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RESEARCH ARTICLE

IMMERSIVE SIMULATION IN SPACE MEDICINE: INTEGRATING VIRTUAL REALITY WITH MICROGRAVITY ANALOGUES FOR CARDIOVASCULAR ANALYSIS

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ABSTRACT

Space medicine necessitates a profound understanding of the physiological and psychological effects of extended space missions on astronauts. This review explores the efficacy of various microgravity simulation methods in understanding the cardiovascular system's responses in space-like conditions. While head down tilt tables and weight-reducing treadmills replicate certain aspects, they lack the comprehensive emulation of the psychological and visual stimuli inherent in space. Enter Virtual Reality (VR), an emerging technology offering immersive experiences resembling space environments. This narrative review delves into the potential applications of VR in simulating space conditions, particularly in analysing cardiovascular and stress hormone changes. Searching literature from 2015 to 2023 across several databases, this study analyses findings showcasing the effectiveness of -6° head-down tilt and AlterG systems in replicating microgravity conditions. Combining VR with these methods promises a more holistic approach, enhancing the fidelity of space simulation. The discussion emphasizes the potential of this amalgamation in understanding space-related health challenges, suggesting it as a crucial tool for future research and interventions aimed at ensuring the well-being of spacefarers. These microgravity analogues not only aid astronaut training but also serve as gateways for investigating life sustainability in space and engaging interdisciplinary exploration.

Keywords: Virtual Reality, Microgravity, Cardiovascular, Space Medicine, Head Down Tilt

INTRODUCTION

In tandem with the advancements in space medicine, clinical research plays a pivotal role in comprehending and addressing the health implications of extended space travel. Rigorous clinical studies enable scientists and medical professionals to delve deeper into the physiological and psychological effects of the prolonged space missions on astronauts. By closely examining data gathered from simulated experiences in the lab, researchers can refine existing medical protocols, develop targeted interventions, and enhance the overall understanding of how the human body responds to the unique challenges of space. This ongoing commitment to clinical research is essential for ensuring the well-being of astronauts and refining our strategies for future space exploration and potential colonization.

Microgravity analogues are environments and/or experimental systems that simulate the conditions of microgravity (weightlessness) on Earth. They play a crucial role in scientific research and space exploration by providing insights into how human organisms, anatomical structures and physiological processes evolve in the absence of gravity (hypogravity) or under reduced gravity (microgravity) conditions. Understanding these behaviours is essential for future long-duration space missions, to the Moon, Mars, or beyond.

When it comes to analysing the effect of the outer space environment on the cardiovascular (CV) system, 2 methods are primarily used for simulating the microgravity environment in space medicine studies: head down tilt table experiment and weight reducing treadmills (like the Alter G system). While these methods are good substitutes for microgravity on cardiovascular adaptations, they do not provide analogues for the psychological and visual stimuli found in an actual space environment.

VR represents an immersive experience that may require a headset to completely replace a user's surrounding experience with a simulated, immersive, and interactive virtual environment.

In recent years, VR technology has emerged as a promising tool in the field of space medicine, offering innovative solutions to the multifaceted challenges posed by the extra-terrestrial environment. VR has the potential to offer a better solution for simulating the conditions felt by astronauts during a space mission. This narrative review delves into the potential landscape of VR implementation in space medicine studies, exploring its applications, benefits, and the challenges that lie ahead.

From simulating extra-terrestrial environments for training purposes to provide therapeutic interventions for mental health, VR represents a versatile tool to better immerse our subjects into a space simulation, providing more accurate data points for cardiovascular and stress hormones changes during such experiences.

This review will navigate through the current state of VR, Tilt Table and Alter G applications in clinical studies emphasizing the effects on the cardiovascular system and the autonomous nervous system (ANS), examining the existing literature, ongoing research, and successful implementation.

MATERIALS AND METHODS

Literature Search Strategy

A systematic search was conducted across multiple databases, including but not limited to PubMed, ScienceDirect, and Google Scholar, encompassing publications between 2015 and 2023. The search utilized keywords such as "virtual reality," "tilt table," "space medicine"," ANS", ”Psychological", ”Cardiovascular", ”Microgravity", ”Space", ”HDT", ”ALTER G", ”weightlessness" and related terms in different combination to identify studies relevant to the investigation.

Inclusion and Exclusion Criteria

The inclusion criteria encompassed studies focusing on the utilization of Virtual Reality (VR), tilt table and ALTERG methods in clinical research, particularly exploring their effects on the cardiovascular system and the autonomic nervous system (ANS). The review targeted articles that offered insights into the applications, benefits, and challenges associated with VR and tilt table in current clinical practice, including such scenarios as intensive care unit (ICU), psychiatric wards and rehabilitation clinics. The most frequent use of VR was connected with testing the potential improvements of cognition and other psychological functions. Our aim was to identify similarities and approaches which could be feasible in Space Medicine research.

Selection Parameters

The selection involved articles detailing experiments that utilized VR technology and tilt table simulations across various clinical conditions. These studies were sought for their relevance in exploring cardiovascular system and Autonomic Nervous System (ANS) responses within simulated space missions. Additionally, the review focused on articles investigating the practical applications, benefits, and challenges of employing VR and tilt table methods. This exploration served as a foundation for establishing a potential protocol aimed at simulating outer space conditions.

Publications on VR applications in Medicine remain quite isolated until now, but definitely it is expected to see rapid growth, together with other digital tools and patient wearables. Based on this, there are good premises that our research is providing relevant information in a limited-explored field.

Data Collection and Analysis

A standardized approach was adopted for data extraction from the selected studies. Relevant information regarding cardiovascular and stress hormone changes, as well as the efficacy of VR and tilt table simulations, was extracted for comprehensive analysis.

RESULTS

The human cardiovascular system has evolved to suit the gravitational pull on Earth, which is around 9.81 m/s^2, equivalent to 1g. This gravitational force creates a significant challenge for the cardiovascular system whenever humans transition from sitting or lying down to standing up. When standing, gravity causes blood to move from the upper body towards the legs and abdomen, leading to venous pooling and a decrease in the volume of plasma within the tissues, thereby lowering the cardiac preload [1].

In situations without gravity, like in weightlessness, the typical head-to-foot pressure gradient caused by gravity is absent. Consequently, blood relocates from the lower extremities and abdomen towards the thorax and head [1].

Tilt table- head down tilt (HDT)

Studies have shown that the microgravity simulation involved having subjects lay on a modified tilt table, which was propped up at the foot end to achieve the −6° of head-down tilt. While there are many angles that researchers will use to see various physiological responses, a −6° tilt has shown to be the most effectively used posture to simulate this microgravity environment., [2]. In the -6° tilt model, subjects are lying in supine position on the table which is inclined 6-degrees to place the head lower than feet, closer to the ground, mimicking the microgravity environment on Earth (Figure 1) [3]. A -6◦ head-down tilt was used to evaluate the microgravity while traveling to the Moon, while an increase in tilting at 9.5◦ head-up tilt was applied to simulate the effects of Moon gravity in a study about deconditioning countermeasures [4]. The same study recommends a 22.3◦ tilting to simulate gravity on Mars.

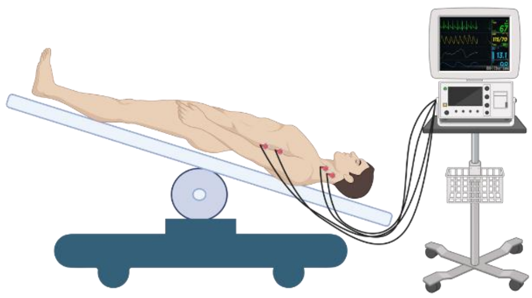

Figure 1 - Subject in supine position on a Head-Down Tilt Table at -6◦

Alter G

Weight-reducing treadmills can simulate the reduction in body weight similar to that experienced in outer space (with demonstrated cardiovascular effects [5]), making them a viable substitute for weightlessness. Devices like the AlterG also influence the respiratory system (Figure 2) [6], which in turn provides cardiovascular influences to better emulate the outer space environment. Studies show that respiratory and cardiac parameters of subjects who use weight-reducing treadmills have altered values compared to those who use regular treadmills, proving the functional effects of these weightlessness simulations [7]. Not only that, but these parameters have been shown to increase during testing, providing enhanced performance, thus replicating the performance experienced during space exploration [8].

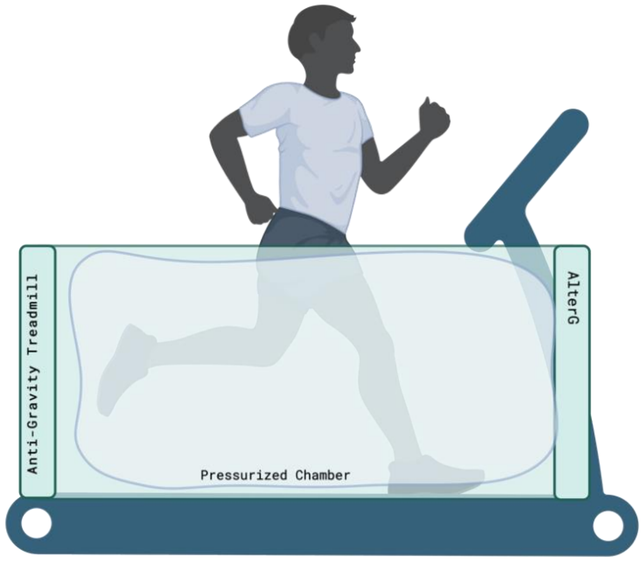

Figure 2 - Subject running on a Weight-reducing treadmill

Virtual Reality

Virtual Reality can be used to modulate a psychological response similar to that experienced in space, which will then initiate physiological changes. Virtual Reality headsets have been used to reduce perceived pain and stress - this suggests they could also be used to augment the physical sensations that are felt while using a weight-reducing treadmill, thus providing a more faithful simulation of an outer space environment.

Furthermore, VR may help to alleviate anxiety, stress and fear, associated with the unfamiliar environment like the clinical research laboratory [9].

Another potential application of VR in the medical field could be the stimulation of the parasympathetic nervous system (PNS) [10]. Different visual stimulation techniques can be used in clinical scenarios such as an intensive care unit (ICU), in order to induce analgesia and decrease stress associated with a hospital environment [11] ,[12].

Incorporating VR/AR into practical research applications for routine use in experiments presents significant challenges. Users might encounter undesired side effects, often referred to as "cybersickness," during VR/AR sessions, potentially restricting its widespread application (Figure 3) [11].

Possible corroboration with the space medicine field can also be traced, for example it could be a solution for long-term isolation, causing higher cortisol levels and inducing cardiovascular changes [13]. A tool such as VR, simulating a more nurturing environment, could be an effective treatment against these modifications.

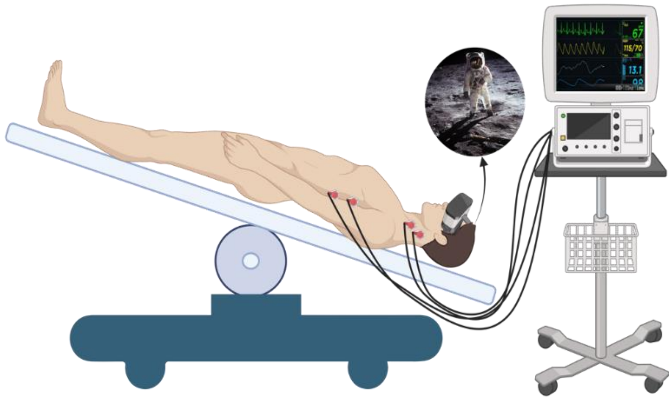

Figure 3 - Subject in supine position on a Head-Down Tilt Table at -6◦ wearing VR Headsets

DISCUSSION

These studies could represent a gateway to understanding how novel technology such as VR could have great implications for controlling stressors for people undergoing such peculiar circumstances, like the ones found on a spacecraft. A new non-invasive way of stimulating the PNS, leading to clear cardiovascular modifications, could also be applied in Space Medicine, either for correcting some of the physiological changes correlated with space missions, and also new methods of treating potential illnesses in the secluded conditions of a space shuttle.

After an exhaustive analysis of the current literature on some of the methods that can recreate the conditions of microgravity with high fidelity, we can confidently put out a conclusion of the effectiveness of HDT tilt table and weight-reducing treadmill experiments. Focusing on the cardiovascular effects, studies have proven that a HDT of -6° is the optimal angle for evaluating these modifications. In combination with VR, which would bring a huge benefit to such research in the form of recreating visual stimuli a spacefarer would find in an actual outer space scenario, we believe a combination of these methods would bring immense improvements to future experiments.

Through the lens of such immersive technology, researchers and space medicine physicians could gain the ability to recreate the space environment and isolation inherent to the spaceship, providing a controlled yet realistic setting for investigating the physiological and psychological effects on human health. As an additional step to better immersing the subjects in a specific and controlled space environment, we vehemently emphasize the corroboration of a pertinent method to recreate a microgravity environment (such as the HDT tilt table and weight-reducing treadmill mentioned). This blend of multiple different kinds of stimuli could represent a new good practice method of simulating space conditions and holds the promise of advancing our understanding of space-related health challenges and developing targeted interventions to ensure the well-being of future spacefarers.

CONCLUSION

Microgravity analogues represent valuable tools for astronauts training for space travel. By mimicking the conditions of microgravity, physicians can study the physiological and psychological effects on the human body, and may develop countermeasures. These analogues reflect organisms' adaptive mechanisms and impact of space travel on human health as well as for investigating the potential for sustaining life in space, and offer opportunities for educational outreach and interdisciplinary engagement.

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