessment of these constructions allowed us to address a series of unique questions at the within-person level rather than the between-person level. While the latter concerns the question how autonomy-dynamics differ between persons, at the within-person level, the question is addressed to what extent fluctuations occur within a given person in their weekly autonomy-based functioning. Our overall objective is then to examine whether weekly ups and downs in the extent to which Mission Support is perceived by the crew to be autonomy-supportive versus controlling, relates to weekly ups and downs in the crew's sense of volition, which in turn would relate to weekly fluctuations in important outcomes of motivation (i.e., internalization, lack of defiance) and collaboration (i.e., cooperation, irritation).

Grounded in SDT, the following two hypotheses will be investigated. First, we hypothesized that week-to-week variations in the crew's experienced autonomy would relate positively to week-to-week variations in self-endorsed motivation for following up instructions by Mission Support, and with week-to-week variations in Mission Support cooperation. In contrast, such weekly variations in autonomy experiences would relate negatively to week-to-week variations in rebellious and defiant reactions towards regulations and instructions by Mission Support, and to week-to-week variations in feelings of irritation towards Mission Support members (Hypothesis 1). Secondly, we hypothesized that the weekly ups and downs in crew volition would be driven by the crew's perception of a more autonomy-supportive versus controlling communication style from Mission Support during that week (Hypothesis 2). Because the current study involved the weekly assessment of crew members' motivation, we examined in a more explorative way how these motives changed over time. Such changes in motivational functioning have been examined by Van Baarsen [14], and Sandal, Bye and van de Vijver [15] in the past, who focused on a different set of motivational factors than those addressed herein [14–16]. The study was approved by the NASA Institutional Review Board and the Ghent University Ethical Commission.

6. Method

6.1. Subjects

The study comprised six volunteers, three women and three men, between 33 and 43 years of age (M = 39, SD = 4) at the beginning of the simulation. The participants were of US, Canadian and Belgian nationalities. The three men and women of this HI-SEAS crew were chosen to have a similar mix of experience and backgrounds as real NASA astronauts.

6.2. Mission

The HI-SEAS I mission simulated a four-month stay on Mars, from mid-April until mid-August 2013. The HI-SEAS habitat, an 11 m diameter geodesic dome connected to a container, is located in an isolated location on the flanks of the Mauna Loa Volcano on Hawaii, an area with Mars-like features, such as the absence of vegetation and animal life and a barren volcanic rock terrain. Crew members performed a variety of routine tasks on a daily, weekly, and monthly basis as well as a more limited set of unique, single time tasks. These standard tasks involved cleaning, maintenance, and reporting duties similar to ISS tasks, which were taken up in a rotating system. Additionally, as part of several ongoing scientific studies, crew members carried out several scientific tasks throughout the duration of the mission.[1] In contrast with current ISS missions, the HI-SEAS crew had significantly more choice and decision latitude than an ISS crew. On the one hand, the crew was given a variety of compulsory tasks set by NASA and outside researchers, which had to be conducted on a daily, weekly or monthly basis. Yet, on the other hand, crewmembers had complete control over the planning, that is, when to conduct these activities during the course of the mission. These protocols were determined at the beginning of the mission, so crew members could jointly set up a daily, weekly or overall mission planning accordingly. Further, the crew was given the opportunity to perform personal research projects, based on their own interests and expertise. The crew commander kept an overview of everyone's tasks and duties, which were recorded in the daily commander report by the end of the day. Ground support members were available all the time to assist crew member in any way, if needed. Note that ground personnel was specifically referred to as Mission Support instead of Mission Control to emphasize the more supportive role of the ground and the increased choice and decision latitude offered to the crew. Crew members and Mission Support communicated throughout the day via email, with a two-way 20-min delay to simulate the Earth-Mars communication lag. The crew only left the module for weekly extravehicular activities, in simulated spacesuits, to explore the surrounding terrain and perform geological studies.

6.3. Procedure

For the purpose of this study, the crew filled out questionnaires on a weekly basis, on Sunday evenings, during eight consecutive weeks. Several existing or self-developed questionnaires were used in various parts of the study. All items in these questionnaires were scored on a five-point Likert scale ranging from one (*I don't agree at all*) to five (*I agree completely*). To avoid question order effects, the different questionnaires were presented in a random sequence every week.

Perceived Autonomy Support versus *Control*. Crew members were asked to report their perception of Mission Support being autonomy-supportive instead of controlling during the past week. Eleven items adapted from the Work Climate Questionnaire [72] were administered to tap into autonomy-supportive (e.g., "Mission Support members tried to understand how I would like to do things, before making any suggestions on how to accomplish my tasks") and controlling behavior (e.g., "Mission Support members were less friendly to me when I didn't complete tasks in the way they expected me to"). Higher scores indicated greater perceptions of autonomy-supportive behavior. Cronbach's alpha was .73.

Autonomy. The crew's general sense of personal freedom and volitional functioning was assessed using eight adapted items from the autonomy subscale of the Basic Psychological Need Satisfaction Scale [62,73], e.g., "I felt my decisions reflected what I truly wanted". Cronbach's alpha was .90.

Motivation. Self-endorsement and acceptance of instructions for daily tasks was assessed using an adapted version of the Self-Regulation Questionnaire - Parental Rules [74,75]. The crew members were asked for their reasons to follow instructions for their daily activities: "During the past week, I followed instructions because …". In total, 19 items were used to measure external regulation (e.g., "this was expected of me"; seven items; Cronbach's alpha = .72), introjected regulation (e.g., "I would have felt guilty otherwise"; 6 items; Cronbach's alpha = .81) and identified regulation (e.g., "I understood why they were important"; six items; Cronbach's alpha = .87). In line with previous work, a summarizing measure was created, the relative internalization index (RII) [74,76–78]. This composite score consists of a weighted combination of volitional and pressuring forms of motivation, wherein the volitional motives were given a positive weight and the pressuring motives were given a negative weight. Because the different kinds of regulations in SDT (i.e., identified, introjected, and external) are supposed to lie on one continuum of self-endorsement, the weights that are assigned to these regulations (i.e., +3, −1, and −2, respectively) when creating a relative internalization index in empirical research are balanced. Such a weighting procedure guarantees that the sum of the assigned weights is zero and that self-endorsed and pressuring types of regulation are equally weighted in the creation of a relative internalization index [77]. Overall then, higher scores on this scale indicate higher levels of acceptance and internalization of instructions.

Oppositional defiance. A tendency towards the dismissal of instructions for daily tasks was measured using four items adapted from Vansteenkiste, Soenens, Van Petegem and Duriez [79]. A sample item reads "From time to time I wanted to disregard the instructions that were set for me". Cronbach's alpha (0.58) revealed a poor internal consistency. Deleting one item from the scale increased alpha to .74 for the three remaining items. This score was used in the analyses.

Irritation with Mission Support. Four items such as "I felt irritated with Mission Support" were used to measure the level of irritation crew members experienced during their interactions with Mission Support. These items were based on the resentment scale of Assor, Roth, and Deci [80]. Internal consistency of this scale was 0.92.

Cooperation with Mission Support. Four self-developed items such as

[1] The primary objective of HI-SEAS 1 was a food, odorant identification, and nasal patency study. The second major category of HI-SEAS 1 studies included research on sleep and lighting, food microbiology and hygiene monitoring, antimicrobial textiles, robotic companions, geological exploration, thermal analysis and evaluation of the habitat, remote-operated robotic farming, and research on personal resilience, education and public outreach, a variety of scientific tasks, activities, and assessments, such as daily intensive physical workouts, light therapy, evaluations, and recordings of meals, completing questionnaires, Extra Vehicular Activities, geological mapping and exploration, to name a few.

Table 1
Means, standard deviations, within- and between-subject correlations, and week-to-week variances for the study variables.

	M (SD)	1.	2.	3.	4.	5.	6.
1. Perceived Autonomy Support vs. Control	3.88 (0.48)	1.00	.91***	.48	-.48	-.37	.78†
2. Autonomy	3.48 (0.80)	.52**	1.00	.48*	-.17	.69	.47
3. Internalization of Instructions	0.99 (1.07)	.32	.54*	1.00	-.66†	-.07	.45
4. Oppositional Defiance towards Instructions	2.78 (0.97)	-.29*	-.34**	-.23	1.00	.59	-.86†
5. Irritation with Mission Support	2.94 (0.96)	-.59***	-.29*	-.18†	.49***	1.00	-.27
6. Cooperation with Mission Support	3.63 (0.56)	.45***	.11	.26*	-.31*	-.61***	1.00
Week-to-week variance		87%	26%	30%	23%	92%	88%

Note. Within-subject correlations are displayed below the diagonal, and between-subject correlations above.
$p^{\dagger} < 0.10$. $p^{*} < 0.05$. $p^{**} < 0.01$. $p^{***} < 0.001$. Based on Wald test in Mplus (estimate/standard error).

"I was able to cooperate well with my Mission Support" were used to measure the perceived cooperation crew members experienced in their interactions with Mission Support. Internal consistency of this scale was 0.69.

6.4. Statistical analysis

To analyze whether variation in crew autonomy during the course of the mission could account for variation in motivation, oppositional defiance and crew-ground interactions, and whether these fluctuations in crew volition related to fluctuations in perceived autonomy support from Mission Support, multilevel analyses, which take into account between- and within-person variation, were conducted with the statistical software package HLM7. In each of the main models, we started with a random intercepts-only model. These random intercepts-only models consist of random intercepts and a constant as the only predictor [81] and decompose the total variation into variation at the between-person level and at the within-person level. In a second step, we added fixed effects to these random intercepts-only models.

7. Results

7.1. Preliminary analyses

Six random intercepts-only models were created to examine the percentage of variance in perceived weekly autonomy support versus control, autonomy satisfaction, internalization, defiance, irritation and cooperation, that is, because of within-person and between-person variation. Aggregated means and standard deviations for the measured variables can be found in Table 1, as well as correlations between the study variables on the between and within level, and week-to-week variances derived from the intra-class correlations. Fig. 1 provides an example of the distribution of variance on the within- and between-person level for our assessment of autonomy.

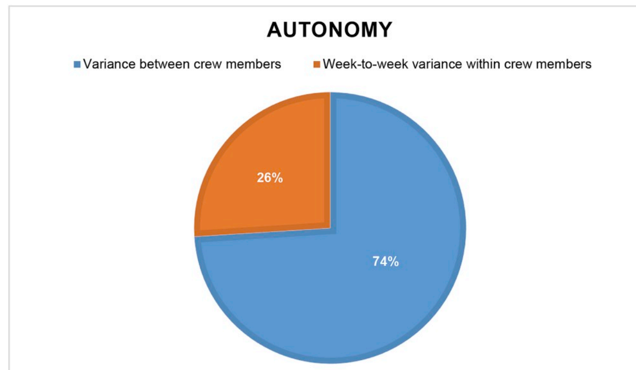

Fig. 1. The distribution of variance on the between- and within-level for autonomy.

7.2. Primary analyses

Hypothesis 1. weekly correlates of autonomy need satisfaction

Multilevel analyses indicated that week-to-week variations in autonomy were significantly related to week-to-week variations in internalization ($b = 0.87$, $t(36) = 2.33$, $p < .05$), oppositional defiance ($b = -0.71$, $t(36) = -2.73$, $p < .05$) and irritation with Mission Support ($b = -0.70$, $t(36) = -2.56$, $p < .05$), but not to week-to-week variation in cooperation with Mission Support ($b = 0.11$, $t(36) = 0.11$, $p = .48$).[2] As expected, during weeks that crew members experienced more volition, they reported a higher level of self-endorsed motivation to follow-up daily instructions from Mission Support, while being less likely to rebel and defy these instructions, and they experienced less irritation towards Mission Support members.

Hypothesis 2. relationship between autonomy-supportive communication and crew autonomy

A multilevel analysis indicated that fluctuations in perceived autonomy support versus control from Mission Support significantly predicted changes in autonomy ($b = .50$, $t(35) = 2.88$, $p < .01$). As expected, the more the crew perceived Mission Support members as being autonomy-supportive, the greater their experience of volition.

7.3. Ancillary analyses

We further tested whether the study variables increased or decreased over time and found a significant increase for internalization during the final eight weeks of the mission ($b = 0.13$, $t(36) = 5.67$, $p < .001$). No significant linear time effects were observed for autonomy-supportive communication ($b = -0.02$, $t(35) = -0.45$, $p = .66$), autonomy ($b = 0.03$, $t(37) = 0.85$, $p = .40$), defiance ($b = 0.04$, $t(36) = 0.78$, $p = .44$), irritation ($b = -0.01$, $t(36) = -0.21$, $p = .84$) or cooperation ($b = -0.04$, $t(36) = -1.14$, $p = .26$).

8. Discussion

Most research on astronaut motivation has remained on a rather descriptive level, making observations on how the crew's motivation fluctuates over time, without relating these variations in motivation to

[2] Since variations in autonomy did not significantly predict variations in cooperation with Mission Support (Hypothesis 1), we further tested whether changes in cooperation would instead relate to changes in perceived autonomy-supportive communication with Mission Support. This indeed was the case, with more perceived autonomy support from Mission Support being

(*footnote continued*)
significantly related to greater perceptions of a fruitful cooperation with Mission Support members ($b = 0.44$, $t(35) = 2.69$, $p < .05$).

variations in other important outcomes (e.g. [15,16]), or without including a conceptualization of motivation and autonomy that would allow to identify a more volitional and self-endorsed form of regulation (e.g. [14]). The present study's aim was to add to this body of research by introducing a) a strong theoretical framework, b) a more nuanced approach to motivation, distinguishing between more self-endorsed and more pressuring forms of motivation, c) the inclusion of measures of crew-ground collaboration, and d) the study of Mission Support's perceived communication style as a potential antecedent to crew volition and subsequent motivation and collaboration. Several interesting findings emerged.

First, our findings show a positive association between week-to-week variations in the crew's sense of volition and week-to-week fluctuations in self-endorsed motives for daily activities, while a negative relation emerged for week-to-week fluctuations in oppositional defiance. Crew members who experienced a greater sense of willingness and personal freedom, identified more with the operation procedures they were provided with, and felt less inclined to discard these task instructions. These findings suggest that instruction defiance could be avoided, and self-endorsed motivation, reflective of acceptance and ownership of behavior, could be enhanced by increasing the crew's sense of willingness and personal freedom, as has been previously observed in other domains (e.g. [82,83]). Especially for a Mars Mission, where sustained motivation is even more at risk than in low-Earth orbit missions due to prolonged mission duration, boredom and isolation, it becomes crucial to safeguard and reinforce such volitional functioning.

Weekly ups and downs in volition were also related to weekly oscillations in crew-ground interactions, with a greater sense of personal freedom being predictive of less irritation towards Mission Support members. This finding is important because, as previously mentioned, crew-ground interactions are expected to be greatly challenged during a Mars Mission, when direct communication between astronauts and Mission Support is no longer feasible. Surprisingly, a greater sense of autonomy was not related to a more fruitful cooperation with Mission Support, but rather, cooperation was associated with an autonomy-supportive communication style from Mission Support as perceived by the crew. However, it is possible for the absence of the significant relation between autonomy and cooperation to be a consequence of the small sample size and limited number of measurement moments. Apart from these statistical issues, it is very likely that crew members were trained in such a way as to comply with Mission Support's requests, regardless of feelings of frustration. A thwarted sense of autonomy might therefore more easily translate into feelings of irritation towards Mission Support, without necessarily harming the crew's cooperative intentions. Also, it is possible for other psychological needs to play a role in crew-ground cooperation, such as the need for relatedness within the crew, or between crew members and Mission Support members.

Finally, we observed that during weeks when the crew viewed Mission Support as being more autonomy-supportive, rather than controlling, they experienced a greater sense of volition and personal freedom during that week. This finding is crucial, since it suggests that the crew's sense of volition could be increased by employing autonomy-supportive measures that have already been proven effective in other domains [63]. From these measures, we can develop guidelines that could be implemented by space agencies when training Mission Control personnel in interacting with astronauts. For instance, Mission Control members should be particularly attentive to avoid overt control and pressuring language in interacting with the crew, such as guilt inducing criticism, negative comparisons to other crew members or even tangible rewards [84,85]. Instead, Mission Control could be trained to use communication skills such as empathic listening or even actively inquiring about and acknowledging the crew's feelings towards a particular task or problem [86–88]. Additionally, when setting up the crew's schedule or instructing astronauts in a particular task, they could try to provide different kinds of choices, especially when the task at hand is not inherently interesting or enjoyable (e.g. [89,90]). While *option choices* (i.e., letting the crew decide what task to perform) might not always be easy to implement in space operations, often *action choices* (i.e., a choice within the task, such as deciding the timing, pacing, amount of guidance or working method for a task) could be just as effective in enhancing volition (e.g. [91]). Alternatively, astronauts can express preferences and act upon interests more when Mission Control assigns them to tasks consistent with their preferences (e.g. [92]), thereby making the task more personally relevant. Another way for Mission Control to enhance personal relevance would be to offer a meaningful rationale for the task at hand (e.g. [93,94]), as well as to emphasize how this task could relate to the crew's personal development [95], or how it contributes to scientific advancement [57]. Finally, after task completion, Mission Control could enhance volition by providing astronauts with corrective feedback through the use of inviting instead of pressuring language [33,64,96].

This study has a number of limitations. As mentioned, the small sample size ($N = 6$) and only eight measurement times per participant limit the power of our analyses. Also, our assessments were limited to the second half of the mission, which might have impacted our results, as adaptation to mission stressors have been observed to evolve during the course of the mission (e.g. [1,5]). Additionally, only self-report measures by crew-members were used. Future research could, for instance, measure autonomy support vs control directly with Mission Control members as informants, or make use of third-person evaluations of crew-ground interactions. Further, the relationships between the variables in this study are of a correlational nature. It would be interesting to study the effects of autonomy support experimentally, by directly manipulating Mission Control's communication style and examining its effect on autonomy satisfaction, and subsequent motivation and crew-ground collaboration [87]. In Self-Determination Theory research, dozens of studies in a variety of domains (see Refs. [9,93], for reviews) have successfully demonstrated the effectiveness of an autonomy-supportive, rather than controlling, communication style in enhancing perceived autonomy-support (e.g. [97]), experiences of autonomy (e.g. [94]) and self-endorsed motivation (e.g. [88]), and reducing negative affect (e.g. [98]). Finally, as with every simulation mission, HI-SEAS I itself has a number of limitations, such as differences in mission duration (only four months) and crew member training and selection, compared to an actual Mars mission. Future studies should aim to replicate these findings during actual spaceflight or a longer simulation mission.

9. Conclusion

The findings in this study attest to the central role of crew members' sense of autonomy and volition in crew motivation and crew-ground collaboration. Crew members who are more satisfied in their need for autonomy, experience greater self-endorsed motivation for daily tasks and are less likely to rebel against task procedures. Additionally, a greater sense of volition was also associated with less irritation vis-à-vis Mission Support. Since the findings also indicate that the crew's volition is associated with a more autonomy-supportive communication style from Mission Support, as perceived by the crew, space agencies could train Mission Control members to actively implement autonomy-supportive measures in their interactions with the crew, to the benefit of the crew members and the success of the mission.

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