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Artificial gravity exposure impairs exercise-related neurophysiological benefits

Tobias Vogt [a], Vera Abeln [a], Heiko K. Strüder [a], Stefan Schneider [a,b,*]

[a] Department of Exercise Neuroscience, Institute of Movement and Neurosciences, German Sport University, Am Sportpark Müngersdorf 6 50933 Cologne, Germany
[b] Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore DC, Queensland, 4558 Australia

HIGHLIGHTS

- Cross-over designed, we compared moderate exercise to artificial gravity exposure.
- EEG and cognitive performance were assessed to track psychophysiological changes.
- Neurophysiological data mirrored enhanced executive functions only after exercise.
- Cognitive performance improved after exercise, but not after artificial gravity.

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ABSTRACT

Artificial gravity (AG) exposure is suggested to counteract health deconditioning, theoretically complementing exercise during space habitations. Exercise-benefits on mental health are well documented (i.e. well-being, enhanced executive functions). Although AG is coherent for the integrity of fundamental physiological systems, the effects of its exposure on neurophysiological processes related to cognitive performance are poorly understood and therefore characterize the primary aim of this study. 16 healthy males participated in two randomly assigned sessions, AG and exercise (30 minute each). Participants were exposed to AG at continuous +2Gz in a short-arm human centrifuge and performed moderate exercise (cycling ergometer). Using 64 active electrodes, resting EEG was recorded before (pre), immediately after (post), and 15 min after (post15) each session. Alpha (7.5–12.5 Hz) and beta frequencies (12.5–35.0 Hz) were exported for analysis. Cognitive performance and mood states were assessed before and after each session. Cognitive performance improved after exercise ($p < 0.05$), but not after AG. This was reflected by typical EEG patterns after exercise, however not after AG. Frontal alpha (post $p < 0.01$, post15 $p < 0.001$) and beta activity (post15 $p < 0.001$) increased after AG compared to a decrease in frontal alpha (post15 $p < 0.05$) and beta activity (post $p < 0.01$) after exercise. Relaxed cortical states were indicated after exercise, but were less apparent after AG. Changes in mood states failed significance after both sessions. Summarized, the benefits to mental health, recorded after exercise, were absent after AG, indicating that AG might cause neurocognitive deconditioning.

1. Introduction

Artificial gravity (AG) exposure may counteract health deconditioning during extended space habitation, tracking the idea to add to or potentially replace exercise. The benefits of exercise on physical health are well documented; for example, it preserves alterations in musculoskeletal systems [1]. In addition, neurophysiological and behavioral research has shown that exercise affects mental health as well, including well-being, cognitive performance, and enhanced executive functions [2–5]. Herein intensity, duration and individual exercise preference need to be considered [6,7]. However, recent microgravity research accentuates the need for a better understanding of neurophysiological processes that can be associated with neurocognitive impairment under AG conditions [8,9].

In life science-related experiments, participants are typically exposed to AG from head to foot (+Gz axis), using long- and short-arm human centrifuges. On principle, the +Gz axis creates the perception of a sustained upright position of the human body. AG has been shown to stimulate and maintain the integrity of fundamental physiological systems when exposed at sufficient magnitudes; for example, when preserving cardiovascular, muscle and bone functions, orthostatic tolerances and the circadian rhythm [10,11]. Similar to the ongoing debate in exercise-related research, different intensities (i.e., gravitational loads) and durations of AG exposure are discussed in order to optimize the effectiveness of AG [12,13]. Due to limits in human tolerance for higher gravitational loads (e.g. signs of syncope [1]), a series of gradual

* Corresponding author. Tel.: +49 221 4982 7520; fax: +49 221 4973 454.
E-mail address: schneider@dshs-koeln.de (S. Schneider).

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accelerations has been suggested, also for AG adaptations in central nervous processes [14]. Although AG mirrors a number of exercise-induced benefits, the effects of AG on neurocognitive processes, such as executive functions, remain unclear.

The positive effects of exercise on well-being and cognitive performance are well documented. Recently, math clusters in psychological test batteries, as well as game-like applications, have been used to assess exercise-linked benefits of one's executive functions, including selective attention, decision making and working memory [5,15,16]. Moreover, neurocognitive studies suggest that the frontal brain regions play an important role in these executive functions [17–19]. Although the most advanced, functional magnetic resonance (fMRI) and positron emission tomography (PET) are limited for exercise science settings and an AG environment. Therefore, electroencephalography (EEG) has been validated as an appropriate method to determine neurocognitive processes in AG conditions and exercise-related research [8,20,21]. EEG is a non-invasive technique and records electro-cortical activity, enabling the analysis of traditionally discussed frequency bands, such as alpha (7.5–12.5 Hz) and beta (12.5–32.0 Hz). In theory, a general model of cortical arousal suggests that increased alpha activity combined with a coexisting decrease in beta activity indicates a relaxed cortical state. It is suggested that these EEG patterns enhance executive functions after exercise, particularly in frontal brain regions [22]. However, exercise-related neurocognitive effects of AG on frontal brain regions may be questioned due to AG-related psychological stress [23]. With AG as a potential countermeasure and its effects on crucial cognitive performances during space habitation, it is therefore important to also understand the neurocognitive processes that may result from an AG environment.

The primary aim of this research is to compare neurophysiological changes and cognitive performance before and after +2Gz AG exposure and before and after moderate cycling exercise, with each session lasting 30 min. It is hypothesized that (1) cognitive performance improves consistently after 30 min of AG and exercise. (2) Both continuous AG exposure and exercise are hypothesized to increase alpha activity and simultaneously decrease beta activity, particularly in frontal brain regions, indicating enhanced executive functions. It is further hypothesized that (3) mood states increase similarly after experiencing AG and exercise.

2. Materials and methods

2.1. Participants

The Medical Council of North-Rhine (Ärztekammer Nordrhein, Germany) obtained human research ethics approval for this study. Following a preliminary medical screening carried out by trained personnel from the German Aerospace Center, 16 healthy males (29.57 ± 6.61 years, 183.21 ± 5.11 cm, 82.14 ± 7.24 kg) provided written informed consent to participate in this study, including in familiarization sessions (use of cognitive tasks and mood assessment; details are below). Procedures were in compliance with national legislation and the Declaration of Helsinki for human participants.

2.2. Experimental design and procedures

Two experimental sessions in a crossover study design were randomly assigned to each participant, with at least a 24-hour time lag in between. The two sessions included moderate cycling exercise (EXC) and artificial gravity exposure (AG), each lasting for 30 min. Exercise was performed on a cycling ergometer (Ergoline ER 900, Ergoline, Bitz, Germany) at moderate intensity, balanced by the participant's heart rate (formula 180-age in years [24]). During AG, participants were exposed to continuous +2Gz at center of mass for 30 min, following a standardized acceleration protocol in a short-arm human centrifuge to serve as familiarization (Fig. 1). Participants were situated in a supine position throughout the centrifugation, harnessed with their head towards the center of rotation and gravitational acceleration towards the feet (+Gz axis).

Experiments were conducted cooperatively at the German Sport University Cologne and the German Aerospace Center, using the short-arm human centrifuge facilities.

Resting electro-cortical (EEG) activity for 2 min was recorded with the participants' eyes closed and in a supine position one minute prior to the start of each session (pre), immediately after each session (post) and 15 min after each session (post15). A profile of mood state (MOOD) and cognitive performance (COG) was assessed before and after each session. A control group (16 males with 20.56 ± 1.26 years, 182.56 ± 11.09 cm, 80.56 ± 11.56 kg) was installed to consider effects of practice and learning due to the assessments of cognitive performance in a pre-post design.

2.3. Cognitive performance

The cognitive performance of each participant in this study was assessed on a 3.5-inch touchscreen of a hand-held pocket PC based on computerized methods (Lumos Labs Inc., San Francisco, CA, USA). A consortium of standardized brain games (Chalkboard Challenge, Memory Matrix, Speed Brain) was used to assess executive functions. Chalkboard Challenge consisted of time-limited mental arithmetic with increasing levels of difficulty. Based on an appearance–disappearance mode, complex patterns were to be memorized in a Memory Matrix.

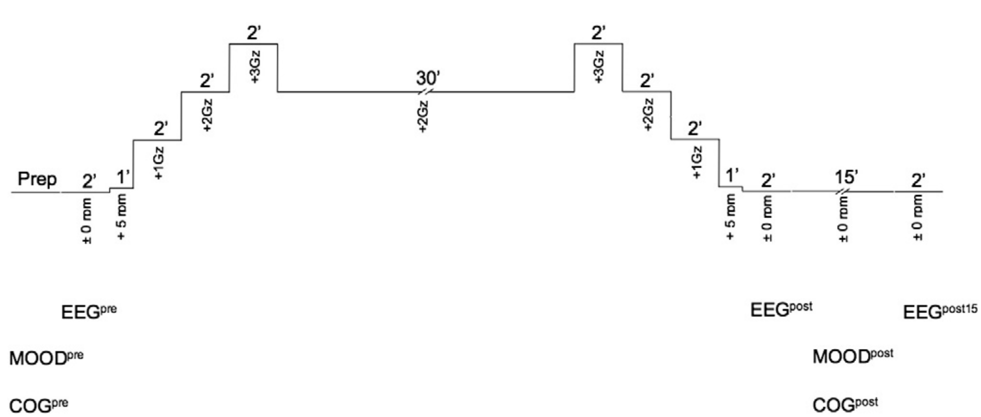

Fig. 1. Experimental protocol of artificial gravity exposure (AG) on a short-arm human centrifuge. Displayed are preparations (Prep) at acceleration speeds (±0 and baseline at +5 rpm) and AG levels (+1, +2 and +3 in Gz axis) including durations (1′, 2′, 15′ and 30′ minutes) of time spans for electro-cortical recordings (EEG), mood perceptions (MOOD) and cognitive performance assessments (COG) before (pre), immediately after (post), and 15 min after (post15) 30 min of AG exposure.