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Gender specific changes in cortical activation patterns during exposure to artificial gravity

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ABSTRACT

Keeping astronauts healthy during long duration spaceflight remains a challenge. Artificial gravity (AG) generated by a short arm human centrifuges (SAHC) is proposed as the next generation of integrated countermeasure devices that will allow human beings to safely spend extended durations in space, although comparatively little is known about any psychological side effects of AG on brain function.

16 participants (8 male and 8 female, GENDER) were exposed to 10 min at a baseline gravitational load (G-Load) of +.03 Gz, then 10 min at +.6 Gz for females and +.8 Gz for males, before being exposed to increasing levels of AG in a stepped manner by increasing the acceleration by +.1 Gz every 3 min until showing signs of pre-syncope. EEG recordings were taken of brain activity during 2 min time periods at each AG level. Analysing the results of the mixed total population of participants by two way ANOVA, a significant effect of centrifugation on alpha and beta activity was found ($p < .01$). Furthermore results revealed a significant interaction between G-LOAD and GENDER alpha-activity ($p < .01$), but not for beta-activity.

Although the increase in alpha and beta activity with G-LOAD does not reflect a general model of cortical arousal and therefore cannot support previous findings reporting that AG may be a cognitively arousing environment, the gender specific responses identified in this study may have wider implications for EEG and AG research.

1. Introduction

Artificial gravity (AG) has been suggested as a key integrated countermeasure for astronauts to combat the physiological deconditioning that occurs during long duration spaceflight [1]. Centrifugal forces would impart +Gz acceleration to the body and these 'head to toe' forces would provide sufficient gravitational loading to stimulate various physiological systems of the body in a way to preserve their normal physiological functions as for example bone and muscle strength [2]. However, the optimal 'dose' of AG for astronauts has not yet been determined [3].

Beside a study by Biernacki et al. [4] reporting no changes in subjective enjoyment during centrifugation, but instead positive changes in arousal such as increased energy and reduced tension currently no further information exist concerning psychophysiological effects of artificial gravity and

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accordingly further work seems necessary to determine exactly how AG is affecting cognition and the brain. Although AG may indeed bring benefits in terms of preventing the physiological deconditioning normally associated with long duration spaceflight, if it is lowering mood, raising the stress levels [5,6] or impairing the cognitive abilities [7] of astronauts already working in a pressured and technical environment, then its suitability as a countermeasure during spaceflight may have to be reconsidered.

To further investigate how the brain responds to hypergravity, it is necessary to record brain activity during centrifugation itself. Given the practical limitations of working within such an environment [8], electroencephalographic (EEG) recordings are an ideal method to employ for such a task. The location of particular interest is the frontal cortex, as it is associated with higher cognition, mood and motivation [9]. Traditionally alpha activity in the frontal cortex has been the main focus of investigations. The traditional model of arousal assumes that the slower alpha activity (8–12 Hz) is predominant in a more relaxed state, whilst a decrease of alpha activity and an increase in beta activity (12–35 Hz) is associated with stress and arousal [10].

As gender differences in cognition and responses to stressful situations have been observed previously [11], and coupled with the fact that males and females show differences in +Gz acceleration tolerance [12], it seems likely that centrifugation may have some gender specific effects on the brain in terms of mood and cognition.

This study was carried out under the hypothesis that centrifugation would induce a stress related state within individuals and would result in observable changes in frontal cortex activity, with beta activity expected to increase whilst alpha activity decreases. This hypothesis was tested by using a short arm human centrifuge to expose participants to increasing levels of AG and measuring cortical activity using EEG in the alpha and beta frequency bands. Additionally, by testing a mixed population, gender specific differences in responses to centrifugation were hypothesised.

2. Methods

2.1. Participants and procedures

After providing informed consent, 16 healthy volunteers (8 male and 8 female; mean age 26.7 ± 4.43 years) with no prior history of vasovagal syncope were selected for this study. None of the participants had any experience with artificial gravity or microgravity. Participants completed a medical examination to confirm suitability, no further exclusion or inclusion criteria existed. Ethical approval was obtained for this study (Ethik-Kommisssion der Ärztekammer Nordrhein, Düsseldorf, Germany) in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Participants could withdraw from the study or terminate participation at any time.

The European Space Agency (ESA) Short Arm Human Centrifuge (SAHC) (Verhaert Space, Belgium) at the DLR Institute for Aerospace Medicine (Cologne, Germany) was used to expose participants to increasing levels of artificial gravity in a stepped manner. One participant at a time lay supine on a nacelle of the SAHC, positioned with their heads towards the centre and feet pointing outwards. All participants were instructed to remain relaxed and refrain from head movements during the experiment. Two separate protocols for males and females were used based on previous findings of gender differences in +Gz tolerance [12]. The protocol began with 60 min in a 6° head down tilt position to simulate the cardiovascular shifts that occurs during spaceflight before returning to a supine position to begin the centrifugation run. Next, participants were exposed to 10 min of a BASELINE centrifugation speed of 5 rpm, producing +.03 Gz (Note that all +Gz levels quoted in this study are as measured at heart level), followed by 10 min of +.8 Gz for males or +.6 Gz for females. The differences between male and female were chosen in order to guarantee a sufficient number of stages to be completed before signs of presyncope occur. Previous experience with the SAHC showed that female participants show signs of presyncope earlier than male participants (unpublished observation by the SAHC team at DLR). Female participants were tested in the middle of their menstrual cycle.

From this point the artificial gravity level was increased by +.1 Gz every 3 min. Centrifugation increased in this manner until the point at which any symptoms of presyncope occurred, as identified by a trained medical monitor.

2.2. EEG recordings

Two minute EEG recordings were taken at each level of centrifugation, during which time the participants were asked to close their eyes so that artefacts from muscle activity such as blinking would be minimised and were asked not to move or speak. During set up, participants were fitted with an EEG cap with 32 active Ag/AgCl electrode sensor sites (ActiCap – Brain Products, Germany) in the positions FP1, FP2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, TP9, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, PO9, O1, Oz, O2, and PO10 as per the international 10–20 system [13]. Two additional references electrodes (GROUND and REF) were also used. To aid signal transduction, prior to fitting the EEG cap each electrode was pre-filled with electrolyte gel (SuperVisc™, EasyCap GmbH, Herrsching, Germany). Additional electrolyte gel was applied using a syringe and blunt cannula to ensure sufficient conductivity between the scalp and the electrode. Sufficient conductivity was confirmed by checking to ensure the impedance of all electrodes did not exceed ten kilo Ohm (kΩ). Analogue EEG signals were converted to digital and stored using a Brain Vision Amplifier and RecView software (Brain Products GmbH, Munich, Germany) with a sample rate of 500 Hz.

2.3. EEG data analysis

EEG data was analysed offline using Brain Vision Analyser (Brain Products GmbH, Munich, Germany). High and low pass filters were applied so that the majority of signals below and above between .5 and 70 Hz were

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