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What happens to the brain in weightlessness? A first approach by EEG tomography

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ABSTRACT

Basic changes in environmental conditions are fundamental to understanding brain cortical mechanisms. Several studies have reported impairment of central nervous processes during weightlessness. There is ongoing debate as to whether these impairments are attributable to primary physiological effects or secondary psychological effects of the weightlessness environment. This study evaluates the physiological effects of changed gravity conditions on brain cortical activity. In a first experiment, EEG activity of seven participants was recorded at normal, increased and zero gravity during a parabolic flight. Additionally an EEG under normal gravity conditions preflight was recorded. In a second experiment, 24 participants were exposed to a supine, seated and 9° head-down tilt position while EEG was recorded. Data were analysed using low resolution brain electromagnetic tomography (LORETA). Beta-2 EEG activity (18–35 Hz) was found to be increased in the right superior frontal gyrus under normal gravity conditions inflight. By exposure to weightlessness a distinct inhibition of this activity within the same areas could be noticed. As the tilt experiment showed changes in the left inferior temporal gyrus in supine and tilted positions we conclude that the observed changes under weightlessness are not explainable by hemodynamic changes but rather reflect emotional processes related to the experience of weightlessness. These findings suggest that weightlessness has a major impact on electro cortical activity and may affect central nervous and adaptation processes.

Introduction

Weightlessness has well-documented influences on cardiovascular, muscle and bone physiology (Aubert et al., 2005; Adams et al., 2003). However, during recent years, there has been an increased focus on the interactions between central nervous activity and weightlessness (Manzey et al., 1993; Fowler et al., 2000). For example, recent studies have related weightlessness to decreases in both sensorimotor (Bock et al., 2001) and cognitive abilities (Manzey, 2000). Due to technical and organisational limits, heretofore, it has not been possible to apply imaging methods to study brain metabolism in weightlessness (Genik et al., 2005). Therefore, it remains unclear whether these alterations in sensorimotor and cognitive function are the primary physiological effects of weightlessness, or whether they are secondary effects associated with environmental factors such as work load or social isolation.

In an attempt to clarify the link between weightlessness and central nervous activity, Cheron et al. (2006) examined the alterations of alpha cortical activity during weightlessness by EEG and showed an increase of power in the peak alpha frequency (PAF) activity. PAF is the most dominant rhythm in the relaxed, eyes-closed state and is regarded as a marker of cortical activity. Furthermore, this oscillation is considered to be involved in mental and cognitive processes (Angelakis et al., 2004, 2007).

Over 2 years (2005–2007) we took part in four parabolic flight campaigns organised by the German Space Agency (DLR) and NOVESPACE. Originally, we aimed to differentiate between the primary physiological effects and the secondary stress related effects of weightlessness on motor control. To address this issue we recorded the stress hormone levels, electro cortical activity and the subjective mood ratings of 23 subjects prior to, throughout and following a parabolic flight (Schneider et al., 2007, 2008). On the final campaign we were given a short-notice offer to conduct a resting, eyes-closed EEG procedure prior to and during each of the first ten parabolas. This EEG procedure was limited to seven subjects. Although

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temporal and experimental limitations did not allow us to augment the EEG procedure with additional methods, we recognised that this small pilot study would provide us with valuable information about the brains' response to weightlessness that may provide a basis for further research in the area of ‘microgravity and brain’.

We designed our investigation around two expectations. First, we expected a physiological reaction to weightlessness. It is assumed that brain hemodynamics change in microgravity. With gravity absent, there is a redistribution of blood that is supposed to results in increased blood volume and blood pressure within the head and brain (Stevens et al., 2005). Similar hemodynamic alterations have been induced using tilt experiments, during which the increase in blood supply leads to increased tissue oxygenation (O_2Hb) measured by near infrared spectroscopy (Kurihara et al., 2003).

Secondly, we expected emotional reactions to the very uncommon experience of weightlessness. For example, changes in frontal lobe activity, have recently been strongly associated with emotional reactions. In particular, the model of frontal asymmetry proposes that the left frontal cortex is involved in the experience and expression of positive, approach-related emotions. Conversely, this model proposes that the right frontal cortex is involved in the expression and experience of negative avoidance-related emotions (Harmon-Jones, 2004, Allen and Kline, 2004; Schutter et al., 2008). As such, frontal EEG asymmetry may serve as a marker of emotional anxiety and/or indisposition (Coan and Allen, 2004) associated with weightlessness.

In order to distinguish between a hemodynamically driven change in brain cortical activity and a more emotionally orientated model, we performed a tilt study in which resting EEG was measured in seated, supine and 9° head-down tilt (HDT) positions. The results of this tilt study were compared with the EEG measures yielded from the inflight portion of the experiment. We hypothesised that if changes in EEG activity are due solely to altered brain hemodynamics, similar changes should be noticed whereas emotionally induced changes should differ in location.

Materials and methods

Parabolic flights

A parabolic flight manoeuvre is characterized by recurring gravitational changes from 1.8 G (20 s) to 0 G (20 s) to 1.8 G (20 s). EEG was used in order to evaluate stress related changes in brain cortical activity throughout the flight. Resting EEG data were recorded over a two-minute interval 1] prior to the start of the flight, 2] approximately 15 min after take-off but prior to the first parabola, 3] after parabola ten, 4] after parabola twenty and 5] post-flight. These data have been published and showed an overall increase in beta-1 (12.5–18 Hz) and beta-2 (18–35 Hz) activity ($n=16$) throughout the whole flight, independent of the onset of gravitational changes (Schneider et al., 2008). In the present study, resting EEG activity during weightlessness (0 G), hyper- (1.8 G) and normal (1 G) gravity was recorded on seven participants during the first 10 parabolas of a flight campaign organised in September 2007 by DLR and NOVESPACE (Fig. 1). Participants in this campaign were aged 32–49 years (male $n=5$, 37.6+/−6.05, female $n=2$, 39.00+/−3.00). Scopolamine, which is normally administered before parabolic flights to prevent motion sickness, was *not* dispensed to the participants; and none of them reported taking any other medication prior to testing. Four out of the seven participants had previous experience with parabolic flights. The participants did not report any motion sickness during the first 10 parabolas. Participants sat strapped in a conventional flight seat that faced away from the experimental area into the rear of the Airbus 300 ZeroG. All participants, experimenters and flight staff involved in this study, underwent an a priori clinical check and provided informed consent. The study was approved by the German Sport University ethics committee and was in compliance with national legislation and the Code of Ethical Principles for Medical Research Involving Human Subjects of the World Medical Association (Declaration of Helsinki).

During the EEG recording, participants closed their eyes and were asked not to move or speak. EEG was recorded using a 64-channel portable EEG-System (IT-Med, Usingen, D). An EEG-Cap (Electro-Cap International, Inc., USA), which was adaptable to individual head size. This cap consisted of 19 electrodes and one reference electrode (mounted in the triangle of FP1, FP2 and FZ) in the 10–20 system (Jasper, 1958). Each electrode was filled with Electro-Gel™ (Electro-Cap International, Inc., Eaton, USA) for signal transduction. The analogue signal of the EEG was amplified and converted to digital signals using Braintronics Iso 1064 CE Box (Braintronics B. V., Hl Almere, NL) and stored with a frequency of 256 Hz on hard disk of Neurofile XP EEG-System (IT-Med, Usingen, D).

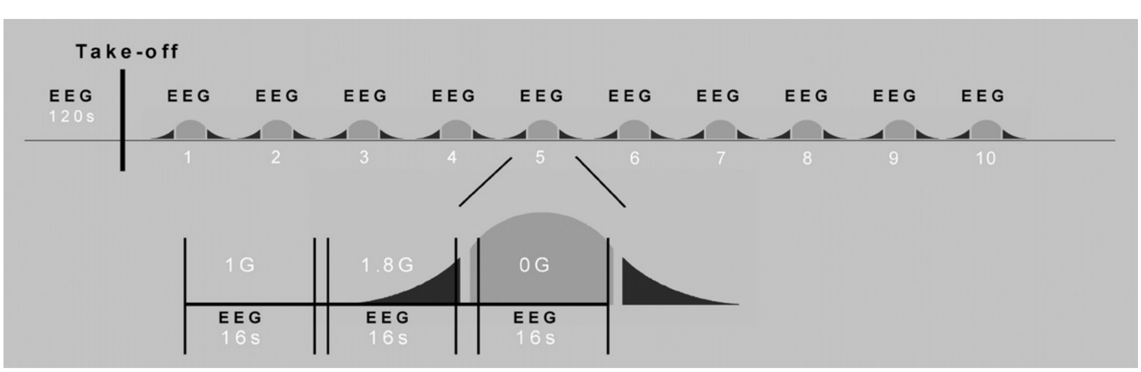

Fig. 1. Timeline of EEG recordings. EEG at rest was recorded prior to take of and inflight before each parabola (1 G) as well as, during the 1.8-G phase and the zero gravity phase of each of the first 10 parabolas.