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Neuro-cognitive performance is enhanced during short periods of microgravity

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HIGHLIGHTS

- Neurocognitive function was found to be improved in microgravity.
- No effect of anti-nausea medication was observed.
- No effect of flight experience was observed.
- Further research is necessary addressing the effects of permanent microgravity.

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ABSTRACT

There is increasing interest in the effects of microgravity on cognitive processing, particularly as it relates to the potential for human space travel. While findings to date are quite inconsistent, studies reporting a decrement in cognitive performance have generally not been able to distinguish between the direct influence of microgravity, and any associated influence of stress. Furthermore, the currently available findings are primarily based on behavioral observations, and there is a need to better understand the underlying neurophysiological responses.

The current study aimed to determine the effects of microgravity on neurophysiological processing during a mental arithmetic task (executive function). During the normal- and microgravity phases of a parabolic flight, four levels of a mental arithmetic task were presented on a touchscreen tablet. The latency between the appearance of the problem and the participants' response was identified as reaction time. In addition visual evoked potentials N1 and P2 were determined using an active EEG system and analyzed using source localization algorithms.

Results showed an increase in reaction time with increasing levels of task difficulty. During the most complex levels, reaction time was significantly reduced during microgravity. This observation was independent of previous parabolic flight experience as well as the use of anti-motion-sickness medication. P2 amplitude decrease during microgravity was concomitant to a related involvement of the superior frontal and medial frontal gyrus.

It is concluded that cortical processes are enhanced during microgravity, and that previously reported impairments in cognitive performance are likely attributable to increased stress rather than weightlessness itself.

1. Introduction

In recent decades, several studies have evaluated cognitive processes in microgravity, including during space travel and during experimental parabolic flights. While it is often assumed that cognitive function is impaired in microgravity, the findings to date have been inconsistent, with most studies reporting no direct effect of microgravity on cognitive function [1,2]. Upon closer examination of previous experiments, it is apparent that a reduction in cognitive function is most likely to occur: (1) during the so called 'transition-phases' of space flight, i.e. observations made in the periods soon after arriving in space or just prior to leaving space [1,3,4], or (2) during the 0G (weightlessness) phase of parabolic flights, compared with ground observations [5–12]. It is likely that measurements during these periods are subject to a mixture of possible influences, namely stress and microgravity, and it is nearly impossible to distinguish between the two. In an attempt to control for the stress-related effects that are associated with parabolic flight [30], a primary aim of the current experiment was to compare cognitive

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function and any underlying neural correlates, identified by event related potentials (ERP), between 1G- and 0G-conditions during parabolic flight. As these conditions are separated by <30s during the same parabola, it is likely that any differences can be attributed directly to the changes in G-load, i.e. the direct effect of microgravity.

To further understand the impact of weightlessness, it is important to not only to describe the behavioral parameters of cognitive performance (e.g. reaction time), but also to investigate the underlying neurophysiological effects. As the use of brain imaging techniques is limited in extreme environments, there has been an increased emphasis on the development and use of valid and reliable portable assessment systems. Electroencephalography (EEG), which allows for the assessment of ERPs with a high temporal resolution, is well suited for the study of brain activity in extreme environments. First studies on microgravity related ERPs already provide us with an idea that central processes in (simulated) weightlessness are altered [37–39].

If the stress related effects of parabolic flight are able to be controlled, it might be expected that brain function and cognitive performance should increase in microgravity, and this may be a function of improved oxygen delivery to the brain during weightlessness [15]. As such, we hypothesized that cognitive function would be enhanced during the microgravity phase of a parabolic flight, as indicated by improved performance during a simple to complex reaction time task, which we anticipated would also be mirrored by changes in neurocognitive markers.

2. Methods

2.1. Participants and procedure

European Space Agency (ESA) and German Space Agency (DLR) parabolic flights take place from Bordeaux International Airport (F), aboard the A300 ZeroG. A parabolic flight maneuver is characterized by gravitational changes from 1G to 1.8G, to 0G (weightlessness, approx. 22 s), and back to 1.8G, and finally to 1G. One campaign consists of three to four flight days, and on each flight day 30 experimental parabolas are completed. During eight parabolic flight campaigns scheduled between November 2010 and November 2013, data from 43 participants were recorded (female: n = 13, age 35.0 +/− 8.7; male: n = 31, age 39.9 +/− 9.2 years). All participants, either staff members or students of the involved universities, underwent a pre-campaign clinical examination and provided informed consent. Prior, the experimental design of the study was approved by the Research Ethics Committee of the German Sport University, in accordance with the Declaration of Helsinki. During the flight, participants were seated in a relaxed position and were firmly and comfortably strapped to the floor in order to avoid artifacts caused by stabilization movements. To standardize the position of the tablet screen on which the arithmetic problem-solving task was presented, the tablet was adhered to the participants' non-dominant forearm. As described below, cognitive performance was assessed throughout the flight using an arithmetic problem solving task, and EEG signals were continuously collected throughout the flight. All participants were familiarized with the arithmetic task and the experimental protocol 24 h prior to take-off.

2.2. Cognitive task

The experimental cognitive task consisted of a mental arithmetic task (problem solving) with two numbers presented on the left and right side of a tablet screen. Participants were to respond by deciding which number was higher, and pressing the corresponding side (left or right) of the tablet screen. The task was divided into four levels with increasing complexity. During the first level participants had to decide between two simple numbers (e.g. 13 vs. 7). With each subsequent level, the difficulty of the task increased so that during the final level (level 4) participants has to decide between complex arithmetic equations (e.g. $8 * (12 - 4)$ vs. $18 - 2 * 5$). Participants were instructed to respond and make their selection as quickly and as accurately as possible. To avoid any external disturbances a flight operator supervised each participant. Appearance of each pair of numbers, as well as the corresponding reaction (touch), was triggered to the EEG signal.

Participants completed the task during the 1G phase and the 0G phase of four consecutive parabolas. Participants were randomly assigned to two subgroups: 16 participants (age 36.3 +/− 10.5 years) repeatedly performed the task at the easiest level (group EASY); and 26 participants (aged 38.5 +/− 8.4 years) performed the task with increasing levels of difficulty during each consecutive parabola (group DIFFICULT). To avoid any order effect, participants in each group were randomly assigned to commence the task during the 0G phase (i.e. 0G followed by 1G), or during the 1G phase (i.e. 1G followed by 0G).

In order to test for possible effects of flight experience and medication (Scopolamine), which is normally administered before parabolic flight in order to prevent motion sickness, this second group (DIFFICULT) was further subdivided into three groups. The first subgroup consisted of participants with no previous parabolic flight experience and without any medication (first time flyers — no medication, n = 10, age 36.2 +/− 7.0 years). The second subgroup also consisted of first time flyers, and participants in this group received Scopolamine, which was administered 60 min before take-off (first time flyers —with medication, n = 8, age 41.4 +/− 6.3 years). The third subgroup consisted of participants with previous parabolic flight experience, who had participated in a minimum of 100 parabolas, without any medication (frequent flyers, n = 8, age 39.6 +/− 11.8 years).

2.3. EEG data collection

An EEG actiCAP (Brain Products GmbH, Munich, Germany) with 32 Ag-AgCI electrodes, arranged in the international 10–20 system at positions Fp1, Fp2, F3, F4, F7, F8, Fz, FC1, FC2, FC5, FC6, C3, C4, Cz, CP1, CP2, CP5, CP6, P3, P4, P7, P8, Pz, PO9, PO10, T7, T8, TP9, TP10, O1, O2 and Oz, was mounted on the participant's head prior to take off. Each electrode was referenced to a reference electrode that was mounted in the triangle of FP1, FP2 and Fz. There was also a ground electrode. Electrodes were filled with Electro-Gel™ (Electro-Cap International, USA) for optimal signal transduction. During the flight, impedance was kept below ten kiloohm [kΩ] by refilling the electrodes with gel. The analog signal

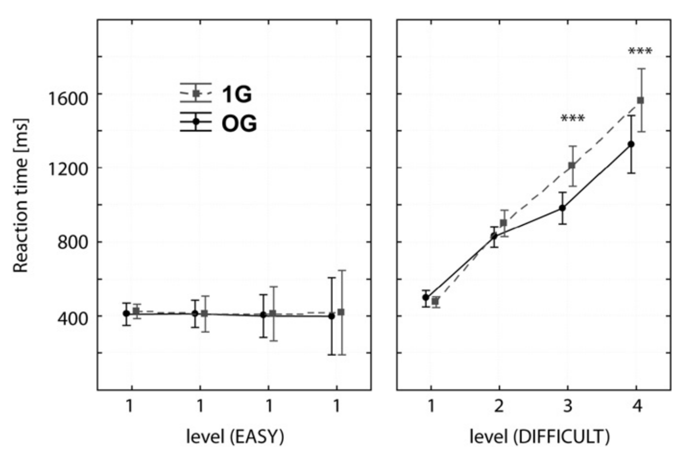

Fig. 1. Reaction time (RT) for the mental arithmetic task performed in normal gravity (dashed line) and microgravity (solid line). Group EASY (left) repeated the task at the easiest level, whereas the level of difficulty was progressively increased for group DIFFICULT (right). With increasing levels of difficulty reaction time increased. ***p < .001 between groups performed in 0G and 1G at levels 3 and 4.