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Imaging of neuro-cognitive performance in extreme Environments—A (p)review

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ABSTRACT

Living in extreme environments is accompanied by a number of stressors, which can be classified either as physiological stressors (e.g. microgravity, missing sunlight) or psychological stressors (e.g. confinement). From earth bound studies a negative impact of stress on mental health and cognitive performance is well known and both factors might impair mission success and mission safety during longer inhabitation of space. Accordingly there is the need to identify adequate countermeasures. Nevertheless causal research of neuro-cognitive impairments in space remains speculative due to missing possibilities of brain imaging. Furthermore the reliability of current psychological tests used to assess and monitor cognitive performance in extreme environments seems to be vulnerable due to a lack of compliance.

With on-going plans of international space agencies to send people to moon and/or mars, this manuscript aims to summarize and review research attempts of the past two decades and to identify methodological shortcomings.

Finally, following the guideline that research has no legacy for its own but must serve the self-concept and well-being of man, this manuscript presents a number of recommendations to enhance future neuro-cognitive research in extreme environments.

A deeper insight into neuro-cognitive coherence is not only desirable to understand the effects of stress on mental health, which seems to be a major issue for our current society, and to develop adequate countermeasures but will also help to maintain and improve mission success and mission safety in manned space flight.

1. Introduction

Living and working in remote and hostile environments like on the International Space Station (ISS) or the Antarctic or – taken into account current plans of national and international space agencies – the moon is not only requiring a very well developed physiological but also psychological status of the individual. Living and working in extreme environments puts a number of stressors to the individual, starting from social stressors (crew dynamic, loneliness), environmental stressors (weightlessness, radiation) to mission stressors (mission goals, duration, high workload vs. boredom) and habitat restrictions (limited resources, stimulus deprivation, artificial life support systems). Whereas a number of studies could show that cognitive performance, general well-being and emotional well-being deteriorate under the influence of multi-factorial stressors (Iwasaki et al., 2007; Sandal, 2002, Schneider et al., 2010), the underlying neurophysiological effects remain widely unknown (Fig. 1).

In the last decades, a multitude of test devices have been developed to quantify changes in mood, cognition and sensorimotor performance under extreme conditions. Currently the Spaceflight Cognitive Assessment Tool for Windows (WinSCAT, (Kane et al., 2005)), a time-constrained questionnaire test of cognitive abilities, as well as a profile of mood state (POMS, (Palinkas et al., 2000)) are routinely performed in space by astronauts aboard the International Space Station (ISS) every 30 days in combination with their periodic health status evaluations. In the Antarctic station Concordia for the last two winter-overs as well as in the MARS500 program the Psychomotor-Vigilance-Test (PVT, specifically developed and validated as a tool for "sleepiness" assessment (Dinges et al., 1997)), a sustained-attention, reaction-timed task that measures the speed

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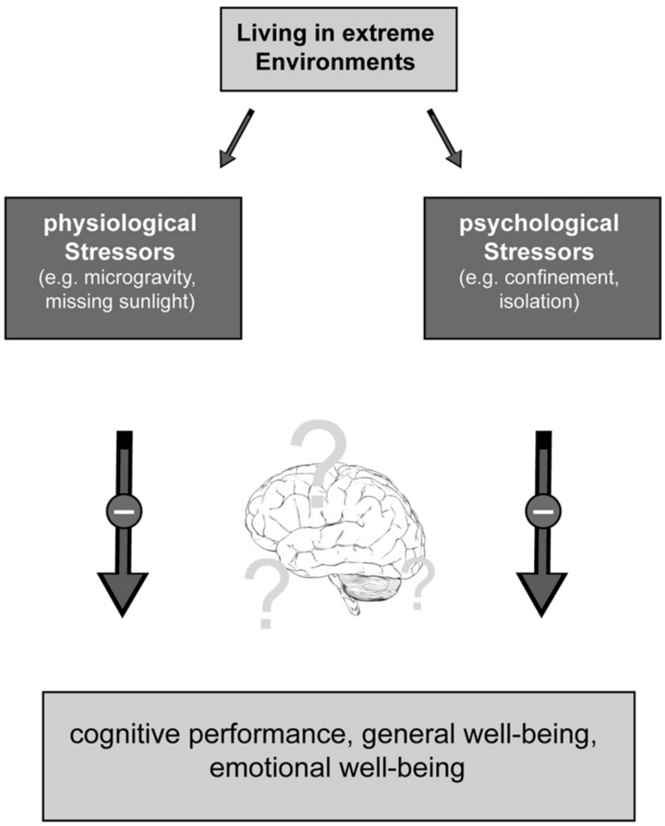

Fig. 1. Living in extreme environments is accompanied by two types of stressors, classified as physiological and psychological, which are known to have a major impact on mental health. The underlying neurophysiological alterations so far remain unknown.

with which subjects respond to a visual stimulus has been performed throughout the isolation.

Whereas these tests provide the responsible flight personnel with a baseline level of performance and subjective mood data and allow drawing a psychological status of crewmembers, from a scientific point of view a more detailed and selective understanding of performance, taking into account also 'hard' neurophysiological data seems adorable. Under normal lab conditions the integration between neurological and behavioral data is more or less a standard procedure today. Techniques like positron emission tomography (PET) or functional magnetic resonance imaging (fMRI), which can be regarded as the gold-standard of imaging brain metabolism/function, allow to display the underlying neurophysiological processes and therefore a deeper understanding of neuro-cognitive performance. Nevertheless these techniques are currently not applicable in space research due to various reasons. Accordingly some first attempts exist using techniques like electroencephalography (EEG) or near infrared spectroscopy (NIRS) to understand the brains reaction to stressors like weightlessness, hypergravity or isolation. But further, more detailed and pronounced research activities are necessary to link these neurophysiological data to mood and cognitive performance. This would help to identify and describe adequate countermeasures and to more effectively maintain and improve mission success and mission safety.

This manuscripts follows three aims: (1) to review past approaches and results concerning cognitive performance under extreme conditions (2) to review first approaches of neuroimaging in space and (3) to provide some inputs for monitoring cognitive performance and associated neurophysiological processes during future missions. This will include technical recommendations as well as methodological approaches.

2. State of the art: cognitive performance under extreme conditions

With respect to the tremendous costs of human error in operational settings, which has been studied extensively in civil aviation, measuring cognitive performance seems of utter importance and can be regarded as a relevant challenge. Accordingly the European Space Agency (ESA) has put a number of requirements and recommendations on monitoring of mental performance during long-duration missions (pp. 82, HUMEX report: Study on the Survivability and Adaptation of Humans to Long-duration Exploratory Missions, 2000 (HUMEX, 2000)). The National Aeronautics and Space Administration (NASA) has requested similar approaches and not only described human performance decrements as one of the major risks in the future of space exploration (pp. 5–6, BPCR: Bioastronautics Critical Path Roadmap, 2004) but also put emphasis on the need to develop adequate instruments to validly and reliably detect such decrements in cognitive performance (pp. D-31, D-32, (BPCR, 2004)). Within a bioastronautics roadmap four risk factors have been identified for long-duration spaceflight regarding behavioral health i.e. performance failure due to problems with psychosocial adaptation, neurobehavioral problems, inadequate cognitive capabilities, and circadian rhythm problems. Two impressive papers by Manzey reviewing psycho-physiological and psychosocial research performed in space in the last decade highlight the consequential importance of psychological and behavioral factors for mission safety and mission success (Manzey, 2000, 2004).

2.1. Changes in cognitive performance during space flight

Terrestrial research has shown that human cognitive and perceptual motor performance deteriorates under stress (Albery, 1989, Hockey, 1983, Lieberman et al., 2002). One therefore expects a similar decrease in the stressful environment of a space mission. Although previous work has shown that various psychomotor functions are degraded during spaceflight, among them the speed (Berger et al., 1997, Bock et al., 2001, Heuer et al., 2003) and accuracy of aimed movements (Grigoriev et al., 1990, Manzey et al., 2000; Watt, 1997), internal timekeeping (Semjen et al., 1998), attentional processes (Pattyn et al., 2005), and the central management of concurrent tasks (Manzey and Lorenz, 1998), it needs to be questioned to what extend those psychomotor functions are dependent on higher cognitive processes. A study by Manzey et al. using the AGARD-STRES battery for example did not find any changes in cognitive function (grammatical reasoning, Sternberg memory-search, unstable tracking, dual task paradigm) during a 438-day spaceflight (Manzey et al., 1998) Eddy et al. (1998) were able to show cognitive decrements only in two out of four astronauts and it could not be excluded that timing of the tests could have a major impact, as proposed and shown by Manzey. Also Benke et al. (1993) reported only minor, not significant effects during a short 6-days space mission to the Russian MIR complex.

Also studies which aim to simulate conditions of weightlessness e.g. in head-down tilt, did not indicate relevant changes in cognitive tasks performed in different body positions, showing that a simple increase in cerebral blood volume seems not to be connected to cognitive performance (DeRoshia and Greenleaf, 1993, Pavy Le-Traon et al., 1994, Shehab et al., 1998).

To sum up, there is good reason to argue that stress levels in space are not generally increased or that standard lab models and testing procedures are not sensible enough to track specific stressors. This might be due to the fact that the operating subject is aware of the 'fake' situation and able to mask an increased stress level by allocating additional attentional resources to the