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Review

Gaining deeper insight into the psychological challenges of human spaceflight: The role of motivational dynamics

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ABSTRACT

Past research in space psychology has produced a plethora of interesting findings with regard to the psychological stressors and benefits associated with human spaceflight. To help synthesize these rather scattered findings and to advance our theorizing about critical psychological phenomena and processes within the rapidly growing field of space psychology, the aim of this contribution is to approach them from the perspective of Self-Determination Theory (SDT; [1] Ryan & Deci, 2000 [1]), a broad theory on human motivation and development. Specifically, we argue that the postulation of the psychological needs for autonomy, competence, and relatedness within SDT allows for (1) a deeper understanding of reported psychological phenomena in current spaceflights and (2) the development of measures to alleviate the negative psychological stressors as well as to enhance the benefits associated with spaceflight.

Contents

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1. Introduction

With the launch of Yuri Gagarin on April 12, 1961, the first man in space, a brand new field in human sciences was born: space psychology. Since then, a substantial amount of research has been conducted to reveal the personal and interpersonal stressors astronauts face when in outer space. In fact, the field of space psychology has been rapidly evolving, thereby producing a number of interesting insights into a broad diversity of phenomena [2,3]. Unfortunately, the findings of these studies remain somewhat disconnected and rather descriptive in nature, thereby lacking a strong theoretical foundation that would allow for greater synthesis between them and for a deeper understanding of their underlying psychological dynamics. Therefore, at this point, the field may benefit from the reliance on an overarching theoretical framework, which would allow for a more unified, coherent, and efficient development of ongoing and future research.

One theory that is ideally suited to fill this void in the literature is Self-Determination Theory (SDT) [1,4], a broad theory on human motivation, development, and well-being. The theory has received wide-spread attention and has been used as a source of inspiration to study the motivational functioning, thriving, and well-being of individuals in diverse life domains, including health care, parenting, education, and environmental sciences, to name a few [5].

Central to SDT is the assumption of the existence of three inherent, psychological needs, that is, the need for autonomy (i.e., experiencing a sense of volition), the need for competence (i.e., experiencing a sense of effectiveness) and the need for relatedness (i.e., experiencing a sense of warmth). The satisfaction of these needs on a day-to-day basis is integral to individuals' well-being and flourishing, while also serving as a source of resilience against adversity [6,7]. Herein, we forward and develop the broader argument that the satisfaction of these psychological needs is equally critical for astronauts' well-being and performance and that their support will be of utmost importance during future Mars missions. In fact, as we are entering a new and fairly unknown era of human spaceflight, which is bound to yield new psychological challenges, a more holistic view on astronauts' functioning is likely to be helpful in formulating predictions about the future psychological challenges for a Mars crew.

The present review consists of three parts. In part one, we briefly discuss two critical topics within space psychology, namely crew autonomy and the beneficial effects of spaceflight, a topic that gained attention under the influence of the positive psychology movement. We opted for these two topics for a number of reasons, including the increasing attention they receive among space psychologists and space agencies [2], the conceptual confusion surrounding the notion of autonomy which can be resolved by taking an SDT-perspective [8,9], the natural fit between the positive psychology movement and SDT, and the fact that both topics are of crucial importance for future interplanetary travel [2,8]. Many other topics in space psychology could have been addressed, such as the issue of social isolation (e.g., [10]), family support (e.g., [11]) and crew-ground communications (e.g., [12]), to name a few. However, space limitations required us to be selective. In part two, we discuss a number of critical principles of SDT which set the foundation for part three, that is, the elucidation of the theoretical potential and applied value of SDT for the field of space psychology. Specifically, we will discuss how SDT's notion of psychological need satisfaction and its differentiated view on human motivation enable us to shed more light on the question of crew autonomy and the beneficial effects of spaceflight.

2. Critical topics in space psychology

2.1. Crew autonomy and bureaucracy

A topic of great discussion among space agencies is the question of crew autonomy. This issue concerns the decision-making authority of the flight crew, and is differentiated from the concept of autonomy as conceived within the framework of SDT, as will be discussed in Section 4.1. There is a tendency, especially in Western space agencies, to restrict the decision-making authority of the flight crew through a variety of detailed regulatory procedures [8,9,13,14]. The ISS crew, for instance, operates under a very strict set of rules and guidelines due to a combination of increasing bureaucratic demands and safety regulations imposed on astronauts. To illustrate, today's astronauts on the ISS cannot decide on their daily work schedule as their daily activities are completely planned by mission control on the ground and every change needs to be reported and evaluated by an expert team on Earth. Although mission control is sometimes willing to take astronauts' preferences into account, they generally are allowed little input and merely seem to be treated as “executive personnel”, “extensions of ISS” or “lab workers” (e.g. [8], p. 925).

Yet, on the rare occasions that mission control takes astronauts' preferences into account, this seems to be very welcomed. As an example, ESA astronaut Frank De Winne's approved request to perform his physical exercises in two separate instead of two consecutive hours was greatly appreciated by him [15]. A further illustration is the following excerpt, which exemplifies how a successful autonomous decision made by the flight crew can produce inherent satisfaction and contentment. Frank De Winne, who was responsible for a technical maintenance on the ISS, shares the following experience: "*Friday I had to replace a technical unit in the Columbus lab. When I wanted to place the spare unit, I noticed that eighteen screws were missing. Those were not ordinary screws, they are the kind that you can loosen without them floating around. Without warning mission control I found a way to remove the screws from the old unit, to place them in the new one and to install the new unit. This was not easy since as we do not have a workbench to do this in a comfortable way. But it worked. Then I told mission control and they were quite pleased with the result. They did not have to find a solution anymore. When they do have to, it can easily take up two to three days because everything needs to be checked by everyone. Meanwhile, the astronauts have to clean up the whole mess so all that work and time would have been useless. By taking initiative I saved a lot of time. But of course, if something had gone wrong, I would have been at fault for not having warned mission control. The astronaut would have done it!*" ([15], p. 101). Unfortunately, these sorts of anecdotal examples of the work schedule seem to be fairly rare. Astronauts are strongly recommended if not pressured to stick to an imposed work schedule, which is based upon strict bureaucratic rules and safety regulations. Moreover, any change in the tight work schedule requires a considerable amount of time and effort for mission control. For these reasons, it is very difficult for astronauts to deviate from the assigned work schedules. Indeed, some anecdotal reports hint at the frustration that emerges from the mere executive role assigned to astronauts [2,15].

Another aspect of restricted crew autonomy is the fact that astronauts are under constant audio and video surveillance by mission control when performing their duties. These audio and video channels are actively monitored by mission control members and payload operators on the ground, and are readily available to the public via the NASA website. Despite the managing and reassuring functions these surveillance measures can have, one cannot ignore their evaluative and pressuring effect on the crew.

Despite astronauts' desire to exercise more authority in their daily activities, Western space agencies remain reluctant to train their flight crew to take such autonomous decisions. To some extent, this is understandable. If astronauts make decisions during dangerous operations and emergency situations, for which they are not trained and without informing mission control, it may create an atmosphere of distrust. Moreover, such personal decision making may yield considerable risks, not only for the psychological well-being of the astronauts themselves, but also for the successful completion of the overall mission. On the other hand, the complete lack of transfer of decision-making power to astronauts is surprising. Especially with respect to rather small or routine tasks, taking personal initiative and seeking solutions without informing mission control may not pose a problem.

Also, the communication delay between the Earth and Mars during a Mars mission almost necessitates the partial transfer of the decision-making power to a Mars crew. Interestingly, instead of granting increasing decision-making power to astronauts, scientists have been searching for different solutions. That is, to provide flight support despite the absence of direct communication, some scientists are developing computer-interactive intervention programs that can assess the crew's cognitive and emotional state and provide them with prevention and intervention information for potential psychological issues [2,3] or are proposing remote crew monitoring by audio recordings of crew interactions [16]. Thus, rather than taking the more limited possibilities for communication during Mars missions as an opportunity and springboard to strengthen the crew's autonomy, technical solutions are sought so as to secure continued monitoring and the associated minimal input of astronauts. This has raised alarm among several Russian cosmonauts and space experts. Kalery, Sorokin, and Tyurin [8], for instance, argued that, due to the increased focus on such technical solutions, the ISS's primary objectives are being overlooked, that is, being on the front edge of science and technology in the exploration of the unknown, and targeting the crew's ability to act autonomously, display initiative and sustain logical and technical adequacy during spaceflight.

2.2. Positive reactions to spaceflight

Traditionally, the major concerns of space agencies involve the avoidance or reduction of the negative psychological consequences of spaceflight. Hence, psychological knowledge was mainly used for the selection of a crew capable of functioning under stressful conditions and for the development of countermeasures to diminish the psychological hazards of spaceflight [2,14]. However, Suedfeld [17] highlighted that an exclusive focus on the negative aspects of spaceflight, such as astronauts' stress and social isolation, fails to explain the manifold positive reactions experienced by astronauts. If space is such a stressful environment, why do thousands of individuals apply to become astronauts? Why are experienced astronauts often eager to return to outer space? To resolve this seeming paradox, the concept of *salutogenesis*, which was previously studied in other contexts [18,19], was introduced within space psychology. Salutogenesis refers to individuals' ability to emerge from stressful experiences with increased psychological or even physiological resistance to future stressors [17].

The process of salutogenesis in extreme environments has mainly been studied through individuals' value shifts during spaceflight (e.g., [20,21,22]), polar expeditions (e.g., [23,24]) or space simulations (e.g., [13,25]). In one study on the beneficial effects of spaceflight, Ihle, Ritsher and Kanas [26,27] developed the Positive Effects of Being in Space (PEBS) questionnaire, which is based on the Post Traumatic

Growth Inventory [28], a valid and reliable measure of positive personal growth that can occur following stressful events. This questionnaire was administered to 39 astronauts to identify several positive changes resulting from being in outer space. Overall, all respondents reported at least some change, with the greatest change being found for the subscale *Perceptions of Earth* and *Perceptions of Space*. Some of these changes were so profound that they even led to behavioral change, such as increased environmental activism. Interestingly, also *Changes in Daily Life* were reported, with, for instance, a majority of respondents indicating that their relationship with their family grew stronger. Yet, cluster analysis revealed that individuals vary considerably in their specific positive reactions to spaceflight, with some of them reporting considerable and others minimal change, an issue that deserves further exploration.

Other studies have found similar results, including an increase in the appreciation of the unity of mankind and an increase in self-confidence accompanied by a sense of accomplishment and satisfaction from spaceflight [14,20,21] and polar expeditions [24]. In general, these results show changes primarily in the direction of more concern with humanity and the planet, implying a more open-minded and caring orientation toward the collective good rather than benefits to oneself [22].

Given the enthusiastic reports by space travelers, some authors have described countermeasures that astronauts developed themselves to highlight the positive experiences of outer space. For instance, Johnson [29] has described four ways by which astronauts transform their sterile environment into a new home. First, astronauts *fill their free time* with a variety of meaningful and interesting activities, such as looking at the Earth and identifying various sites and personally relevant places, but also activities such as reading, watching movies, sketching or taking photographs. Second, Johnson [29] highlighted the necessity of *making daily activities fun* as to nurture the psychological health of astronauts. Humor plays an important role in this and in some situation helps to smooth crew-ground interactions. According to many astronauts, practical jokes, playful interactions and experimenting with food are common practice on the ISS, and help to alleviate the burdens of daily activities. Third, *space traditions* have been extensively observed, especially in Russian spacefaring, but have also found their way to the ISS in the form of handover ceremonies when there is, for instance, a change of command. Celebrations of space activities include specific space history landmarks that occurred during their time on the station (e.g., the anniversary of the first man launched into space), personal landmarks of the crew (e.g., breaking a previous record of time in space), and recognitions of a job well done (e.g., Extra-Vehicular Activity). These are usually celebrated with a special meal that has been especially selected for the occasion. Finally, communication with, and thoughts about *friends and family* have helped to close the gap between home on Earth and outer space. Contact with loved-ones, either through direct audio or video messaging, regular updates on news from home and care packages were viewed positively by all astronauts, as it elicited the feeling they were involved in the daily life of their friends and families.

Overall, two conclusions can be drawn from these first studies. First, they suggest that positive reactions to human spaceflight are a fairly common instead of a rare experience. Second, these positive experiences may play an important role not only in safeguarding astronauts against experiencing ill-being, but they may even have a health-enhancing effect. Despite these findings, many researchers remain concerned with the fact that space agencies and space psychologists primarily focus on the negative effects of spaceflight, and do not pay sufficient attention to the beneficial long-term after-effects of spaceflight [13,14,30]. As a consequence, very little is known about how these benefits come about and how they can be promoted through the development of particular measures.

2.3. Conclusion

When considering the topics of crew autonomy and the positive effects of spaceflight, it is interesting to note that, although several studies described these phenomena in detail, little is understood about their underlying psychological dynamics. Such lack of deep understanding prevents us from developing effective countermeasures aimed at alleviating the detrimental effects of reduced crew autonomy and harvesting the favorable effects of spaceflight on psychological well-being.

Additionally, sending humans to Mars brings forward a series of potential new hazards, the effects of which remain difficult to study on Earth [2]. With this unknown era of human spaceflight ahead, it is timely to borrow and further develop ideas from other research areas of psychology. Indeed, as current knowledge of space psychology may have reached its limits when it comes to Mars missions, a more holistic view on human functioning could provide helpful predictions about potential psychological challenges and countermeasures during an interplanetary mission.

The question then arises which theoretical framework could shed some light on current issues in space psychology and allow for the formulation of predictions about future psychological challenges of a Mars mission? When looking for such a framework, several criteria need to be taken into consideration. One has to look for:

- A theory embedded in positive psychology, meaning the theory not only focuses on the avoidance or reduction of ill-being, but also on the nurturance of well-being and its underlying processes.
- A theory that is universal, that can be applied across cultures, age, educational level, and gender.
- A theory that is strongly evidence-based and that has been studied and implemented successfully across several life domains and settings.
- A theory that can provide specific predictions and countermeasures to reduce the stressful aspect of missions, while at the same time nurturing astronauts' psychological well-being.

When reviewing current psychological knowledge, the Self-Determination Theory [31] seems to be a good fit for these criteria.

3. Self-Determination Theory

3.1. Nutrients of growth

Self-Determination Theory is a macro theory of human motivation, behavior, and well-being [1,32], which investigates people's innate psychological needs that are at the basis of their motivation and personality integration, as well as the conditions that foster those positive processes. The theory can be used to make predictions about the way social environments can be designed to optimize people's development, performance and well-being. SDT is strongly embedded in positive psychology, as the theory helps to explain how people's natural tendency for growth and learning can be enhanced and elevated [33,34]. At the same time, it accounts for ill-being and maladaptive behavior by regarding them as outcomes of encountered frustration of these same psychological needs. In doing so, SDT goes beyond most positive psychological theories because it provides a dialectic account of both the positive and negative processes in human development [1,6].

According to SDT, people have three inherent psychological needs: competence, relatedness and autonomy.

1. When people experience *competence*, they feel effective and successful in dealing with the environment. It is the belief that one has the ability to influence important outcomes.
2. When people experience *relatedness*, they feel connected and experience care for important others, through satisfying, supportive social relationships.
3. When people experience *autonomy*, they experience a sense of personal choice, volition and psychological freedom, through acting upon personally endorsed values and interests.

Different from other motivational frameworks, including the Motive Disposition Perspective, [2] which consider the needs to be personal preferences acquired through different childhood experiences [40]. SDT considers these needs to be inherent and universal. Also, whereas other frameworks focus on interpersonal differences in the strength of needs, SDT focuses on the very satisfaction of these needs. The argument is forwarded that the satisfaction of the psychological needs for competence, relatedness and autonomy would yield benefits regardless of people's cultural background, gender and socio-economic status. These needs are not merely theoretical constructs; they were proposed in an attempt to meaningfully interpret a wealth of findings obtained in studies relying on a variety of study designs, making use of diverse methodologies, and sampling participants differing in age, educational and cultural background [31].

Across these studies, satisfaction of the needs for relatedness, autonomy and competence have been found to foster well-being and development, and are therefore considered essential nutrients of growth (e.g., [41,42]), while the very frustration of these needs engenders passivity, alienation, or even opposition (e.g., [43]). To the extent that astronauts volitionally engage in daily activities, experience a sense of mutual care with the ground crew and other astronauts, and feel effective in dealing with the challenges they encounter, they are more likely to thrive. Although no single empirical study has provided empirical support for this claim among astronauts, abundant research in diverse populations has provided evidence for the benefits associated with need satisfaction and the costs associated with need frustration (see e.g., [1,6]). For instance, in the work domain, research has shown that employees who experience greater need satisfaction report feeling less exhausted and more engaged in their job [44].

Further, a variety of methods have been used to study people's experienced need satisfaction and need frustration. Within the SDT tradition, the assessment of need satisfaction or frustration is usually done by self-report. For instance, participants are asked whether they feel effective in executing their daily activities (competence), whether they feel connected to others (relatedness) and whether they feel pressured to do certain things (autonomy; e.g., [41]). Apart from explicit self-reports, nowadays scholars are developing a number of implicit measures to tap into need satisfaction as well (e.g., [45]). Additionally, to document the consequences of need satisfaction or frustration, several measures other than self-reports have been used to assess health, motivation, performance and behavior, such as teacher-rated school adjustment of children (e.g., [46]), free choice persistence (e.g., [47]), or peaks in cortisol secretion (e.g., [48]), to name a few [6].

Overall, from existing evidence we can conclude that individuals from different socio-economic and cultural backgrounds, different ages and genders benefit from need satisfaction (e.g., [41]). Increasingly, scholars (e.g., [49,50,51]) have examined whether the benefits of need satisfaction also emerge for those being low in the strength of these needs, as suggested from the Motive Disposition Perspective. It appears that the benefits of need satisfaction are more pronounced for those with a greater strength of these needs. Yet, this moderation effect appears only for implicit measures (e.g., [51]), and not for explicit measures of need strength (e.g., [41]).

As for the contextual support and undermining of the psychological needs, different methodologies have also been used. To illustrate, in experimental studies, the degree of need thwarting has been experimentally manipulated by

[2] *The connection between SDT and the Motives Disposition Theory [35,36] has gained increasing attention in recent years. Although these theories deal with closely related topics, the psychological needs are defined differently (see [31] for a more extensive discussion). The motive for affiliation is defined as the preference for warm, intimate relationships and is similar to the need for relatedness. However, whereas the need for competence involves the experience of a sense of effectiveness and mastery in dealing with the environment, the motive to succeed involves the recurrent desire to surpass standards of excellence [37,38]. The need for autonomy differs from the motive to exert power [39]. Most motive researchers regard the need for power as the desire to influence others in order to feel strong. In contrast, the need for autonomy reflects an individual's need to experience willingness and voluntariness in his actions [38].*

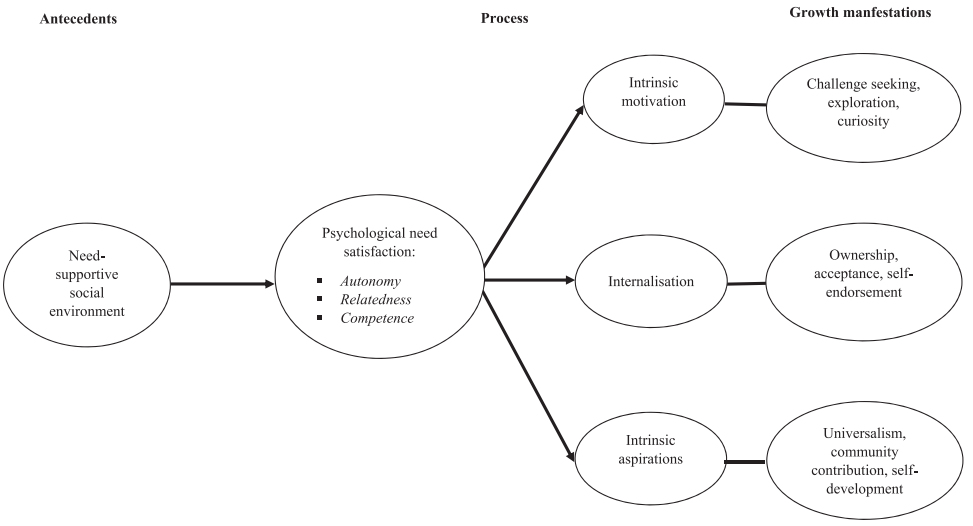

Fig. 1. Graphic overview of growth model of Self-Determination Theory [1,57].

creating conditions where people are approached in cold and dismissive ways (frustrating relatedness; e.g., [52]), are given judgmental feedback (frustrating competence; e.g., [53]) or are subjected to pressuring deadlines, evaluations and monitoring (frustrating autonomy; e.g., [54]). In other experimental studies, people are shown care and made to feel welcome (fostering relatedness; e.g. [52]), they are provided with constructive feedback (fostering competence; e.g., [55]) or they are involved in the decision-making procedures (fostering autonomy; e.g., [56]). To the extent that individuals' needs got supported, they reported enhanced engagement and well-being, continued persistence and improved performance, while they were more likely to defy or give up in need-thwarting circumstances.

3.2. Manifestations of growth

Apart from documenting the well-being and performance benefits of the satisfaction of these psychological needs, SDT has also specified the processes through which these effects accrue. That is, need satisfaction is said to fuel three different growth manifestations, all of which are relevant for the functioning of astronauts. As can be noticed in Fig. 1, these three growth manifestations concern the processes of (a) intrinsic motivation, (b) internalization, and (c) intrinsic goal pursuit [1,57].

3.2.1. Intrinsic motivation

Intrinsic motivation is described as the inherent assimilative tendency to seek out novelty and challenges, to extend and exercise one's capacities, and to explore one's inner and outer environment driven by curiosity [58] (cfr. Fig. 1). When intrinsically motivated, people engage in the activity for its own sake as the reward lies in the satisfaction inherent to or spontaneously following from the activity itself. For instance, when intrinsically motivated, people find their jobs to be interesting and enjoyable and they may even be passionate [59].

Astronauts who express excitement at the prospect of going into space to discover new things can be described as intrinsically motivated. Although individuals cannot be forced to enjoy and be interested in an activity, a social environment that supports individuals' needs for autonomy and competence has been shown to awaken and nurture intrinsic motivation and passion in individuals. Indeed, to the extent that individuals are offered choice (e.g., [60]) and provided sincere, competence-affirming feedback [55,61], they are more likely to develop an interest in the activity at hand. In contrast, the use of autonomy-suppressing and pressuring language (e.g., [62]) and criticism (e.g., [63]) have been found to forestall need satisfaction and subsequent intrinsic motivation. Relatedness satisfaction is said to play a more distal role in the nurturing of intrinsic motivation [31], as individuals can also enjoy engaging in leisure time activities by themselves. Indeed, astronauts may like to have some free time reserved for themselves, without much interaction with other crewmembers.

3.2.2. Internalization

Rather unfortunately, much of what people do is not intrinsically motivated. That is, many of our daily activities are not interesting, yet they are important to do. This is also true for astronauts, who may feel little challenge and interest in executing (some) routine activities. Does this imply that astronauts by definition feel pressured to execute such activities? No. To the extent that they have come to endorse or internalize the reasons for performing the activity, they are more likely to perform these activities with a greater sense of willingness.

In this respect, SDT differentiates between different types of extrinsic motivation, depending on the degree to which internalization has occurred [1]. Thereby, *internalization* refers to the adoption and full acceptance (i.e., endorsement) of an initially externally offered value or behavioral regulation. Internalization is high when people perceive the self-importance and personal value of a specific activity. In this case, people are said to be autonomously motivated as they engage in the activity with a sense of volition, willingness and ownership of their behavior (cfr. Fig. 1). In contrast,

when people engage in an activity because they feel externally pressured to do so (e.g., to avoid criticism or to gain appreciation) or to meet internal feelings of pressure (e.g., to avoid feelings of guilt, shame or to attain self-aggrandization), their actions are said to be regulated by controlling forces. In the case of controlled motivation, no or only partial internalization has occurred.

The satisfaction of all three needs is said to be integral for the internalization and full endorsement of activities. Indeed, requests that are formulated by significant others to whom one feels strongly attached are more likely to be accepted. Similarly, one is more likely to internalize the introduced requests when one feels efficacious in executing them. Yet, full internalization is only achieved when a sense of psychological freedom and autonomy need satisfaction is experienced [31,63]. Indeed, one may comply with instructions and effectively carry out activities out of a sense of conflicted loyalty vis-à-vis the person introducing the request. Yet, only when this request is formulated in an autonomy-supportive way, for instance, by allowing a person to voice their opinion or by explaining the importance of the task at hand, one is more likely to fully endorse the reason for performing the activity [64].

At this point, it is crucial to clarify the exact meaning of autonomy as conceived within the framework of SDT. In SDT, autonomy is not equated with *independence*, that is, as making decisions without reliance on external guidance. Instead, autonomy is defined as self-endorsement, which pertains to the degree to which one fully concurs with the reasons or motives underlying one's actions, such that one's actions are grounded in authentic values and interests [63,65].In other words, autonomy does not relate to the locus of decision-making (i.e., *Who* is making the decision?), which varies from total independence (i.e., without relying on anyone) to total dependence (i.e., completely giving away ownership of the decision). Instead, autonomy relates to the motives for making decisions independently or dependently (i.e., *Why* is the decision made independently, or why is the decision given to someone else?) [66]. Although independent decision-making would grant more opportunities for the enactment and realization of one's self-endorsed convictions and interests (thereby contributing to a sense of volition and inner psychological freedom), autonomy satisfaction can also be experienced in a state of dependence, if the motives for the dependent behavior have been internalized [67]. Fig. 2 provides a graphical overview of this idea as the dimension of independent relative to dependent functioning are crossed with the autonomous and controlled motives underlying these behaviors. When mission control grants astronauts the freedom to make independent decisions or when it provides astronauts with support and guidance on request, then mission control can be said to promote, respectively, independence and dependence in a volitional (autonomous) fashion (i.e., the upper left and lower left quadrant). Similarly, mission control can also promote dependence either in a volitional (i.e., the lower left quadrant) or in a controlling fashion (i.e., the lower right quadrant). When autonomy is operationally differentiated from independence, it has been shown to be positively related to psychological well-being, even in collectivistic cultures (e.g. [66]).

3.2.3. *Intrinsic life goals*

SDT is also concerned with the differential content of types of life goals that people pursue [68]. Intrinsic goals, such as community contribution, self-development, and universalism (i.e. the promotion of welfare for all humankind and the natural environment [69]), are goals that are inherently satisfying because they are more conducive to individuals' need satisfaction [70,71]. Extrinsic goals, such as financial success, physical appearance, and image, are oriented towards external valuation because they require the contingent reaction of others and are therefore more likely to be at odds with the satisfaction of one's basic psychological needs [71].

The satisfaction of the psychological needs is not only said to follow from the content of one's pursued life goals, but it also said to be rooted in a different degree of encountered need satisfaction. Specifically, when people experience need satisfaction, they are likely better in touch with their personal values and goals, and they therefore likely attach greater importance to intrinsic life goals. In contrast, when people experience need frustration, they become more likely to pursue extrinsic goals, as the approval of others would constitute a way to gain some sense of worth so as to compensate for encountered need frustration [72].

This idea is supported by several empirical studies. Indeed, individuals were found to be especially oriented towards extrinsic life goals when growing up in social environments that undermine growth and need satisfaction, such as in a cold and controlling family [73,74], in situations where people feel threatened [75] or are made to feel insecure and self-doubt [76], and when family socio-economic status is low [77]. By contrast, individuals growing up in need-supportive contexts were found to be much more oriented towards intrinsic life goals (e.g., [78]).

Interestingly, some studies suggested that natural environments can also promote the valuation of intrinsic life goals and even engender greater vitality. For instance, experimental studies have demonstrated that people who were immersed in a natural environment (either simulated or real) reported an increased pursuit of intrinsic aspirations, greater vitality, and engaging in more generous behavior, when compared to people exposed to non-natural environments [79,80]. The authors suggested that natural environments may foster experiences of autonomy and connectedness with nature. Specifically, nature can nurture autonomy directly by affording stimulating sensations and opportunities to integrate experience by encouraging introspection and a coherent sense of self, and indirectly by providing an alternative to the pressures of everyday life.

Not only does need satisfaction predict people's orientation towards intrinsic life goals, but numerous studies across life domains (e.g., exercising, school, relationships, work) and in diverse age samples (e.g., adolescents, adults, seniors) have revealed that both the pursuit and the attainment of intrinsic goals, relative to extrinsic goals, is associated with greater health, well-being, and performance (for a review, see [4,81]). Indeed, a recent meta-analysis by

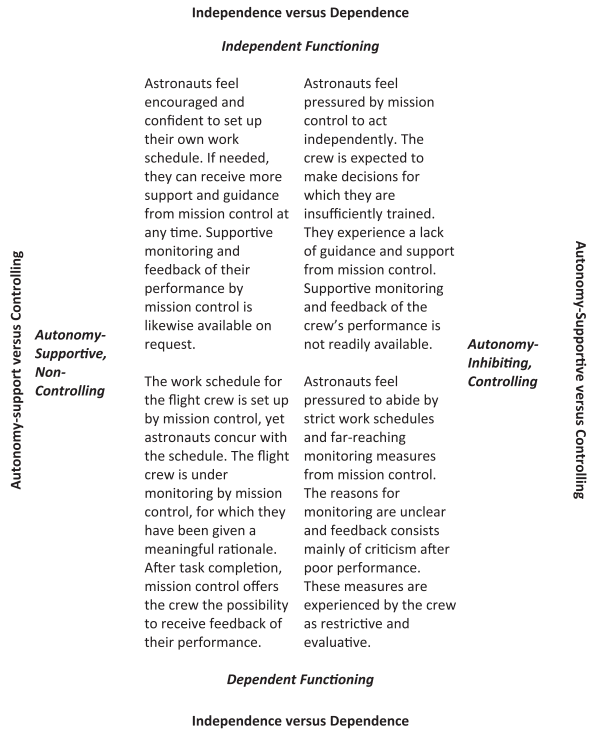

Fig. 2. Graphic overview of the distinction between independence and autonomy dimensions as applied to the interaction between astronauts and mission control (adapted from Soenens and Vansteenkiste [96]).

Dittmar, Bond, Hurst and Kasser [82] provided further confirmatory evidence for this claim.

It is important to note that intrinsic and extrinsic aspirations are distinct from autonomous and controlled extrinsic motivation, since both intrinsic and extrinsic goals can be pursued for either autonomous or controlled reasons. Although intrinsic goals usually tend to be pursued for autonomous reasons and extrinsic goals tend to be pursued for controlled reasons, the content of, and reasons for pursuing aspirations can be crossed. This was done in a longitudinal study by Sheldon, Ryan, Deci and Kasser [81] in which the authors assessed participant's goal content ('what' they aspire), their motives for doing so ('why' they aspire) and their well-being. They found that both goal content and motives significantly predicted well-being, after controlling for each-other. Beyond the fact that extrinsic goals are often pursued for controlled motives, and that controlled motivation is predictive of ill-being, it appears that people's intrinsic aspirations positively affect their subsequent well-being.

3.3. Summary

In conclusion, SDT postulates three basic psychological needs that are inherent and universal. Dozens of studies have confirmed that satisfaction of the needs for relatedness, autonomy and competence fosters well-being, while the frustration of these very same needs engenders passivity, alienation or even opposition. Need satisfaction yields these desirable outcomes because it forms the impetus for the actualization of three growth manifestations, that is, the engagement in enjoyable, challenging and interesting activities (i.e., intrinsic motivation), the full endorsement of external requests (i.e., internalization), and the pursuit of inherently valuable goals, such as self-development, community contribution and universalism (i.e., intrinsic goal pursuit).

4. SDT applied to spaceflight

Having reviewed a number of central theoretical constructs within SDT, we now turn to the application of SDT to the topics of crew autonomy and the positive effects of spaceflight. As will be argued, the satisfaction of the needs for relatedness, competence and autonomy and the growth manifestations it engenders, may play an important role in human spaceflight.

4.1. How to promote volitional functioning during spaceflight?

Much of the flight crew's work consists of routine, monotonous or unpleasant tasks, such as cleaning, maintenance tasks, physical exercise and medically invasive or monotonous experimental tasks. From the SDT-perspective, such tasks can be described as being low in intrinsic motivation. Yet, the degree of willingness to perform these non-enjoyable activities among astronauts will depend on the internalization of the reasons underlying their execution. Clearly, astronauts who went through very strict and demanding selection procedures are presumably highly motivated and willing to put effort into their profession. Yet, the way their ongoing daily activities are regulated by mission control will engender variable degrees of need satisfaction and need frustration and yield resulting consequences for the ownership of their daily behavior. In fact, it seems that the tendency in Western space agencies to increase bureaucracy, flight rules and safety regulations may hamper astronauts' need satisfaction. For such a highly trained and capable flight crew, this type of work environment may even thwart their need to feel volitional and competent in their activities. In an attempt to resist these need-thwarts, astronauts may make independent decisions without informing mission control so as to establish their autonomy. Yet, such independent decision making is not volitional, but rather reactive and, hence, controlled in nature. That is, it reflects a form of opposition, which has been found to result from the frustration of the needs for autonomy and competence [43]. Perhaps, although not necessarily deliberate, it is a way for the crew to attempt to regain a sense of freedom and efficacy. Despite the constraints of the environment, from an SDT-perspective, mission control can steer astronauts in more motivating and need-supportive ways. Specifically, the flight crew could (a) be granted action choice and option choice in their daily tasks [60,83]. However, even in situations of high dependency, mission control can still take autonomy-supportive measures, for instance by (b) explaining why they monitor astronaut's behavior, and

by (c) providing effective and competence enhancing feedback.

4.1.1. Option and action choice

Although many space experts are dreading the increase in crew independence that is bound to happen for interplanetary travel, and fear for the potential threat of an isolated independent crew [2], SDT actually suggests that an increase in crew independence could provide new opportunities for the crew to feel more competent and volitional, by letting the flight crew choose which tasks to perform (option choice). These opportunities to choose between options generally facilitates the perception of choice and, hence, a sense of autonomy or willingness. However, in cases where tasks have been assigned to crewmembers, they can still be given choice within the task (action choice), by for example deciding the timing and pace according to their preferences, which is likewise expected to increase autonomy.

Unfortunately, only a few pilot studies have provided preliminary support for the positive effects of an increase in crew choice. Specifically, a simulation study by Kanas et al. [84] showed that an increase in crew action choice was well-received by the crewmembers, while no adverse effects were observed and mission goals were generally accomplished. Other studies provided evidence for the importance of choice for improved mood, personal discovery, and innovation. For instance, Roma et al. [85] reported that when members were free to choose the way they performed their tasks (cfr. action choice), they showed better performance, less negative emotions, more socially-referent language and lower levels of salivary cortisol production. Similarly, Sandal, Bye, and van de Vijver [25] found that the Mars 500 crewmembers' perceptions of stress decreased when they were allowed greater option choice. They described the reduction in contact with mission control as “a relief”, resulting in a calmer atmosphere and decreased on-board tension. Overall, these studies suggest that an increase in the crew’s volitional functioning, either through option or action choice, may enhance their well-being and performance, as predicted by SDT.

Of course, a number of critical questions remain. First, initial studies [85] also suggest that there might be cultural differences in the enactment of autonomy. From an SDT-perspective, this is no surprise. That is, the route to the experience of volition may be – at least to some extent – culture-bound. While astronauts from Western and individualistic nations may experience a greater sense of volition through independent decision making, astronauts from Eastern and collectivistic nations may achieve a greater sense of volition by acting dependently, that is, by complying with guidelines and instructions [66,86]. However, in spite of their elevated dependency, astronauts from collectivistic nations would not benefit from pressure!

Second, when space experts talk about the inevitable future increase in crew autonomy, from an SDT-perspective, they are actually talking about crew independence, i.e. the crew acting and taking decisions independently from mission control (see Fig. 2). What ultimately matters from the SDT-perspective is whether such dependent or independent behavior is being forced upon astronauts, or whether it is being volitionally enacted by them. More research is needed to identify the appropriate degree of afforded crew independence. This will likely be determined by circumstantial elements, such as the difficulty and risks associated with the task at hand, whether the activity belongs to astronauts' personal territory or domain and the presence of technical and physical restrictions. For instance, when tasks are more difficult, when more risks are associated and when technical or physical restrictions are present, astronauts' independent functioning is restrained. Instead, with respect to more personal issues (e.g., leisure time activities), they may be granted more choice and independence. Likewise, when astronauts are highly experienced with a certain task, the guidance may be less desirable as continued instruction may signal distrust to the astronauts, and therefore may be experienced as controlling and autonomy-suppressing. In other words, the ongoing support of astronauts’ psychological needs essentially is about being sensitive about how and to whom certain tasks are presented, and about building in different degrees of choice. Such sensitivity requires mission control personnel to take the frame of reference of the astronaut as to estimate whether the task fits the astronaut's interest and expertize level.

Finally, crewmembers will need to be properly trained for an increase in crew independent decision making, preferably during actual space missions. The increase in independence can be a gradual process, in part because astronauts currently lack the routine of making their own decisions, in part because some choices made may yield considerable risks for which they may be made accountable. To facilitate this process, mission control could start by involving flight crew in decision-making processes. Their opinions should be heard and action could be taken in mutual agreement. By doing so, astronauts can regain a sense of volition, and will be better able to internalize the rationales behind their daily tasks, thus creating the possibility to enhance autonomous motivation and psychological well-being. Over time, astronauts could then be granted greater decision-making power over more difficult decisions involving greater risks. This evolution should not be dreaded but rather viewed as an opportunity for the crew to become more strongly engaged. The ISS could be used to simulate an expedition to Mars, as has been suggested by several authors already [3,8,87].

4.1.2. Meaningful rationale for monitoring

Even in situations where no possibilities for either option or action choice are available, as is often the case in present-day ISS missions, astronauts can be approached in an autonomy-supportive way. Critical in this respect is that the astronauts' frame of reference is maximally supported, for instance, by fully recognizing the irritation that may arise from being denied choice and input. Also, the provision of a meaningful rationale for introduced instructions or ongoing monitoring is critical. As for the monitoring by mission control, astronauts perform their tasks under constant audio and video surveillance. Surveillance as such is often viewed as fairly controlling and evaluative, with resulting implications for individuals' sense of autonomy

and intrinsic motivation [88]. This effect may even be enhanced among astronauts given astronauts' videotaped behavior is made readily available to a broader public. The added value of such public monitoring for astronauts' daily functioning can be questioned, as it may increase pressure and even elicit anxiety. This does not imply that astronauts' behavior should not be monitored at all, yet, the way of doing so yields differential motivational implications.

In one informative experimental study, Enzle and Anderson [54] experimentally varied the reason for monitoring participants' behavior so as to impact the perceived meaning of the monitoring. That is, the monitoring can be perceived as more informational and helpful or rather evaluative and pressuring [89], with resulting consequences for individuals' need satisfaction and their willingness to comply with the requests of the surveilling individual. Specifically, in the Enzle and Anderson study [54], participants were told that the aim of monitoring their behavior was either to ensure that participants would strictly comply with the instructions and to evaluate their performance (i.e., evaluative monitoring) or they were told that they were being watched out of pure curiosity, that is, to see how they were handling the tasks (i.e., informational monitoring). So, both groups of participants were monitored, yet, those in the evaluative monitoring group not only lost their interest in the activity when compared to participants in the informational monitoring group, but also when compared to the group who were not provided any rationale at all. Therefore, it is crucial for mission control to pay careful attention to the specific intent of monitoring measures and to explicitly provide the crew with informational and supportive rationales for surveillance. In this way, astronauts may come to better understand the necessity for continued monitoring and show less signs of resistance.

4.1.3. Effective feedback

Abundant research has demonstrated the importance of feedback for the satisfaction of individuals' need for competence [55,90]. Positive feedback provides individuals with affirmative feedback regarding their capabilities and may boost their confidence to handle future challenges. However, the provision of corrective feedback, that is, feedback that is provided in response to lower performance or mistakes, is inevitable, as it is inherently tied with the learning process. Corrective feedback needs to be distinguished from negative feedback. Whereas negative feedback focuses on the end result and on the astronauts' failure to achieve a certain outcome, corrective feedback focuses more on the process itself and the way individuals can remedy their task performance.

Given that crew-ground conversations are monitored by thousands of people, the provision of authentic and honest feedback can be fairly challenging, especially if this information yields messages of failure. Nevertheless, there are different ways in which criticism can be delivered, and not all of them are necessarily need frustrating. Research has shown that even corrective feedback does not necessarily forestall individuals' competence, provided it is communicated in an autonomy-supportive way. Several strategies are vital in this respect [61,91]. For instance, after task completion, mission control could solicit the astronauts' opinion about their performance instead of providing straightforward feedback and advice themselves. Further, mission control could ask permission to provide feedback, thereby creating a greater receptivity for the corrective feedback. In addition, the corrective feedback could be accompanied by a meaningful rationale so astronauts could come to fully understand the need for correction and change. Finally, the feedback would need to be sufficiently clear and informative so astronauts would understand clearly how to improve the situation, by preference and at their own pace.

Overall then, while positive feedback and stimulation is vital to guarantee competence need satisfaction and continued engagement, mission control will inevitably also provide corrective feedback. Their style of doing so may vary considerably though, with resultant implications for astronauts' experience of overall need satisfaction.

4.2. How to promote the beneficial effects of spaceflight?

From an SDT-perspective, the positive effects of spaceflight reported by astronauts can be explained as consequences of improved need satisfaction. Several actions can therefore be taken by mission control to safeguard these effects and harvest their benefits, such as (a) increasing the experience of competence through the provision of challenges and celebrations, (b) creating the possibilities for astronauts to personalize their stay in space so as to experience a feeling of autonomy and (c) securing a strong connection with Earth to satisfy a sense of relatedness. To conclude, we discuss possible individual differences in need satisfaction, and how these could potentially influence crew selection.

4.2.1. Challenges and celebrations

When reviewing the experimental study by Ihle, Ritsher and Kanas [26,27], it becomes evident that many of the subscales that were used to evaluate the positive effects of spaceflight yield a reference to the satisfaction of the need for competence. The subscale of *new possibilities* ("*New opportunities are available which would not have been otherwise*") and *personal strength* ("*I know better I can handle difficulties*") reflect a feeling of competence that is being satisfied by successfully completing such an ambitious endeavor. The space environment provides new challenges and situations in which the astronaut can discover new talents and develop new capabilities. In fact, the whole idea of salutogenesis as presented by Suedfeld [17] can be regarded as a redefinition of the satisfaction of the need for competence: the ability to cope with stressors and conceive them as challenges providing an opportunity to exercise competence and mastery. The importance astronauts attach to *space traditions and celebrations* [29] can be regarded as an intense experience of competence that is being acted out during a ceremony. Celebrating the successful completion of a difficult task such as an EVA or a record of a hundred days in space helps to boost their vigor and many astronauts have emphasized the importance of these rituals. Traditions and celebrations may therefore be actively encouraged by mission control. For a

Mars mission, festivities can be simultaneously celebrated on Earth and recordings of these events could be exchanged between mission control and the flight crew.

4.2.2. Personalization of space

As has been previously discussed, experiencing a sense of autonomy can be challenging for astronauts in a space environment. At the same time, having *leisure time* and being able to execute *personalized routines* was repeatedly reported as a key path towards well-being by many astronauts. As astronauts are often subjected to bureaucratic rules and are subjected to ongoing monitoring from mission control, leisure activities allow one to temporarily get away from these pressures and to recharge one's batteries. As leisure time activities are often intrinsically motivated, that is, executed out of inherent enjoyment, they are accompanied with a sense of volition. Reports show considerable variability in favorite leisure activities and demonstrate the importance of personalizing leisure time, according to the astronaut's own interests. Likewise, *making daily activities fun* can be regarded as an attempt by the crew to achieve a sense of volition. Therefore, mission control should make sure astronaut's leisure time is respected, and the possibility to personalize leisure times should be guaranteed. For Mars missions, a possible change in preferences and interests in certain leisure activities may be taken into consideration.

4.2.3. Connection with Earth

A *stronger appreciation for the Earth and space*, and *stronger relationship with family members* [26,27] are indicative of the nourishment of the need for relatedness. Presumably, when flying in an aluminum tube 400 km above the Earth's surface, astronauts are both physically and psychologically taking a more observing perspective, which allows them to connect more deeply with humankind, nature, and the universe in general. Indeed, almost all astronauts reported an increased appreciation for the Earth's beauty, along with more involvement in environmental causes. These results are in accordance with studies suggesting that natural environments increase valuing of intrinsic aspirations and vitality because natural environments create experiences fostering autonomy and relatedness with nature [80]. It seems as if the space environment and the views of Earth have a similar beneficial effect on astronauts, orienting them towards intrinsic goals and nurturing a sense of universalism and community (see Fig. 1). It is possible that the views of Earth encourage introspection and a more mindful stance, which foster autonomy and relatedness, and subsequently the valuing of intrinsic aspirations [92,93]. This increased valuing of intrinsic aspirations is something that may be further encouraged and exploited, as several studies found intrinsic aspirations to be conducive to individuals' psychological well-being [70,94].

While Mars missions may constitute an opportunity for improved autonomy and competence satisfaction, this may not be the case for relatedness. Due to the distance between Earth and Mars and the associated communication delay, direct contact with loved ones, a crucial factor for individuals' psychological well-being [29], will no longer be possible. Of course, the crew can still rely on email and possibly video recordings to keep in touch with friends and families, and they will still have each other to rely on for emotional support. However the potential frustration from such a situation is not to be underestimated, as feelings of loneliness may be more likely to surface. Indeed, based on SDT, one can predict that social isolation and the lack of intimate human relationships might constitute the major risk of a Mars mission. Therefore, more research should be performed and more countermeasures should be developed to take on this particular issue. Mission controls primary focus could therefore be to assure a strong connection with Earth, through optimizing communication between the crew and their loved ones. Regular updates on important news, political changes, and sport events – depending on the crew's interests – could be sent to the crew, as well as frequent inquiries regarding their well-being. An increased reliance on computers to assess the crew's cognitive state and to present prevention and intervention information, as has been proposed by some space experts [16], might induce an opposite effect than intended. It could restrict the crew in their sense of relatedness, as having to entrust one's personal feelings to a machine might actually induce a sense of isolation and loneliness.

4.2.4. Individual differences

The study by Ihle, Ritsher and Kanas [26,27] also highlighted substantial individual differences in the positive effects of spaceflight. According to SDT, the satisfaction of the needs for relatedness, competence and autonomy should yield universal benefits. Yet, there could be substantial variation, that is, individual differences, in the way these needs are satisfied, a possibility also recognized within the Motive Disposition Perspective. For instance, a person who shows less change in perceptions of the Earth, might simply be less dependent upon a view of the Earth for relatedness need satisfaction. This person might benefit more from interpersonal interventions to feel connected to their loved ones. Although these issues would need to be empirically confirmed in future research, they can be taken into consideration when selecting a crew for a specific mission. If one profile is more adaptive or if each profile corresponds to different performance patterns, these should be taken into account when composing flight crews [26,27].

Although the positive reactions to spaceflight that have been described are considered to be desirable, it could be possible that those who have especially positive experiences in space may have a particular difficulty reintegrating with their family or other aspects of their social environment upon return [95]. Individual differences in the way needs are satisfied could therefore also be examined in relation to post-flight adjustment. How will astronauts who seek to overcome tremendous challenges react when they return and face the conditions of everyday life? Will they manage to adjust or rather go through a difficult transitional period, given the immense contrast between the participation in the greatest adventure of humanity and the everyday terrestrial concerns? Unfortunately, so far, very little is known about the individual

differences in the way needs are satisfied. As previously mentioned, it appears that the benefits of need satisfaction are more pronounced for those with a greater strength of these needs, when implicit measures are used, but not for explicit measures of need strength. Overall, this topic deserves further research.

5. Conclusions

Although dozens of studies in space psychology have generated fascinating insights into the psychological environment of astronauts during missions, more systematic research is needed to fully understand the influences, mechanisms and consequences of the stressors and benefits of human spaceflight. Throughout this review, we hope to have shown that SDT is valuable framework that can be used to synthesize these findings, bring further conceptual clarity, and to offer a number of future research directions. The notion of the psychological needs for autonomy, competence and relatedness, the essential nutrients of growth, provides a deeper insight into the dynamics underlying diverse observed psychological phenomena, sheds a refreshing light on potential future psychological stressors for interplanetary travel, and allows for the formulation of possible countermeasures to alleviate these stressors as well as the formulation of measures to actualize the potential benefits. Yet, given that many of suggested (counter)measures are purely derived from the theory, research is needed to test their effectiveness. Thus, multiple challenges still await psychologists and researchers working in the area of human spaceflight.

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