Promoting Tech Transfer Between Space and Global Mental Health

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INTRODUCTION: Numerous issues in mental health benefit from technological innovation. An example involves the mental health challenges of long-duration spaceflight (such as a Mars mission), including prolonged confinement, microgravity, and different sunlight exposure lengths. Persisting on Earth are global mental health challenges stemming from disease burdens, limited interview-based diagnostic systems, trial-and-error treatment approaches, and suboptimal access. There is potential for cross-pollinating solutions between these seemingly disparate challenges using a range of emerging technologies such as sensors, 'omics', and big data. In this review, we highlight the bidirectional value of mental health technology transfer aimed to address issues both on Earth and in space.

METHODS: We prepared a systematic review of studies pertaining to mental health technological innovation and space medicine.

RESULTS: For Earth mental health technologies translatable to long-duration space missions, we cite several example technologies, including device-based psychotherapy and social support, conversational agents 'aka chatbots', and nutritional and physical activity focused mental health. Space technologies translatable to Earth mental health include remote sensing devices, global navigation satellite systems, satellite communications, chronotherapies, and nutritional advances.

DISCUSSION: There is a rich history of space technologies informing Earth technological trends, including general health care on Earth, and vice versa. To avoid the traditional happenstance approach that results in delays, missed opportunities, and increased cost, and to improve outcomes for both Earth and space utilization of these technologies, we propose increased dialogue and training opportunities to enhance innovation and outcomes.

KEYWORDS: mental health, astronautics, space medicine, technology, psychology, psychiatry.

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The first human interplanetary mission to Mars is anticipated to take place this century. One analysis of space travel modeling and propulsion calculations suggests a time frame of ~930 d as a standard time frame for round trip travel to Mars (including ~180 d to Mars, ~570 d on Mars, and ~180 d to return). This timeframe is more than ~500 d beyond the duration that humans have remained confined in a space mission to date.

The results from a 520-d simulated interplanetary mission to Mars (i.e., a ground-based analog isolation study) suggest significant psychological challenges and demands during prolonged confinement even without the physiological challenges of space missions such as extended exposure to radiation and microgravity.[3,7,32] Indeed, existing space missions have already reported a number of psychiatric problems that occur.[32,58] The most common are adaptation reactions that generally present

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with symptoms of anxiety or depression.[57,59] Key challenges in space include isolation from friends and family, confinement, conflict among flight participants, pervasive danger, circadian disruption secondary to shifting light exposure, spaceflight-associated stressors (e.g., microgravity, radiation, and noise), boredom, monotony, and an unusual environment. Due to communication delays and limited medical support, a Mars mission will also require substantially more crew autonomy than prior space missions.[60] Current knowledge, practice, and preparations are not equipped or situated to support the unique circumstances these astronaut pioneers will face. Clearly, innovation is required to mitigate these major concerns for a Mars mission.[109]

While certain technological innovations have been postulated to add value in long-term space missions, clinical trials assessing the value of these tools are challenging due to the cost and operational constraints of testing for or during a long-duration spaceflight. Furthermore, the biological changes associated with prolonged microgravity during a spaceflight make Earth trials limited in applicability. Yet, there are notable examples taking this challenge head-on, including MyCompass, an online cognitive behavioral therapy platform currently being tested for its relevance and value for long-term spaceflight.[106] This ground-based clinical trial will involve 135 participants who are demographically similar to astronauts: well-educated individuals who are relatively healthy and have high stress occupations, e.g., physicians, residents, and graduate students. Participants will be randomly assigned to one of three groups: 1) MyCompass intervention in isolation; 2) MyCompass intervention supported by delayed therapist contact via text messages; or 3) or MyCompass intervention supported by delayed therapist contact via recorded video messages. The asymmetric time lapse in delivery of therapist support is designed to mimic the real-life delay of up to 44 min that would be encountered in long-duration space missions. The treatment will occur over 7 wk (49 d), followed by assessments 4 wk later to evaluate progress and the participant's experience of the treatment package. This clinical trial will be the first time this technology will be tested among 'astronaut-like' adults. The research will assess how effective such programs are with and without video or text-based messaging, when real-time and face-to-face psychological assistance is unavailable, mimicking constraints of long-term spaceflight.

Concurrent with overcoming the mental health challenges of long-duration spaceflight, extensive innovation is also required to overcome existing mental health challenges on Earth. Indeed, the prolonged confinement of long-duration spaceflight is akin to the COVID-19 pandemic social and physical distancing. Disability and lost productivity secondary to mental illness are a significant global burden in developing and developed countries alike.[118] Conditions include depression, anxiety disorders, schizophrenia, bipolar disorder, alcohol and drug use disorders, eating disorders, personality disorders, attention deficit hyperactivity disorder, autism spectrum disorder, and health conditions with strong linkages with psychiatric copresentations such as migraines, dementias, and epilepsy. Moreover, these conditions are expected to cost the world \$16 trillion USD by 2030.[75] Individuals with these disorders additionally face increased rates of morbidity and mortality from general medical conditions (e.g., heart disease) as well as illness-related functional disability.[64] There are currently significant limitations with interview-based diagnostic systems, trial-and-error treatment approaches, and limited evidence-based preventive strategies. In addition, mental health care often suffers from the challenges of stigma and discrimination, limited access due to poor funding, hard to access service delivery models, and inadequate numbers of licensed mental health providers.[2,36,75] Many organizations and groups have concluded that these issues are unsustainable, including the U.S. National Council for Behavioral Health Medication Director Institute and the Lancet Commission for Global Mental Health.[36,75,89] Fortunately, however, there are promising developments with technological innovations in digital, personalized, and convergence science-based tools (for reviews see Bousman et al.[17] and Eyre et al.[36,38]).

The concurrent issues of mental health care and support needed for long-duration spaceflights and global mental health lead us to speculate: Is there value in cross-pollination of technological innovations for mental health between Earth and space applications?

To begin with, there is a rich history of space technologies informing Earth technological trends, including general health care on Earth. For example, there are now movements to explore the role of space technologies in global health with frameworks such as the United Nations' Sustainable Development Goals.[31] A scoping review outlined key examples already in use and ready for optimization for global health, such as global navigation satellite systems (GNSS) and geographic information systems used for the study and forecasting of communicable and noncommunicable diseases. The review also outlined satellite communication and global navigation satellite systems for disaster response; satellite communication for telemedicine and tele-education; and global navigation satellite systems to improve autonomy for disabled individuals using geolocation, access to health care, and for safe and efficient transportation.[31]

Conversely, Earth-based tools such as telemedicine are already used in spaceflight medical care.[5] Further, there are a number of potential Earth-based tools which may be effectively used in space mental health, such as chat bots, telemedicine platforms, and app-based support tools; however, there is no systematic model exploring these tools and innovations. We are not aware of any systematic literature exploring the potential value of space technologies in Earth mental health. In this review, we highlight the bidirectional value of mental health technology transfer between Earth and space.

METHODS

Studies were identified for inclusion in this review by searching PubMed, Google Scholar, PsychINFO, and Ovid Medicine from inception through December 2019. Articles were limited to those published in English. The literature search strategy used combinations of the following keywords: mental health, technological innovation, space medicine, Mars mission, brain health, and cross-pollination.

Role of Technology in Clinical Mental Health Innovation

In recent years, technology has emerged as an important clinical tool in mental health therapy.[75] Perhaps the best developed is the area of internet and app-based therapies for mental health disorders. A plethora of evidence-based interventions (some for independent use and some for use in conjunction with mental health professionals) are being studied for conditions including insomnia, depression, bipolar disorder, and anxiety disorders.[126]

A review of 49 studies of digital technology interventions from over 20 low- and middle-income countries and the literature on their use in high-income settings reveals 4 distinct roles of these technologies: technology for supporting clinical care and educating health workers; mobile tools for facilitating diagnosis and detection of mental disorders, including substance use disorders; technologies for promoting treatment adherence and supporting recovery; and online self-help programs for individuals with mental disorders.[86] Lifestyle has become a very active area of investigation and implementation, focusing on diet and physical activity.

Pharmacogenetic-based clinical decision support tools show promise to improve outcomes for medication-based treatment. Several companies have developed pharmacogenetic-based decision support tools, marketed to prescribers to inform the process of medication treatment and dose selection for individual patients.[18] These decision support tools characterize a patient's genetic profile based on a select number of genes.

Driving Mental Health Innovation Through Entrepreneurship

Parallel to advances in mental health technology is the emergence and contribution of the entrepreneurial sector in mental health innovation. This trend is encouraging and exemplified by the number of start-up and investments focused on mental health. One report examining venture capital-backed deals into mental health and wellness start-ups since 2012 shows funding to mental health tech start-ups has increased every year since 2013, nearly reaching USD $200M in 2016.[26] Many mental health tech start-ups raising funds today are purportedly working to increase access to mental healthcare. Such strategies include telemedicine platforms that enable remote access to care, interactive apps that track fluctuations in emotional states, daily motivational text messaging services, chat bots, and augmented/virtual reality tools. Another report details how major hospital systems (e.g., Cedars-Sinai), technology companies (e.g., Google), and health insurers (e.g., Aetna and BlueCross BlueShield) are now partnering and participating in agreements with mental health start-ups, underscoring the growing recognition and importance of entrepreneurship in mental health innovation.[25]

We suggest the importance of the field of Responsible Innovation to guide and monitor the implementation of new products and services in mental health care.[35] Responsible innovation entails a set of principles and practices in the development of technical solutions for complex problems. It encapsulates collaborative endeavors, wherein stakeholders commit to identifying and meeting a set of ethical and social principles by designing products and services to identify and manage risks in order to sustainably address the needs and challenges of users. Responsible innovation is an increasingly prominent initiative. A recent Organizations for Economic Co-operation and Development Recommendation on Responsible Innovation in Neurotechnology[92] proposed the first international standard in this domain. It 'aims to guide governments and innovators to anticipate and address the ethical, legal, and social challenges raised by novel neurotechnologies while promoting innovation in the field.' It articulates 'the importance of 1) high-level values such as stewardship, trust, safety, and privacy in this technological context, 2) building the capacity of key institutions like foresight, oversight, and advice bodies, and 3) processes of societal deliberation, inclusive innovation, and collaboration.' These principles can be usefully adapted to guide the development and implementation of novel technologies for dementia care problems. Altogether, technology innovation and multinetwork collaborations are, therefore, critical components for advancing mental health therapies and improving outcomes.

Mental Health-Related Biological Changes Induced by Prolonged Spaceflight

Understanding the biological mechanisms of the brain that create mental illness is challenging both on Earth and in space. If we could study the brain's physiological changes on orbit, it might enable technological advances to develop targeted therapies and personalized care for astronauts. Perhaps the tools developed to study those on-orbit changes could then make the terrestrial brain's physiological changes in mental illness more accessible, as well.

A recent study explored the effects of spaceflight on anatomical configuration of the brain and on cerebrospinal fluid spaces.[98] In this study, researchers used magnetic resonance imaging to compare images of 18 astronauts' brains before and after missions of long duration, involving stays on the International Space Station (ISS), and of 16 astronauts' brains before and after missions of short duration, involving participation in the Space Shuttle program. Narrowing of the central sulcus, upward shift of the brain, and narrowing of cerebrospinal fluid spaces at the vertex occurred frequently and predominantly in astronauts after long-duration flights, an interesting observation as this goes against the natural progression of aging, which entails enlargement of cerebrospinal fluid spaces. Postflight astronauts are at risk of "visual impairment and intracranial pressure" (VIIP) syndrome, recently renamed Spaceflight Associated Neuro-ocular Syndrome (SANS). Studies to date have offered interesting physiological observations; the clinical significance of these changes and its relationship to the brain, including the ocular system, is a subject of current analysis and research. A recent study explored multiple biomarkers from a pair of male monozygotic twins, one of whom spent 340 d aboard the ISS (flight subject), while his identical twin remained on Earth (ground subject).[43] The subjects were 50 yr of age at onset. Physiological, telomeric, transcriptomic, epigenetic, proteomic, metabolomic, immune, microbiomic, cardiovascular, vision-related, and cognitive data were collected over 25 mo. The results demonstrated both transient and persistent changes associated with long-duration spaceflight across multiple cell types, tissues, genotypes, and phenotypes. These specific data, as well as the broader biomedical measures and sample collection methods, can now serve as a foundation for scientific and medical assessments of future astronauts, especially for those on prolonged, exploration-class missions.

Earth Technologies Translatable to Mental Health in Long-Duration Space Missions

In this section, we outline several fields of mental health technology and review their potential space mental health significance, current limitations of knowledge, and potential innovations and opportunities. Supplementary **Table A** (online, https://doi.org/10.3357/AMHP.5589sd.2020) outlines these technologies, their significance in long-duration space missions, and potential for insights to be transferred to space. We note the critical role of the crew medical officer in the safe and efficacious use of these tools.

Space Technologies Translatable to Mental Health on Earth

We broadly consider there to be two types of space technologies translatable to Earth mental health: 1) those arising from fundamental engineering and physics advances (i.e., GNSS, satellite communications, noninvasive and remote sensing devices); and 2) those arising from space medicine advances (e.g., nutritional advances, chronotherapies, conflict resolution, and group stress). Supplementary **Table B** and **Table C** (online, https://doi.org/10.3357/AMHP.5589sd.2020) provide overviews of these areas.

The Mars Mental Health Model: Innovation and Bidirectional Technology Transfer at the Intersection of the Mars Mission and Global Mental Health

We hereby postulate a comprehensive model of 'Innovation and Bidirectional Technology Transfer at the Intersection of the Mars Mission and Global Mental Health' (**Fig. 1**). The aim is to create a bidirectional model for effective cross-pollination between space technologies in long-duration spaceflight environments with Earth mental health. By facilitating exchanges of ideas and technology, the hope is to improve mental health outcomes both during long-duration spaceflight environments and on Earth.

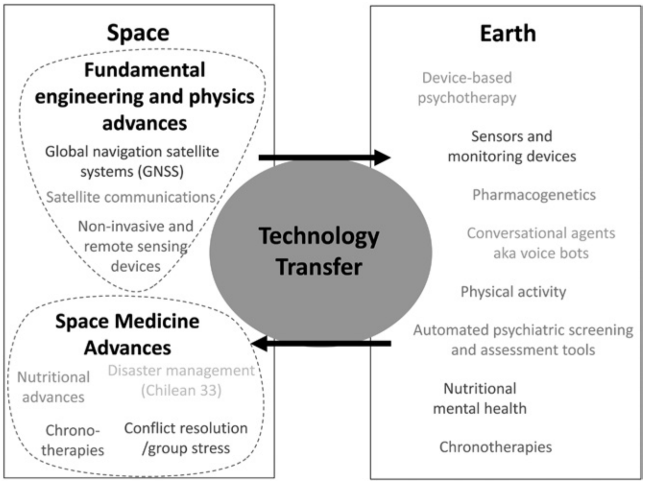

Fig. 1. The Mars Mental Health Model: innovation and bidirectional technology transfer at the intersection of the Mars mission and global mental health.

Recommendations

Accelerate Earth mental health technologies into the space market. Given the complexities of fitting Earth technologies into the space market, novel mechanisms and processes are required to support companies and entrepreneurs. There are a number of examples of these types of organizations and events. Established in 1997, the National Space Biomedical Research Institute (NSBRI) was a unique nonprofit research consortium in partnership with NASA and over 70 other agencies, universities, and institutions. Their objective was to work on countermeasures to address the health-related problems as well as the physical and psychological challenges astronauts will face on long-duration missions.[85] Research addressed key technologies required to enable and enhance exploration. In particular, NSBRI scientists and physicians developed technologies to provide medical monitoring, diagnosis, and treatment in the extreme environments that will be faced during exploration missions. Examples of technologies that NSBRI accelerated from human health care into the space environment include: lower back pain therapy with ultrasound[13] and a novel brain monitoring device (leveraging magnetic induction phase-shift spectroscopy to monitor CSF pressure).[12] The Translational Research Institute for Space Health (TRISH; https://www.bcm.edu/centers/space-medicine/translational-research-institute), supported by the NASA Human Research Program and based at the Baylor College of Medicine, provides a useful example of a strategy 'Launch Pad.'[114] The TRISH Launch Pad aims to prepare early-stage companies and precompanies to meet the needs of the space medicine industry. Launch Pad provides a 10-wk intensive program. Sessions are led by industry veterans who help teams create a viable commercialization pathway to Earth's health technology market and a secondary space market. Launch Pad provides companies and precompanies with: 1) access to experts working in space health care and at NASA, 2) rapid technology maturation and de-risking, 3) preparation for commercial success in U.S. healthcare markets, and 4) pathways to government sales in the emerging space market. TRISH has also announced an 'Industry Program 2020'[115] grant call for industry and academic behavioral health experts to contribute toward the development of specific key areas of interest, including the optimization of communications which have inherent delays (modeling the real-life delay in transmissions), novel anxiety and stress monitoring techniques, and unobtrusive monitoring technologies.

Accelerate space technologies into the Earth mental health market. There are a number of examples of mechanisms to accelerate space technologies into the Earth health care market. NASA's Spinoff provides extensive cataloguing of technologies that are benefitting life on Earth (see https://spinoff.nasa.gov). The aforementioned NSBRI generated a number of technologies which were applied to the Earth health care market, namely a noninvasive ultrasound method to expel kidney stones.[14]

Bidirectional training programs. As the field of space medicine and mental health simultaneously develop, there will be a need for a targeted training program focused on merging the two fields. Examples can include conferences such as one offered earlier this year by TRISH and the MIT Media Lab Space Exploration Initiative, which focused on "optimizing behavioural health and cognitive performance in confined environments."[113] Further, we recently proposed that the new field of innovation diplomacy can be adapted to promote responsible innovation in mental health.[37,111] This could be useful in merging these two fields. To this end, we articulated a model of Mental Health Innovation Diplomacy[37,111] which aims to strengthen the positive role of novel solutions and recognize and work to manage both real and potential risks of digital platforms. It recognizes that mental health technological innovation can have political, ethical, cultural, and economic influences. Adapted from the NESTA Innovation Policy Toolkit,[16] we elucidated roles relevant to Mental Health Innovation diplomats.[111]

As of now, there is no formal training program with this particular focus and training modules are limited to conferences such as the aforementioned. Developing a focused training program that aims to train individuals well-versed in both space medicine and clinical mental health may accelerate the discovery process of mental health technologies in space. Graduates of such a program would not only be able to identify the unmet needs in both arenas, but also be able to recognize and identify technologies that have the potential to cross over and be applied.

Enriched dialogue between mental health technology innovators and space medicine experts. Key to any technological development across two fields is a productive cross-collaboration. To that end, key opinion leaders in mental health and space medicine experts will need to establish an open channel of communication, share skillsets, and discuss ideas in order to foster important foundations to advance the development of mental health applications in long manned spaceflight missions. One example forum is the 2019 Space Health Innovation Conference in San Francisco cohosted by the University of California, San Francisco and TRISH.[116] Their aim was to "convene a diverse audience of Space experts and Health Tech Innovation stakeholders with a goal to inform, inspire, and invite participation in the exciting challenge of optimizing health and medical management in Space environments." Future development and production of similar forums will be critical in facilitating a productive cross-collaboration.

Ethical and legal considerations with the global nature of the Mars mission. With the multicountry nature of the Mars mission, it is important to consider legal and regulatory perspectives through a global lens. Critical questions include: what regulatory framework will be used for medical devices, digital health solutions, and genetic-based clinical tools? How do health care ethics from different countries reconcile in space? What legal framework applies on Mars?

The World Health Organization (WHO) has recently released guidelines for digital health tools where they pay particular attention to data privacy issues.[122] Furthermore, the WHO has also developed guidelines for quality and safety in clinical genetic testing.[120] There is also work from the WHO to create guidelines and standardization for medical device regulation.[121] As technological acceleration continues in the coming years, careful and diligent work is required to ensure regulations keep up with innovation.

Track outcomes of this bidirectional model. The success of any model is measured by the outcomes of the effort itself so it is important to define the deliverables of this model. However, a challenge unique to space medicine that can hamper outcome measurement are the infrequent space missions as compared to the rapid pace of study outcomes done on Earth. Whereas a mental health research study could potentially be completed within months, a space mission is on the scale of at least years. Thus, outcomes reports should be cognizant of space mission deadlines and special attention devoted to ensure all relevant data are collected from each space mission from which to compare with Earth studies, given the infrequency. More discernible outcomes from the model include results from the application of technologies in simulated labs, multicenter trial outcomes, and publications. With regards to clinical outcomes, this is more difficult, but the most direct approach is large randomized control trials of the technological tools. A pragmatic approach would likely be to first assess clinical outcomes on Earth sample populations before trialing it on space missions. Outcome assessment should be tracked and staged in increments, including: 1) number of interactions between space and Earth experts, 2) forms of collaboration, 3) potential developments, 4) intellectual property developed, 5) translation, and 6) implementation.

Conclusion

Both long-distance space missions and global society do and will continue to experience mental health issues. With the advent of new technologies, it is critical we leverage these to invent and innovate to optimize mental health and wellbeing. While space and Earth represent seemingly disparate environments, they nevertheless require overlapping solutions. Our research suggests there are likely benefits to cross-pollinating between space technology and Earth mental health and we hope to further promote bidirectional sharing of innovations.

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