Institute of Movement and Neurosciences
German Sport University Cologne
Head of Institute: Univ.-Prof. Dr. H. K. Strüder

From Space To School – Neurophysiological Relation Of Physical Exercise And Cognitive Performance In Field

Doctoral thesis accepted for the degree

Doktorin der Sportwissenschaft/PhD in Sport Sciences

by

Petra Wollseiffen

from

Düren, Germany

Cologne (2019)

First reviewer: Univ. Prof. Dr. Heiko K. Strüder
Second reviewer: Univ. Prof. Dr. Kirsten Albracht
Chair of the doctorate committee: Univ. Prof. Dr. Heiko K. Strüder
Thesis defend on: 17.07.2019

Affidavits following § 7 section 2 No. 4 and 5 of the doctoral regulations from the German Sport University Cologne, February 20th 2013:

Hereby I declare:

The work presented in this thesis is the original work of the author except where acknowledged in the text. This material has not been submitted either in whole or in part for a degree at this or any other institution. Those parts or single sentences, which have been taken verbatim from other sources, are identified as citations.

I further declare that I complied with the actual "guidelines of qualified scientific work" of the German Sport University Cologne.

09.03.2019

Date and Signature

“Nothing in live is to be feared. It is only to be understood.”

Marie Curie

Financial Support

The present work was financially supported by an internal grant awarded from the German Sport University Cologne (*Hochschulinterne Forschungsförderung 2011*), grants from the German Space Agency (*DLR 50WB1161, DLR 50WB1561*) and funding from the German Academic Exchange Service (*Staff Exchange Service 2018*).

General Comments

The submission of this cumulative thesis integrates five peer-reviewed journal articles in international journals, PubMed-listed as first-author, two co-authorship in peer-reviewed, PubMed-listed international journals and one first-author manuscript under review in a peer-reviewed international journal (please refer to the PHD Curriculum below).

Published journal articles and under review manuscripts in the present cumulative doctoral thesis are restricted to formatting guidelines. For reasons of uniformity, layouts, citation styles, figures, and tables might slightly differ from originals. To avoid doubling within Chapter headlines, figures and tables, superscripts are included, respectively. References are compiled in Chapter X.

Table of Contents

I. General Introduction

Throughout the past decades exercise has gained enormous societal relevance and nowadays, at least in the western societies, exercise plays a key role in maintaining and restoring health. This essential role of exercise in the prevention of disease and maintenance of health is mainly caused by an increasingly sedentary society and targets the complete lifespan.

Although in nearly any definition of health, health is defined as a holistic state incorporating physical, mental and social aspects [1], exercise science so far has mainly focused on the physical aspect of health. With focus on restoring physical conditions after traumatic casualties or maintaining cardiovascular and musculoskeletal fitness. A mental and social health aspect of exercise has been widely neglected in the early years of exercise science research, and only few behavioral studies reported a positive impact of exercise on mood and cognitive performance. Nevertheless, these behavioral studies mainly regarded the central nervous system (CNS) as a black box and, due to missing technological approaches, the CNS remained widely unexplored and unattended in exercise science research. The only discipline targeting the CNS and its role in programming and execution of motor commands was the motor control area.

Beside this top-down approach, i.e. the aim to understand how the brain is organizing movements, since the late 1990s there has been a growing interest in understanding how exercise affects the CNS. Further, to describe models and mechanisms that might help to understand the underlying neurophysiological effects of exercise on mood and cognitive performance. First studies on the effects of exercise on the serotonergic and dopaminergic system and its role in mood regulation [2-7], where followed by animal experiments on central neuroplasticity caused by exercise [8-11]. With technological development, it has become possible to investigate the underlying neurophysiology of exercise using electroencephalography more profound and to link previously reported behavioral effects of exercise on mood and cognitive performance with neurophysiological data [12-16].

Today an increasing body of literature covers the effects of exercise on mental health throughout the lifespan. One criticism and therefore limitation of most of the studies is, that they are often lab-based studies and a transfer to the real-life situation is difficult. Studies by Dietrich [17, 18], Ekkekakis [19], Schneider [20-22] and others have pointed out that the positive effects of exercise on mood and cognitive performance are most likely provoked by a bias towards exercise, including the kind, duration and intensity of exercise. Placing participants in a lab with a pre-defined protocol obviously meets todays scientific criteria, but perhaps fails to investigate the unsophisticatedness of exercise. This is probably more important investigating the effects of exercise on mood or cognitive performance and less important when considering physical aspects of exercise. To give an example: Whereas a predefined exercise protocol on a treadmill or bike ergometer will provoke specific physiological reactions, the individual perception of this exercise will differ. Whereas some participants might enjoy the protocol (which plays a crucial role when it comes to mood regulations), others might feel over- or undertaxed.

Research in a real-life situation is probably the central topic of this dissertation. Based on technological developments allowing to do research in the field, me and my co-authors aimed to push further towards an embedded research approach and trying to identify possible underlying neurophysiological effects of exercise on mood and cognition and therefore delivering data that will contribute to emphasize the important role of exercise within a holistic health approach in different settings and the throughout the lifespan.

I.1. BACKGROUND

I.1.1. Neuroimaging in non-lab conditions

Gold-standard methods for brain imaging are positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and Diffusion Tensor Imaging (DTI). These techniques allow to identify an event related increase in brain metabolism and therefore the detection of task relevant brain regions. Unfortunately, due to their dimensions, these techniques are not applicable under non-laboratory filed conditions and during exercise. Despite their high spatial resolution, these techniques offer a very low temporal resolution, which also makes them inappropriate for many experimental conditions especially in the area of exercise science. In contrast to those stationary systems near infrared spectroscopy (NIRS) allows measuring regional changes in oxygenized and deoxygenized brain blood flow under experimental conditions in the field. Although a NIRS system is portable and easy to use unfortunately, NIRS offers limited spatial resolution. In addition, a systemic increase in cardiovascular activity and therefore brain blood flow during exercise might superimpose any neural effect in the NIRS data [23]. It remains unclear how much of the signal is influenced by changes in blood flow in the superficial tissue as previous research revealed no correlation between changes in hemokinetics measured by NIRS and electro-cortical activity [24, 25]. Similar to fMRI or PET, NIRS only offers a secondary signal of neural activity as these techniques reflect the increased metabolic demand caused by neural activity. In contrast, electroencephalography (EEG) allows to record the primary signal of neural activity with a high temporal, albeit low spatial resolution. To overcome the limitation of low spatial resolution, electroencephalography in combination with source localization algorithms offer a reliable, inexpensive and easy to use technique that is applicable to the very specific situation under field conditions and might help to identify the underlying neuro-behavioral and neuro-cognitive effects of exercise [26] and / or weightlessness [27].

I.1.2. Introduction to EEG: Recording and analysis

EEG activity that is recorded via scalp located electrodes is evoked by synchronized postsynaptic potentials [28]. Today multi-electrode EEG caps are used for recording EEG activity. Electrodes are organized in the international 10-20 system [29], which are referenced either to the right and left earlobe or a pre-defined reference electrode embedded in the cap architecture. Modern systems like the ones by ActiCap system (BrainProducts, Gilching, Germany) allow an artefact-free recording by actively shielding the recorded EEG signal. This, in combination with battery powered systems allow to record under field conditions.

Frequency analysis

One way to analyze EEG activity is by frequency analysis. Here the raw signal after filtering and segmentation is divided into different wave bands, i.e. delta (0.5 - 3.5Hz), theta (3.5.-7.5Hz), alpha (7.5 - 12.5 Hz), beta (12.5 - 35Hz) and gamma (>35Hz). Sometimes the alpha and beta wavebands are subdivided into higher and lower wave bands (alpha -1: 7.5 - 10Hz / alpha-2: 10 - 12.5Hz; beta-1: 12.5 - 18.0Hz / beta-2: 18.0-35.0Hz). In the resting waking EEG the delta and theta band can be widely neglected as they typically show activity during sleep and drowsiness. A general model of cortical arousal assumes that arousal is negatively correlated with alpha activity (decrease of alpha activity) which is accompanied by a shift of activity towards high Hz waveforms (beta activity). This is probably caused by cholinergic neuromodulation [30], which affects the synchrony of interneuron networks, involved in higher frequency oscillations [31]. In contrast, an increase of cortical relaxation, a so-called synchronized state of the brain, is thought to be reflected in an increased alpha activity and a decreased beta activity [32, 33]. Higher beta and gamma activity is also present during the processing of sensory information [34].

Cortical current density

Another way to analyze EEG activity is by defining the amount of cortical current density (CCD) [35]. Cortical current density is a measure of electric activity caused by neural activity per unit area of cross section. In a two-dimensional area the amount of activity is measured in µV/mm2. But in a three-dimensional and voxel based analysis – as in the brain – activity is squared so that the unit is µV2/mm4. The analysis of cortical current density is equivalent to a signal analysis using blood oxygen level dependence (BOLD) [36]. The BOLD signal defines the increase in regional blood flow caused by energy expenditure of neural activity – but therefore is – a secondary signal (see explanation above). Directly recording and analyzing the electrical activity that causes an increase in cell metabolism might be considered superior – at least when considering a temporal resolution. In combination with source localization methods, as standardized low resolution brain electromagnetic tomography (sLORETA) [37-39] using triangulation, the localization of activity within the CNS has become possible. Spatial resolution of a CCD analysis is dependent on the number of available electrodes, with a number of 19 electrodes proposed as a minimum requirement.

Event related potentials

While EEG frequency and CCD analysis allows to determine a general state of cortical arousal within a given time window, the analysis of event related potentials (ERP) allows to determine brain responses that are directly resulting from an external or internal stimulus, e.g. a thought, motor command, or perception. It is assumed that ERPs are a result of "higher" cognitive processes, such as memory, expectation, and attention [40].

An ERP, in the current literature also described as neurocognitive marker, represents the average of a series of voltage oscillations in the brain in response to any discrete stimulus event [41]. An ERP analysis is considering a latency component, describing the time between stimulus onset and ERP response, and an amplitude component, describing the voltage difference caused by the

ERP. Whereas the early components (up to 70 ms) of an ERP are mostly related to the physical characteristics of the stimulus (detection) the later components (> 200 ms) are more related to the higher cognitive processes [42, 43].

Prominent ERP markers to identify higher cognitive processes have been identified to occur between 100 and 700ms after stimulus onset [40]. The N2 or N200 component is a negative peak occurring between 200 and 350 ms following stimulus onset. For visual stimulations this component is present in occipital brain regions and is reported to reflect strategic monitoring (decision making) and therefore control of movement responses [44, 45]. Another prominent marker is the P300, a positive deflection of the EEG with an latency between 200 up to 700 ms [46]. The P300 is associated with cognitive performance, characterizing neuropsychological responses that refer to specific stimuli being of relevance among other stimuli, which have to be ignored (oddball paradigm). Regardless of early understandings, that assigned the P300 within functional analysis [47], today its characterization becomes more and more detailed, including information processes that are engaged with attention and memory mechanisms [48]. It could be demonstrated that the magnitude of the P300 decreases with increasing difficulty of a task, and with increasing memory load. Nieuwenhuis et al [49] provided an anatomical model reflecting similarities of the P300 with the orientation response.

I.1.3. Exercise and neuro-cognitive performance

For the context of physical exercise and cognitive achievement, far back in history since the ancient Greeks (fourth century B.C.), it was believed that physical activity would be closely connected to intellectual abilities [50].

Scientific investigations of the relation began in the 1930th. Back in the 1950th and 1960th the focus of research turned to psychological benefits of physical activity, followed by a shift of interest to physical benefits [51]. Since the 1970th the first systematic examinations of the relation between physical activity and cognition were conducted [52].

Today there is broad literature describing the effect of exercise on cognitive function. Although in general a positive relation is agreed, effect sizes vary and results are dependent on a number of contributing factors [53].

Regarding many authors conflicting results could be affected by the possible range of cognitive tasks that have been assessed as information processing, attention capacity, performance on task that demand visual-spatial processing, psychomotor speed and / or executive-control processes [54, 55].

There is no standardization concerning the different physiological requirements of the type of exercise [56] as its duration, intensity, and type of physical activity. The participants characteristics often differ in age, range, status of health, gender and education as well as the level of cardiovascular and physical fitness. Studies report either an acute effect of exercise on cognitive performance (especially executive functions) and mental well-being, which is probably mediated by functional exercise induced CNS-changes or outlasting effects on general brain health (e.g. memory), which are more likely exercise induced structural changes in the brain.

Furthermore, lifestyle factors as intellectual engagement, social interaction, diet and physical activity are associated with the maintenance of cognitive function as well as downsizing the risk for neurodegenerative disorders and vascular dementia, [57-60].

Whereas early research on the influence of exercise on cognitive function was conducted merely on a behavioral level, due to technological developments in the recent years an increasing number of studies started to investigate the underlying neuro-physiology of exercise, which allowed to define some key principles on how exercise affects cognitive performance and mental well-being. Arne Dietrich [61] was amongst the first to attribute positive aspects of exercise to specific changes in brain regions involved in cognitive performance, mainly frontal and temporal brain areas. His theory of a transient hypofrontality assumed a shift of cortical activity away from fronto-temporal brain areas during exercise, as limited neuronal capacity [62], was needed to maintain activity in those regions being responsible for the planning, execution and control of exercise, i.e. the primary motor cortex and associated motor and sensory areas. Following the initial and theoretical idea of such a transient hypofrontality [61] a number of studies confirmed this idea [12, 15, 63] and the theory today is widely accepted in the literature [64]. An important link to the previously described increase in cognitive performance following exercise, has been provided by further studies, proving that the hypofrontality is outlasting a single exercise session by at least 30 min [14]. This “down-regulation” of cortical activity in frontal-temporal brain areas is proposed to counteract stress induced dysfunctions in fronto-temporal brain areas [65] and to “normalize” activity in these regions. Research has also linked the theory of transient hypofrontality to the flow experience [66, 67] and creativity [68].

To reach such a flow state, the physiological requirements of exercise play a crucial role [56], as the transient hypofrontality seems to be dependent on exercise intensity (dose-response relationship [69]) as well as exercise preferences [12]. A dose-response relationship on the effects of exercise on cognitive performance has been reported before on a behavioral level [69] and actually mimics a phenomenon that is already known from arousal research: for peak performance there is an optimum of arousal level (inverted-U theory). Several authors [12, 16, 19, 70] showed that the transient hypofrontality and related positive effects of exercise on mood and cognitive performance appear neither when intensity or duration of exercise is experienced as too high or too low but only when the exercise defining parameters are set on an individual optimum.

Following further studies Schneider et al proposed an exercise preference hypothesis, which assumes that the described link between a transient hypofrontality and neuro-cognitive and neuro-behavioral effects of exercise is based on a personal bias towards exercise [12, 16, 71].

This all provides relevance for further research, showing that it is not only important to exercise, as widely recommended, but also to identify the right kind, the right duration and the right intensity of exercise. If these factors are not considered, neither will subjects' experience the positive effects of exercise on neuro-cognitive performance (functional adaptation of the CNS), nor will they show any kind of compliance, which is essential to have an outlasting neuro-cognitive benefit (structural adaptation of the CNS).

As the positive effects of an acute bout of exercise on functional neuro-cognitive performance are probably limited to one or two hours post exercise, there is furthermore the need to investigate its effectiveness and the affecting variable in the specific field setting. If exercise is expected to improve employee's mental performance in a workplace setting (this includes working on the International Space Station (ISS), see below) or children's academic achievement in school, there is a need for interventions which are applicable and reasonable.

I.1.4. Changes in cognitive performance during space flight and gravity induced changes in brain cortical activity

Terrestrial research has shown that stress is one of the main contributing factors influencing cognitive and perceptual motor performance [72-74]. During prolonged exposure to microgravity and embedded in an isolated and confined environment, one would expect a stress related decrease in performance and indeed, previous research revealed the deterioration of various psychomotor functions during prolonged spaceflight, especially when mental work load was high as for example during dual tasks experiments [75-85]. So far it remains unknown, if these effects were caused primarily by the weightlessness situation or by the stressful situation of living confined and isolated in an encapsulated habitat on board of the ISS and/or former MIR station. Studies by Manzey et al. [86] and Lorenz et al. [87] proposed that the detrimental effects on cognitive and perceptual performance are mainly visible during transition phases of high stress, i.e. the beginning and the end of a mission and therefore are not dependent on the experience of weightlessness. From a mere physiological viewpoint, assuming that an increase in blood supply to the brain would positively impact on cognitive performance, one would argue that the redistribution of blood volume to the upper extremities and the head [88] would have a positive impact on mental performance.

With respect to future developments like a deep space gateway, where individuals are supposed to be inhabited for several months, one of the current aims in space life-science research is to differentiate and further investigate a possible impact of these two parameters, weightlessness and isolation on cognitive performance in order to define appropriate countermeasures and to support the success of the mission.

As already described in the section above, only in the last decade technological developments have made it possible, not only to rely on behavioral data, but also to assess and identify the underlying neurophysiological effects of weightlessness and confinement on cognitive performance and mental health.

It has been shown sensory deprivation during long-term isolation is resulting in detrimental effects on the CNS and cognitive performance [11, 87, 89-91], which could be counteracted by a regular exercise regimen [11, 14, 92, 93]. Experiments designed to understand the effects of weightlessness on the CNS show opposed, positive effects. A first study by Cheron et al. [94], using the integrated Multi Electrodes Encephalogram Measurement Module (*MEEMM) on the ISS,* showed an increase of power in the peak alpha frequency (PAF), which is one of the dominating frequencies in the resting brain. As previous studies showed that the PAF is a marker of increased cognitive performance [95, 96], Cheron et al. proposed that the reduction in multimodal graviceptive inputs to cortical networks might positively affect cognitive function. Unfortunately, their experiment did not include any assessment of cognitive function and therefore the interpretation must remain speculative.

Currently the only way to further investigate on the effects of weightlessness on neuro-cognitive performance is by using a parabolic flight model. Parabolic flights are characterized by recurring phases of microgravity (0G) of 22 seconds, accumulating in approximately 11 minutes of weightlessness for one experimental session. Pletser and Quadens [97] were the first to demonstrate that changes in EEG-activity are varying with changes in gravity caused by parabolic flight. However, these changes were inter-subject dependent, which marks some important limitations that have to be considered when designing experiments for a parabolic flight: First, it is necessary to control for the individual stress level, e.g. by comparing inflight data obtained during normal gravity (1G) and 0G in flight, rather than comparing an inflight 0G scenario with a lab-based 1G scenario. Secondly, the effect of anti-nausea medication needs to be controlled. However, such an effect might be ruled out, if comparing experimental results obtained during inflight 1G to inflight 0G as the medication is active in both cases. Finally, the individuals experience needs to be controlled. In a first study using EEG recordings in combination with a source localization analysis (sLORETA) Schneider et al. [98] could show that the initial experience of weightlessness is provoking specific changes in the prefrontal cortex, a brain region that is well known to play a major role in emotional processing and the modulation of performance [99, 100]. A tilt table study with 9° head down-tilt (a position that is used to mimic the redistribution of blood volume during weightlessness [101]) did not obtain similar results. Accordingly, the authors propose that the observed changes during microgravity reflect emotional processes related to the experience of weightlessness, which needs to be considered when designing future experiments. It is hypothesized that such an effect is less pronounced with individuals that have been exposed to weightlessness during parabolic flights before.

To conclude, it can be stated, that beside a number of behavioral studies on cognitive and sensorimotor performance both, during parabolic flight and on board the former Russian MIR station and some initial studies on the effects of weightlessness / isolation on the CNS provide confounding results. This is due to the fact that these studies (1) are barely able to differentiate between a primary effect of weightlessness and a secondary effect of isolation and (2) fail to provide a link between cognitive processing and the underlying neuro-physiological mechanism.

I.2. STUDY OVERVIEW AND BROADER CONTEXT

I.2.1. Study 1

In the latter years companies have shown an increased awareness for workplace health promotion. The motivation for such programs is two folded. First companies aim to increase their attractiveness on the market by offering health packages for their employees. In an era of a shortage of skilled professionals the competition for high performers is increasingly important for companies and a work place with a dedicated work-life balance program is one of the top wish list for employees. Companies like Amazon and Apple in the US have designed sophisticated campuses for their employees, offering a variety of exercise possibilities for free use. Such a concept is hardly transferable to Germany with predominant small and medium sized companies. In Germany, from both a social and an economic perspective, companies are becoming increasingly aware of their responsibility for employees' health. As a consequence, the corporate field has shown an increasing interest in concepts of "corporate health management" and in a variety of offers related to health benefits for employees (e.g. [102]. In the organizational setting, work breaks (in the literature also called breaks, rest breaks, lunch breaks, pauses) are considered to positively affect employees' physical and cognitive performance. The rationale behind work breaks is: they should allow mental recovery to maintain or improve task performance such as higher output or reduced error rates or reduced incident risks [103]. Although a number of studies exist, one limitation is the missing link between performance assessments and the underlying neurophysiological effects. The first study of this dissertation

(Chapter II) investigated possible positive effects of exercise on neuro-cognitive performance and mood in the context of workplace health promotion. It was hypothesized that an exercise work break would positively affect neuro-cognitive and neuro-behavioral performance in contrast to a standardized and/or meditative work break.

I.2.2. Study 2

Although in today's work-life more and more jobs are defined by a sedentary behavior (office jobs), still some exist, which are defined by prolonged phases of physical activity (e.g. firefighter, special forces). Also, prolonged physical exercise is performed in recreational activities as (ultra-)marathons. Multiple components of the physical (physiological) and mental (psychological) effects of prolonged exercise are unknown an especially specific components of brain activity, and the correlation with mood, emotional intelligence, emotional regulation, and physical and mental effort are not known. Two effects of prolonged exercise on mental performance are discussed in exercise science. Whereas it has been shown that prolonged exercise causes mental fatigue [104] other studies assume prolonged exercise to result in a flow experience with benefits for mental performance [61]. Study 2 (Chapter III) used a repeated-measures design in which the participants completed a series of physical and mental measurements before and during a non-competitive 6-hours run conducted at their own pace. It was hypothesized that 6 hours of exercise will cause specific changes in brain cortical activity, especially prefrontal cortex regions and that these changes will be correlated with changes in flow state, mood and perceived exertion.

I.2.3. Study 3

The German health survey for children and adolescents shows, that approximately 9% of the German school children are overweight and 6% severely obese [105]. Programs like „Be Active Stay Healthy“ (BASH) in England or the „Children’s Health Interventional Trial“ (CHILT) in Germany are primarily focusing on the metabolic [106], orthopedic [107] and cardiovascular [108] adaptations caused by exercise. Lately more and more research has been conducted to assess how exercise influences the young brain and children`s mental development [109-114]. Larger trials like the study of Booth et al. [115] were targeting the role of regular physical activity in school for an improvement of academic achievement. This role cannot necessarily be filled completely by school sport as the curriculum of school sport is manifold: Beside an introduction to different sports, which is reflecting both, the need for a broad motor development of children as well as an introduction into the cultural aspects of sports (rules and standards), school sport is targeting the personal development (e.g. values, fair play) as well as general health aspects of sport and exercise. Apparently active school breaks or even an exercise session in the beginning of the morning are proposed and the effects examined [109]. In this context it is important to remark that regular physical activity most likely does not make school children smarter, but specific neurophysiological changes caused by exercise (a transient hypofrontality) are thought to be the neuronal basis for an increase in attention and concentrativeness, supporting an enhanced learning process [116]. This, in the long-term, obviously increases academic achievements.

One of the major contributions to an improvement in cognitive performance after a bout of exercise, either school sport or an active break, is probably the factor distraction. Following the theory of a transient hypofrontality, stress or "cognitive overload" is accompanied by an increase in prefrontal brain areas that hinder further concentration and attention. Similar to exercise, other non-major subjects like arts or music might have similar effects by offering cognitive distraction.

Study 3 (Chapter IV) examined the role of non-major subjects in school on changes in brain cortical activity and the achievements in a national assessment in grade 3. It is the first study examining the effects of school sport with another non-major subject (arts). It was hypothesized that exercise in contrast to an arts class would result in a decrease in fronto-temporal cortical activity and an improvement in academic performance assessed through a nation-wide learning assessment in grade 3 (Vera3).

I.2.4. Study 4-6

The final three studies (Chapter V-VII) investigated the effects of exercise on neurocognitive performance in weightlessness. Since the first Apollo mission, the role of exercise in space in order to maintain musculoskeletal and cardiovascular fitness has played a crucial role. Without exercise, the unloading condition of weightlessness leads to a maladaptation of the cardiovascular system and a loss of muscle strength and muscle mass (up to 24% after 6 months of spaceflight [117]) as well as a loss of bone density (approx. 1% per month in space [118]). To counteract this deconditioning, astronauts and cosmonauts are exercising approximately 2hrs per day on a treadmill / bike ergometer and/or the advanced resistive exercise devices (ARED) on board of the ISS. With prolonged mission duration and serious plans of national and international space agencies for a manned mission to Mars the role of exercise has been redefined in the roadmaps of NASA [119] and ESA [120]. Today exercise is regarded as tool to counteract isolation and confinement related stress, to maintain mental health during long-term spaceflight and therefore contribute to mission success and mission safety [121]. Unfortunately, it remains currently unknown, whether previously reported decrease in behavioral data (reaction time, decision making, executive function) is caused by weightlessness or the confined and isolated situation. Accordingly, individually tailored exercise programs are difficult to define. Therefore, a couple of experiments were designed to identify the mere effect of weightlessness on neurocognitive performance. It was hypothesized that weightlessness itself has no influence on neuro-cognitive performance.

II. Short Bouts Of Intensive Exercise During The Workday Have A Positive Effect On Neuro-cognitive Performance,

Article published in Stress and Health (2015) 32(5):514-523, DOI: 10.1002/smi.2654

Petra Wollseiffen[1], Argang Ghadiri[2], André Scholz[2], Heiko K. Strüder[1], Rainer Herpers[2], Theo Peters[2] & Stefan Schneider[1,3]

[1] Institute of Movement and Neuroscience, German Sport University Cologne, Cologne, Germany

[2] Bonn-Rhein-Sieg University of Applied Sciences, Sankt Augustin, Germany

[3] Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore, Queensland Australia

Article Info

Received 25.08.2014

Accepted 01.09.2015

Published online 09.10.2015

Impact 1.814

Number of text pages: 12

Number of Figures: 4

Number of Tables: 1

II.1. ABSTRACT

Beside its positive impact on physical health, exercise is indicated to positively affect cognitive performance based on a relocation of cortical activity. This study examined the influence of different types of breaks on cognitive performance and related cortical activity in office-based employees. Breaks were filled with either exercise, resting or a usual break and a control condition where employees continued working without any break.

Cognitive performance was assessed using the d2-R test and two commercially available cognitive tasks. Brain cortical activity was recorded using electroencephalography before and after breaks. Individual's mood was analyzed using a profile of mood state.

Results indicate a positive effect of a three-minute boxing intervention on cognitive performance, mirrored by a decrease in prefrontal cortex activity. Although perceived psychological state was increased after the usual break, this is neither reflected in cortical activity nor cognitive performance. With respect to the fact that also bike activity resulted an increase in prefrontal alpha-2 activity, a positive effect of exercise on neuro-cognitive performance can be stated. Health and economic benefits may result from brief physical activity breaks and help to maintain work-place performance and job satisfaction.

Keywords: workday breaks; prefrontal cortex; physical activity; neuro-cognitive performance; mood.

II.2. REFERENCES

Please refer to Chapter X.

III. The Effect Of 6 H Of Running On Brain Activity, Mood, And Cognitive Performance,

Article published in Experimental Brain Research (2016) 234:1829–1836, DOI 10.1007/s00221-016-4587-7

Petra Wollseiffen[1], Stefan Schneider[1,2], Lisa A. Martin[2], Hugo A. Kerhervé[2], Timo Klein[1,2], Collin Solomon[2]

[1] Institute of Movement and Neurosciences, German Sport, University Cologne, Am Sportpark Müngersdorf 6, 50933 Cologne, Germany

[2] Faculty of Science, Health Education and Engineering, University of the Sunshine Coast, Maroochydore, QLD, Australia

Article Info

Received 14.10.2015

Accepted 30.01.2016

Published online 18.02.2016

Impact 2.036

Number of text pages: 8

Number of Figures: 3

Number of Tables: 4

III.1. ABSTRACT

Long duration exercise has been linked with the psychological model of Flow. It is expected that the flow experience is characterized by specific changes in cortical activity, especially a transient hypofrontality, which has recently been connected with an increase in cognitive performance post exercise. Nevertheless, data on neuro-affective and neuro-cognitive effects during prolonged exercise are rare.

The cognitive performance, mental state, flow experience and brain cortical activity of eleven ultramarathon runners (six females, five males) were assessed before, several times during, and after a 6-hours run. A decrease of cortical activity (beta-activity) was measured in the frontal cortex, whereas no changes were measured for global beta, frontal or global alpha-activity. Perceived physical relaxation and flow state increased significantly after one hour of running but decreased during the following five hours. Perceived physical state and motivational state remained stable during the first hour of running but then decreased significantly. Cognitive performance as well as the underlying neurophysiological events (recorded as event-related potentials) remained stable across the 6-hours run. Despite the fact that women reported significant higher levels of flow, no further gender effects were noticeable. Supporting the theory of a transient hypofrontality, a clear decrease in frontal cortex activity was noticeable. Interestingly this had no effect on cognitive performance. The fact that self-reported flow experience only increased during the first hour of running before decreasing, leads us to assume that changes in cortical activity and the experience of Flow may not be linked as previously supposed.

Keywords: prolonged exercise; brain activity; cognitive performance; Flow; affective state

III.2. REFERENCES

Please refer to Chapter X.

IV. Distraction Versus Intensity - The Importance Of Non-major Subjects On Academic Performance In School,

Article published in Medical Principles and Practice (2017) 27:61–65, DOI: 10.1159/000486281

Petra Wollseiffen[1], Tobias Vogt[3], Heiko K. Strüder[1], Stefan Schneider[1,2]

[1] Institute of Movement and Neurosciences, German Sport University Cologne

[2] Faculty of Science, Health, Education and Engineering, University of Sunshine Coast Maroochydore, Queensland, Australia

[3] Institute of Professional Sport Education and Sport Qualifications

Article Info

Received 14.05.2017

Accepted 13.12.2017

Published online 13.12.2017

Impact 1.536

Number of text pages: 5

Number of Figures: 0

Number of Tables: 2

IV.1. ABSTRACT

The aim of this study was to compare the influence of a class of aerobic exercise and an arts class on brain cortical activity and possible effects on cognitive performance.

Electroencephalography was used to record the electro cortical activity of sixteen (16) school children (8-10 years) before and after an aerobic exercise class, and an arts class. Performance in a standardized assessment of educational attainment (VERA-3) was assessed following both classes.

A significant decrease of cortical activity was detected in all four lobes after exercise but not art classes ($p < .05$). No changes in cognitive performance were observed after exercise and art classes.

In this study, cortical activity was reduced after an exercise class but effect on cognitive performance was not observed. No changes on cortical activity and cognitive performance were obtained after an art class. Hence, the neurophysiological effect of exercise should be further evaluated regarding different kinds of cognitive performance: creativity, knowledge acquisition as well as the outlasting effects of exercise on academic achievement.

Keywords: EEG, exercise and art classes, cognitive function

IV.2. REFERENCES

Please refer to Chapter X.

V. Neuro-cognitive Performance Is Enhanced During Short Periods Of Microgravity

Article published in Physiology and Behavior (2015) 155:9-16, DOI 10.1016/j.physbeh.2015.11.036

Petra Wollseiffen[1], Tobias Vogt[1], Vera Abeln[1], Heiko K. Strüder[1], Christopher D. Askew[2], Stefan Schneider[1,2]

[1] Institute of Movement and Neurosciences, German Sport University Cologne, Germany

[2] School of Health and Sport Sciences, University of the Sunshine Coast, Maroochydore, Australia

Article Info:

Received 15.10.2015

Accepted 30.11.2015

Published online 01.12.2015

Impact 2.976

Number of text pages: 8

Number of Figures: 5

Number of Tables: 0

V.1. 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.

Keywords: Parabolic flight; EEG; ERP; cognitive processing; P2; reaction time

V.2. REFERENCES

Please refer to Chapter X.

VI. The Influence Of Microgravity On Cerebral Blood Flow And Electrocortical Activity,

Article published in Experimental Brain Research (2019), DOI: 10.1007/s00221-019-05490-6

Timo Klein[1,2*], Petra Wollseiffen[1*], Marit Sanders[3], Jurgen Claassen[3], Heather Carnahan[4], Vera Abeln[1], Tobias Vogt[5], Heiko K. Strüder[1], Stefan Schneider[1, 2, 4]

[*] TK and PW share the first authorship

[1] Institute of Movement and Neuroscience, German Sport University Cologne, Cologne, Germany

[2] Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore, Queensland Australia

[3] Department of Geriatric Medicine, Radboud Alzheimer Centre, Radboud University Medical Center, Donders, Institute for Brain, Cognition and Behavior, 925 PO box 9101, 6500 HB Nijmegen, The Netherlands

[4] School of Maritime Studies, Offshore Safety and Survival Centre, Marine Institute, Memorial
University of Newfoundland, Canada

[5] Institute of Professional Sport Education and Sport Qualifications, German Sport University Cologne.

Article Info

Received 25.09.2018

Accepted 04.02.2019

Published online 11.02.2019

Impact 1.87

Number of text pages: 6

Number of Figures: 2

Number of Tables: 0

VI.1. ABSTRACT

Changes in gravity conditions have previously been reported to influence brain hemodynamics as well as neuronal activity. This paper attempts to identify a possible link between changes in brain blood flow and neuronal activity during microgravity.

Middle cerebral artery flow velocity (MCAv) was measured using doppler ultrasound. Brain cortical activity (i.e. cortical current density) was measured using electroencephalography. Finger blood pressure was recorded and exported to generate beat-by-beat systolic (SBP), diastolic (DBP) and mean arterial pressure (MAP), heart rate (HR), cardiac output (CO), and cerebrovascular conductance index (CVCi). Seventeen participants were evaluated under normal gravity conditions and microgravity conditions, during 15 bouts of 22 second intervals of weightlessness during a parabolic flight.

Although MAP decreased and CO increased, MCAv remained unchanged in the microgravity condition. CVCi as the quotient of MCAv and MAP increased in microgravity. Cortical current density showed a global decrease.

Our data supports earlier data reporting a decrease in the amplitude of event related potentials recorded during microgravity. However, the general decrease in neural excitability in microgravity seems not to be dependent on hemodynamic changes.

Keywords: Parabolic flight; EEG; transcranial doppler ultrasound; MCA

VI.2. REFERENCES

Please refer to Chapter X.

VII. Neuro-Cognitive Performance Is Enhanced During Short Periods Of Microgravity – Part 2,

Article to be published

Petra Wollseiffen[1*], Timo Klein[1,3*], Tobias Vogt[2], Vera Abeln[1], Heiko K. Strüder[1], Tim Stuckenschneider[1,3], Marit Sanders[4], Jurgen Claassen[4], Christopher D. Askew[3], Heather Carnahan[5], Stefan Schneider[1, 3, 5]

[*] PW and TK share the first authorship

[1] Institute of Movement and Neurosciences, German Sport University Cologne

[2] Institute of Professional Sport Education and Sport Qualifications, German Sport University Cologne

[3] School of Health and Sport Sciences, University of the Sunshine Coast, Maroochydore, Australia.

[4] Department of Geriatric Medicine, Radboud Alzheimer Centre, Radboud University Medical Center, Donders Institute for Brain, Cognition and Behaviour, Nijmegen, The Netherlands.

[5] School of Maritime Studies, Offshore Safety and Survival Centre, Marine Institute, Memorial University of Newfoundland, Canada

Article Info

Received 05.02.2019 (under Revision Physiology and Behavior:

PHB_2019_147)

Accepted

Published online

Impact 2.45

Number of text pages: 7

Number of Figures: 4

Number of Tables: 0

VII.1. ABSTRACT

Previous studies have demonstrated no, or a slightly negative impact, of space flight on cognitive performance but were not able to distinguish between the primary effects of weightlessness and any secondary effects of stress and confinement. When isolating the effect of weightlessness, achieved by parabolic flights, reaction time while solving an arithmetic task was shown to be enhanced. This effect was found to be stronger with increasing task complexity and was independent of previous experience of weightlessness as well as anti-nausea medication. Analysis of event related potentials showed a decreased amplitude of the N100-P200 complex in weightlessness but was not able to distinguish a possible effect of task complexity.

The present study aimed to extend this previous work, by comparing behavioral (reaction time) and neurological (event related potentials analysis) performance to a simple (oddball) and a complex (mental arithmetic + oddball) task during weightlessness.

28 participants participated in two experiments. 11 participants performed a simple oddball experiment in the 1G and 0G phases of a parabolic flight. A further 17 participants were presented a complex arithmetic task in combination with an oddball task again during the 1G and 0G phases of a parabolic flight. Reaction time as well as event related potentials (ERP) were assessed.

Results revealed a reduced reaction time ($p < .05$) for the complex task during 0G. No gravity effects on reaction time were found for the simple task. In both experiments a reduction of typical ERP amplitudes was noticeable in weightlessness, whereas latency remained unaffected.

As task complexity plays a major role, which casts a possible effect of arousal into doubt, it is assumed that the weightlessness induced fluid shift to the brain is positively affecting neuro-behavioral performance.

Keywords: Parabolic flight; EEG; ERP; electro-cortical processing; oddball, reaction time

VII.2. REFERENCES

Please refer to Chapter X.

VIII. Overall Thesis Discussion

Living and working conditions have substantially changed during the last centuries, with a gain of free time for leisure activities but also due to the growing absence of physical labor. Further, the beneficial influence of sport and exercise on developing and maintaining health, especially under its´ preventive aspect of diseases, is gathering more and more public attention. In this respect, there is a growing community of actively engaged individuals in sports. Moreover, exercise science today offers fundamental knowledge on exercise-related processes, e.g. locomotion, musculoskeletal system, physiological adaptations, metabolism, hormone responses, cardiovascular system, and recommendations on sports and exercise place strong emphasis on improving health. As a fact, many of the studies dealing with exercise or physical activity concentrate on the bodily benefits in this sense of health. Only a limited number of studies has targeted also effects of exercise on mental and social health, e.g. on reduced symptoms of some psychological diseases [261]. And only in the past years, researchers started to identify and analyze the underlying neurophysiological parameters of exercise on mental performance and emotional wellbeing [12, 16, 262]. Still, there is an existing knowledge gap on exercise related neurophysiological mechanisms and adaptation of functional and structural processes and its benefit for cognitive performance. The research objective of this cumulative doctoral thesis was to explore the neurophysiological relation of physical exercise on cognitive performance in different field settings. It was aimed to reveal neurophysiological benefits of exercise for the first time in various real-life settings like space (microgravity in parabolic flights), ultramarathon, office and school and to further show its´ impact also on emotional parameters.

VIII.1. SUMMARY OF FINDINGS

VIII.1.1. Study 1

For the first study in Chapter II it was hypothesized that an active (exercise) work break would positively affect neuro-cognitive and neuro-behavioral performance in contrast to a standardized and/or meditative work break. Study 1 contributed to the general idea that breaks, interrupting the daily office work, lead to reduced fatigue, control for risk at work and enhance productivity [167, 168]. Recommendations promoted active breaks in a workday for a better physical health, positive psychological effects, like the reduction of stress, and support work satisfaction [103] and therefore reduce the loss of productivity. In this respect, the aim of study 1 was to prove these beneficial effects of an active work break also on cognitive performance and mood, due to specific neurophysiological changes in brain cortical activity.

Results revealed that different types of work breaks had different effects on mood and cognition of office workers. Especially the benefits of an exercise intervention on cognitive performance were mirrored by specific neurophysiological events (transient hypofrontality). The positive effect of a short bout of high intensity (boxing) and moderate intensity exercise (biking) on cognitive performance and perceived psychological state coincided with an increase in electrocortical activity. No increase in cortical activation could be found for a usual break or a meditative break, which clearly lacked in effectiveness concerning both, cortical activity and cognitive performance. Physical activity, could reinforce beneficial effects coupled with the positive impact on stress reduction, decreased anxiety and the alleviation of depression [263]. The promotion of work satisfaction for office workers and positive psychological effects due to work breaks, could positively influence the growing prevalence of work-related mental health conditions, e.g. burnout. The results in perceived psychological state showed an increase only after the usual break. This was neither reflected in cortical activity nor in cognitive performance. The individuals´ perceptions of mental recovery might be due to social interactions [264]. This was different to objective measurements of neuro-physiological functions. In consequence, short active breaks were suggested to enhance and promote the recovery of workplace performance in office workers, albeit the existence of individual preferences. A work break with physical relaxation, like resting in a massage chair, did not result in the mentioned effects. This led to the conclusion, that intensity of activation could play an important role. Heart rate was significantly increased for the short boxing intervention, compared to all others. A positive bias towards the boxing, hence the novelty of the intervention for most of the participants, cannot be ruled out. This might have affected the results and needs to be considered in subsequent research. Implementing exercise-regimens into workday-routine should be further promoted. High-intensity but short-time exercise interventions might offer a valid alternative, as they lead to a quick recovery from a high workload with a minimum of set-up, time and cost.

What study 1 adds:

Study 1 bridges the gap between phenomenological and empirical research. Describing the underlying neurophysiological effects of breaks in an office work day and combining subjective and objective data. No study to date has examined the influence of alternative break-activities on cognitive performance and related cortical activity in office-based employees´.

VIII.1.2. Study 2

For study 2 in Chapter III it was hypothesized that six hours of running will result in a decrease in prefrontal cortex activity, and that these changes will be correlated with changes in mood, flow experience and cognitive performance. Study 2 is linking subjective data (emotional well-being and possibly related flow experience) to objective neurophysiological effects and the influence on cognitive performance during prolonged exercise tested in the field. All of the participants were experienced ultramarathon runners with a personal history of a supreme athletic lifestyle.

Results revealed an early effect of exercise on brain cortical activity, identified by a decrease in frontal activity after the first hour, which remained stable across the 6-hours run. The decrease in cortical frontal and prefrontal activity is in line with previous research, showing a shift of cortical activity (transient hypofrontality) up to 60 min of moderate to high intensity exercise [13]. No further decline over the long term and no return to baseline, can be interpreted as indicator of an outlasting ceiling effect. Cognitive performance was not affected by the 6-hours run. Former research showed a decrease in working memory after an exhaustive exercise task [265] and a worsening of attentional processes [266]. Fatigue caused by exhaustive exercise is depending on peripheral and central factors [267]. Surprisingly, no mental fatigue due to prolonged exercise was noticeable in study 2. Reaction time and cognitive accuracy was not affected by several hours of exercise and neurophysiological events remained constant. In former studies dealing with central fatigue, prolonged exercise was linked to a decrease in motor performance and/or (neuro-) muscular performance [185]. Mental fatigue is affecting mainly cognition and/or cognitive functions and therefore needs to be clearly distinguished from central fatigue [268]. This is in line with previous research reporting no effect of prolonged exercise (3 hours) on cognitive performance [187], especially executive functions, even if this exercise (90 min) is performed in the heat [188]. Changes in perceived physical state, psychological relaxation and perceived motivational state decreased during the 6-hours run and confirmed earlier studies [92]. Interestingly, perceived psychological relaxation was increased after the first hour, correlating with the personal feeling of flow condition. The term flow is used to describe a subjective internal state during which a person feels fully immersed in the process of an action [66], but is also applicable for the mental state through changes in brain activity [67]. The flow experience is quite rare and not easy to trigger [269]. The immersion into exercise (flow precondition) was possibly limited due to testing time of 8 min after each hour of running. Entering a flow state might enhance motor performance as well as the individuals` mental state based on the described neurophysiological processes.

What study 2 adds:

Study 2 is linking subjective data (emotional well-being and possibly related flow experience) to objective neurophysiological evidence (electrocortical activity and cognitive performance) tested in field during prolonged exercise. So far, no study has dealt with the effect of a 6-hours run in self-chosen intensity and its influence on perceived changes in mood, flow experience, cognitive performance and related cortical activity.

VIII.1.3. Study 3

The aim of study 3 was to compare the influence of a class of aerobic exercise and an art class in an elementary school on brain cortical activity and possible effects on cognitive performance (Chapter IV). It was hypothesized that a physical exercise class in contrast to an arts class would result in a decrease in fronto-temporal cortical activity and in an improvement in academic performance. Results proved for the first time a central decrease in cortical activity after a school sports lesson. This exercise-specific neurophysiological decrease in cortical current density over all four lobes was clearly demonstrated, as no cortical changes were obtained after the art class. The neurophysiological effects could be set in reference to the theory of transient hypofrontality by Dietrich [270], assuming a shift of prefrontal and frontal cortical activity away towards the motor cortices, necessary to maintain physical performance, as some researchers assumed limited cortical resources [271]. Though, following a more general model of cortical arousal, the obtained data can be interpreted as a relaxed overall cortical state following the exercise class. These neurophysiological effects in study 3 were not accompanied by an increase in cognitive performance (standardized assessment of educational attainment and working memory). The beneficial effect of transient hypofrontality on cognitive performance seemed to be visible only after higher exercise intensities [71]. Following further studies the shift of resources within the brain was accompanied by a relocation of attention (distraction) caused by the joy of exercise [14, 71]. These changes were being discussed with respect to improving attentiveness and concentration and underline the relaxing effect of sport, but also other minor subjects, on learning processes in the setting of school.

What study 3 adds:

Findings in study 3 can contribute to the understanding of the underlying neurophysiological effects of exercise, inducing a decrease in brain cortical activity, and probably have practical implications for schools. No study to date has examined the influence of minor or major subjects on cognitive performance and on related cortical activity in school students´ in a field situation.

VIII.1.4. Studies 4-6

Studies 4-6 in Chapter V-VII comprehensively address the impact of weightlessness on neuro-cognitive processes and aimed to determine the effects of short-term microgravity and cognitive functioning with associated neurocognitive markers as well as on cerebral blood flow (study 5).

In study 4 we hypothesized that cognitive function would be enhanced during the short-term microgravity phase of a parabolic flight, as indicated by improved performance during a simple to complex reaction time task (executive function), which we anticipated would also be mirrored by changes in neurocognitive markers.

In study 5 we aimed to identify gravity-induced changes in cerebral blood flow (middle cerebral artery velocity) and brain cortical activity. We hypothesized that an increase in cerebral blood flow during short-term microgravity will be mirrored by a decrease in brain cortical activity.

In study 6 we hypothesized that both behavioral data (processing time) as well as the underlying ERP signals during a complex (arithmetic and auditive) task would benefit from the short-term microgravity condition, and that reaction time would be reduced for the complex but not the simple task (auditive) in the short-term microgravity condition, going along with a decrease in ERP amplitude.

The data collected in several DLR and ESA parabolic flights impressively demonstrate a positive effect of weightlessness on cognitive performance and its underlying neural parameters (ERP analysis). Weightlessness is in general accompanied by a decline of multiple psychomotor and cognitive functions. The resulting deficits [76, 260] represented the main source for accidents in space [272] and could cause additional stress [86]. Also for parabolic flights previous research described an increase in stress levels during the flight as well as a negative effect on perceived physical and emotional state [224-226]. Results in these studies showed a significant shorter reaction time (RT as latency of appearance of the problem and the participants´ response) with increasing task complexity during short-term microgravity. This observation was independent of previous parabolic flight experience, the use of anti-nausea medication (Scopolamine) or stress parameters. In addition, a positive impact on neural processing quantified by ERPs could be shown. For study 4 a decrease of P200 amplitude during short term microgravity was concomitant to a related involvement of the superior frontal and medial frontal gyrus. Although analysis of ERP showed a decreased amplitude of the N100-P200 complex in weightlessness, no distinction of task complexity was possible due to the short time of microgravity in each parabola (22 sec.). Accordingly study 6 was conducted to further discriminate between task complexity and ERP amplitude and latency, comparing behavioral (RT) and neurophysiological (ERP analysis) performance to a simple (oddball) and a complex (mental arithmetic + oddball) task during weightlessness. The neurocognitive ERP components could be found for the simple (P300) and the complex task (N200) significantly reduced in the microgravity condition in study 6. However, the decrease in reaction time in microgravity indicated no change in task difficulty, and a general reduction in cortical current density in microgravity [256] did let us assume, that a task specific explanation might not be appropriate. Changes in gravity conditions have also been reported to have an impact on brain hemodynamics as well as on neuronal activity. Previous experiments have shown an accumulation of blood volume to the brain during microgravity [88]. In contrast to the initial hypothesis, no increase in cerebral blood flow during microgravity could be observed in study 5. Middle cerebral artery flow velocity (MCAv) remained unchanged in the microgravity condition, whereas brain cortical activity was reduced globally, as previously hypothesized. Both of these findings in study 5 support previous data, describing no gravity induced changes in MCAv during parabolic flight manoeuvres [235] and reduced electrocortical activity during microgravity. However, the general decrease in neural excitability in microgravity seemed not to be dependent on hemodynamic changes. These studies further link neuro-physiological mechanisms and cerebral hemodynamics with cognitive processing, showing that the effects cannot be explained by a shift in blood volume into the cortex, as is often assumed. This will have relevance in planning and scheduling exercise units to maintain mental performance during long-term missions.

What study 4 adds:

Study 4 demonstrates that previous findings of a decrease in cognitive performance during microgravity may not be related to the gravity condition itself, as the results in reaction time and in the underlying early neural processes (Visually Evoked Potentials) seem to be enhanced in microgravity. Until now, no study has distinguished between the effect of short-term microgravity per se on cognitive performance with control for the confounding effects of stress parameters.

What study 5 adds:

Study 5 attempts to identify a possible link between changes in brain blood flow and neuronal activity during microgravity. The general decrease in neural excitability seems not to be dependent on hemodynamic changes in gravity conditions. No study today has investigated in gravity induced changes in cerebral blood flow and its effect on neurocognitive processing.

What study 6 adds:

In study 6 previously investigated results of enhanced neuro-cognitive performance during short periods of microgravity are revised, comparing behavioral (reaction time) and neurophysiological (event related potentials analysis) performance to a simple (oddball) and a complex (mental arithmetic + oddball) task. As task complexity plays a major role, it is assumed that neuro-behavioral performance benefits from the gravity-induced fluid shift to the brain in short-term microgravity conditions. Until now, no study has measured the effect of short-term microgravity on cognitive performance under the aspect of different levels of task complexity.

VIII.2. LIMITATIONS AND FUTURE DIRECTIONS

Following previous research [53] there is concurrent understanding of the beneficial relation between exercise and cognition. Still results are inconsistent, as a number of contributing factors vary, especially the possible range of cognitive tasks [54, 55]. Within this work the cognitive tasks were chosen for reasons of validity and reliability but also practical feasibility (application) within the field setting of each study. For the cognitive testing in study 3 the participants age as well as the scholar curriculum had to be considered, concerning the amount of time for the testing. Especially the limited amount of time for testing in studies 4-6, depending on the parabolas with the given very short amount of microgravity, restricted the possible cognitive testing methods. As the applied cognitive tasks were consistently assessed pre and post the interventions or referred to a baseline measurement, the range of task should not have a major impact on the results in the studies. One important concern about the reliability and effectiveness of interventions on mental performance was a laboratory setting in former research. A clinical setting will per se influence mental performance as various aspects are affected by an artificial environment. Due to the technological development, and in particular the development of modern methods for the detection and analysis of central nervous parameters, it is now possible to illustrate cortical changes provoked by sports and exercise also "in the field" i.e. in the immediate real-life situation and thus specify recommendations regarding the application of sports and exercise to preserve cognitive functions and emotional well-being. Recommendations for duration and intensity of exercise are under constant review. The Guidelines of the American College of Sports Medicine (ACSM) recommend for children´s (5-17 years of age) healthy growth a dose of 60 minutes per day of moderate to vigorous physical activity. Greater daily amounts are supposed to provide additional health benefits [273]. Again, these Guidelines focus on physical benefits and do mostly not include cognitive benefits. So, further research is needed to find the optimal dose of exercise also for improving brain health. And for practical implications, it is of importance to find the optimal dose of exercise appropriate in different (age-)groups and under the aspect of gender differences. Results of Booth et al. [194] suggest that gender might play a role in the way physical activity is having an impact on the brain. These need to be considered, also under social and motivational aspects, on a given task in a group setting. It appears, that in younger age groups the gender effect on cognitive performance is not considered to be very significant, whereas growing older the more influence gender might play [274]. These considerations need to be confirmed by further randomized control trials in field setting to provide essential statements for neurocognitive changes. The time of intervention (early in childhood or late in older age) might also be important for improvements and/or maintenance of cognitive health and function throughout the lifespan, and therefore should also be included in future studies. Motivating mature adults to be physically active can be seen as one of the main challenges in future time [58]. The design of programs capable of mobilizing individuals in or despite their actual live situation, is here a major aim. Albeit understanding of the way exercise is influencing cognitive performance is still limited and the existing models or theories are still to be completely verified, its´ impact on the brain has already been proofed by a number of studies.

Transferring the knowledge about the beneficially effects physical exercise seems to have on the body and the brains´ health and the maintenance of cognitive abilities in older age, might have an influence on everybody´s personal attitude towards physical activity.

Results presented in this cumulative doctoral thesis also suggest that the type of exercise, including motivational and social aspects, is not to underestimate. Not only the dose of exercise and physiological parameters, like the individuals' level of fitness or acute and long-term exercise need to be controlled in studies, but also psychological parameters, as individual preferences and comfort seem to be important factors when investigating in cognitive performance. Besides a regular participation in exercise, the importance of the individual preference, which may be grown out of the personal education- and socialization-history, seems crucial for an active living throughout the lifespan. Although results in study 1 let assume, that the individual preference is not the main factor for improvements, neither under the physical nor the neurophysiological perspective, personal preferences have to be considered, especially in the need to exercise on a life-long basis. While for many years the effects of sport and exercise on cognition and emotion were only indirectly reproducible, the work of this cumulative doctoral thesis, provides an insight into the neurophysiological changes and their relation provoked by sport and exercise or extreme environmental conditions in distinct real-live settings from space to school and on different population groups like parabonauts, ultramarathon runners, office workers and school children on cognitive and emotional parameters. Albeit further studies on neurophysiological correlates and the influence of personalized exercise preferences are required, it seems reasonable that physical exercise may enhance academic attainment and perceived individuals´ mood state and therefore contributes to a better health over the lifespan. With respect to previous findings, future research projects should aim at a thorough and interdisciplinary knowledge, including psychological, clinical, gerontologic, gender and social aspects of exercise-related benefits on cognitive performance and mood to contribute to the lifelong process of ensuring life quality.

IX. Summary/Zusammenfassung

SUMMARY

Following developmental changes in the last century, requirements concerning living and working conditions have substantially changed, with a gain of free leisure time but also the absence of physical labor. Subsequently, a large and manifold community of persons, actively engaged in sports, has grown. Today, at the heart of this movement lies the interest to develop and maintain health, primary under a preventive aspect. However, health is no longer reduced to physical health alone, but as proofed by studies from the past two decades, sports and exercise also have a positive effect on cognitive performance and emotional well-being. In recent years, an interest to investigate further in the neurophysiological changes provoked by sports and exercise and their relationship to observed behavioral, cognitive and emotional parameters has evolved. Previous research was often limited to the artificial laboratory situation. Due to the technological development, and in particular the development of modern methods for the detection and analysis of central nervous parameters, it is now possible to illustrate cortical changes provoked by sports and exercise also "in the field" i.e. in the immediate real-life situation and thus specify recommendations regarding the application of sports and exercise to preserve cognitive functions and emotional well-being. **Chapter I** introduces the five studies and topics underlying this cumulative doctoral thesis. The first study in **Chapter II** deals with the question how an active break in the office can maintain cognitive performance. The results show that both high-intensity exercise (boxing) and moderate exercise (cycling) are associated with special cortical activation patterns (transient hypofrontality), which is reflected in an increase in cognitive performance after the work break. **Chapter III** addresses the issue of central nervous fatigue during a 6-hour Ultramarathon. While there is an initial decrease in fronto-temporal activity, which, interestingly, correlates with the personal feeling of a flow condition, the data for the next five hours show no cortical fatigue nor decrease in cognitive performance during such prolonged endurance exercise. The following study in an elementary school in **Chapter IV** proves for the first time a central decrease in cortical activity after a school sports lesson. These changes are being discussed with respect to improving attentiveness and concentration and underline the relaxing effect of sport, but also other minor subjects such as music and art, on learning processes in the school setting. **Chapters V-VII** comprehensively address the impact of weightlessness on neuro-cognitive processes. The data collected in several DLR and ESA parabolic flights impressively demonstrate a positive effect of weightlessness on cognitive performance and its underlying neural parameters (ERP analysis). These effects cannot be explained by a shift in blood volume into the cortex, as is often assumed. For the first time, these studies show that there is an urgent need to differentiate between primary effects of weightlessness and secondary effects of stress and isolation on cognition and emotion during future long-term missions. In particular, this will have relevance in planning and scheduling exercise units to maintain mental performance during long-term missions. **Chapter VIII** summarizes the questions and approaches raised in the introduction to an overall picture and demonstrates the relevance of modern neuroscience research. While for many years the effects of sport and exercise on cognition and emotion were only indirectly reproducible, the work of this

cumulative doctoral thesis in various real-live settings, provides an insight into the neurophysiological changes and their relation provoked by sport and exercise or extreme environmental conditions to cognitive and emotional parameters.

ZUSAMMENFASSUNG

Bedingt durch weit reichende Veränderungen in den Lebens- und Arbeitsbedingungen, dem damit verbundenen Gewinn an Freizeit, aber auch dem Verlust der Notwendigkeit körperlicher Erwerbstätigkeit, ist in den vergangenen Jahrzehnten eine große und vielfältige Gemeinde aktiv Sport Treibender gewachsen. Im Zentrum dieser Bewegung steht heute vor allem der Wunsch, präventiv im Sinne der Gesundheit zu handeln. Gesundheit wird jedoch nicht mehr allein auf die körperliche Gesundheit reduziert, sondern Sport und Bewegung, das zeigen Studien der vergangenen zwei Dekaden, wirken auch positiv auf die kognitive Leistungsfähigkeit und das emotionale Wohlbefinden. Zunehmend ist in den vergangenen Jahren auch ein Interesse an den durch Sport und Bewegung provozierten neurophysiologischen Veränderungen und deren Beziehung zu beobachteten behavioralen, kognitiven und emotionalen Parametern entstanden. Eine Limitierung bestehender Forschungsarbeiten lag dabei in der oft künstlichen Laborsituation. Bedingt durch die technologische Entwicklung und hier insbesondere der Entwicklung moderner Verfahren zur Erfassung und Analyse zentralnervöser Parameter ist es heute möglich, die durch Sport und Bewegung provozierten kortikalen Veränderungen auch „im Feld“, d.h. in der unmittelbaren Lebenssituation abzubilden und damit deutlich konkretere Empfehlung bzgl. des Einsatzes von Sport und Bewegung zum Erhalt der kognitiven Funktionen und dem emotionalen Wohlbefinden auszusprechen. **Kapitel I** gibt eine Einführung in die fünf dieser kumulativen Promotion zugrundeliegenden Studien und Themenfelder. Die erste Studie in **Kapitel II** beschäftigt sich mit der Frage, inwieweit eine aktive Pausengestaltung am Arbeitsplatz die kognitive Leistungsfähigkeit erhalten kann. Die Ergebnisse belegen, dass sowohl eine hochintensive Belastung (Boxen) als auch eine moderate Belastung (Radfahren) verbunden sind mit speziellen kortikalen Aktivierungsmustern (transiente Hypofrontalität), welche sich in einer Erhöhung der kognitiven Leistungsfähigkeit im Anschluss an die Pause widerspiegelt. **Kapitel III** beschäftigt sich mit der Frage nach der zentralnervösen Ermüdung während eines 6-stündigen Ultra-Marathonlaufs. Während es zu Beginn zu einer Abnahme fronto-temporaler Aktivität kommt, was interessanterweise mit dem persönlichen Empfinden eines Flow Zustandes korreliert, zeigen die Daten der folgenden fünf Stunden, dass es während einer solch langandauernden Ausdauerbelastung weder zu einer kortikalen Ermüdung, noch zu einer Abnahme der kognitiven Leistungsfähigkeit kommt. Die folgende Studie in der Grundschule in **Kapitel IV** belegt erstmals eine zentrale Abnahme der kortikalen Erregungsaktivität nach einer Schulsportstunde. Diese Veränderung wird diskutiert mit Blick auf eine Verbesserung der Aufmerksamkeits- und der Konzentrationsfähigkeit und unterstreicht die relaxierende Wirkung von Sport, aber auch anderen Nebenfächern wie Musik und Kunst, auf Lernprozesse im Setting Schule. Die **Kapitel V-VII** behandeln umfassend die Auswirkung von Schwerelosigkeit auf neuro-kognitive Prozesse. Die in mehreren DLR und ESA Parabelflügen erhobenen Daten belegen eindrücklich eine positiven Effekt von Schwerelosigkeit auf die kognitive Leistungsfähigkeit und deren zugrundeliegenden neuronalen Parameter (ERP Analyse). Diese Effekte sind nicht, wie oftmals angenommen, mit einer Verschiebung von Blutvolumina in den Kortex zu erklären. Erstmals wird mit diesen Studien belegt, dass es dringend nötig ist während zukünftiger Langzeitmissionen zu differenzieren zwischen

primären Effekten von Schwerelosigkeit und sekundären Effekten von Stress und Isolation auf Kognition und Emotion. Insbesondere wird dies von Relevanz in der Planung und Terminierung von Sporteinheiten zum Erhalt der mentalen Leistungsfähigkeit während Langzeitmissionen haben. Kapitel **VIII** führt die in der Einleitung aufgeworfenen Fragen und Ansätze zu einem Gesamtbild zusammen und belegt die Relevanz einer modernen bewegungsneurowissenschaftlichen Forschung. Während lange Jahre die Effekte von Sport und Bewegung auf Kognition und Emotion nur mittelbar abbildbar waren, ermöglichen die Arbeiten dieser Promotion, in verschiedenen Real-Live-Settings, einen Einblick in die durch Sport und Bewegung bzw. extremen Umweltbedingungen provozierten neurophysiologischen Veränderungen und deren Relation zu kognitiven und emotionalen Parametern.

X. References

[1] Huber M, Knottnerus JA, Green L, van der Horst H, Jadad AR, Kromhout D, et al. How should we define health? Bmj. 2011;343:d4163.
[2] Struder HK, Hollmann W, Donike M, Platen P, Weber K. Effect of O2 availability on neuroendocrine variables at rest and during exercise: O2 breathing increases plasma prolactin. Eur J Appl Physiol Occup Physiol. 1996;74:443-9.
[3] Struder HK, Hollmann W, Platen P, Rost R, Weicker H, Kirchhof O, et al. Neuroendocrine system and mental function in sedentary and endurance-trained elderly males. Int J Sports Med. 1999;20:159-66.
[4] Struder HK, Hollmann W, Platen P, Wostmann R, Ferrauti A, Weber K. Effect of exercise intensity on free tryptophan to branched-chain amino acids ratio and plasma prolactin during endurance exercise. Can J Appl Physiol. 1997;22:280-91.
[5] Struder HK, Hollmann W, Platen P, Wostmann R, Weicker H, Molderings GJ. Effect of acute and chronic exercise on plasma amino acids and prolactin concentrations and on. Eur J Appl Physiol Occup Physiol. 1999;79:318-24.
[6] Struder HK, Weicker H. Physiology and pathophysiology of the serotonergic system and its implications on mental and physical performance. Part II. Int J Sports Med. 2001;22:482-97.
[7] Meeusen R, De Meirleir K. Exercise and brain neurotransmission. Sports Med. 1995;20:160-88.
[8] van Praag H, Christie BR, Sejnowski TJ, Gage FH. Running enhances neurogenesis, learning, and long-term potentiation in mice. Proc Natl Acad Sci U S A. 1999;96:13427-31.
[9] van Praag H, Kempermann G, Gage FH. Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus. Nat Neurosci. 1999;2:266-70.
[10] van Praag H, Shubert T, Zhao C, Gage FH. Exercise enhances learning and hippocampal neurogenesis in aged mice. J Neurosci. 2005;25:8680-5.
[11] Freund J, Brandmaier AM, Lewejohann L, Kirste I, Kritzler M, Kruger A, et al. Emergence of individuality in genetically identical mice. Science. 2013;340:756-9.
[12] Brummer V, Schneider S, Abel T, Vogt T, Struder HK. Brain cortical activity is influenced by exercise mode and intensity. Med Sci Sports Exerc. 2011;43:1863-72.
[13] Brummer V, Schneider S, Struder HK, Askew CD. Primary motor cortex activity is elevated with incremental exercise intensity. Neuroscience. 2011;181:150-62.
[14] Schneider S, Abeln V, Popova J, Fomina E, Jacubowski A, Meeusen R, et al. The influence of exercise on prefrontal cortex activity and cognitive performance during a simulated space flight to Mars (MARS500). Behav Brain Res. 2013;236:1-7.

[15] Schneider S, Askew CD, Abel T, Mierau A, Struder HK. Brain and Exercise: A First Approach Using Electro Tomography. Med Sci Sports Exerc. 2010;Mar;42:600-7.
[16] Schneider S, Askew CD, Diehl J, Mierau A, Kleinert J, Abel T, et al. EEG activity and mood in health orientated runners after different exercise intensities. Physiol Behav. 2009;96:709-16.
[17] Dietrich A. Mind on the run. Methods. 2008;45:253-4.
[18] Dietrich A, Audiffren M. The reticular-activating hypofrontality (RAH) model of acute exercise. Neurosci Biobehav Rev. 2011;35:1305-25.
[19] Ekkekakis P. Illuminating the black box: investigating prefrontal cortical hemodynamics during exercise with near-infrared spectroscopy. J Sport Exerc Psychol. 2009;31:505-53.
[20] Schneider S, Bubeev JA, Choukèr A, Morukov B, Johannes B, Strüder HK. Imaging of Neuro-Cognitive Performance in Extreme Environments – a (p)review. Planetary and Space Science. 2012;submitted for invited review.
[21] Schneider S, Vogt T, Frysch J, Guardiera P, Struder HK. School sport - a neurophysiological approach. Neurosci Lett. 2009;467:131-4.
[22] Vogt T, Schneider S, Abeln V, Anneken V, Struder HK. Exercise, mood and cognitive performance in intellectual disability - a neurophysiological approach. Behav Brain Res. 2012;226:473-80.
[23] Jung R, Moser M, Baucsek S, Dern S, Schneider S. Activation patterns of different brain areas during incremental exercise measured by near-infrared spectroscopy. Exp Brain Res. 2015;233:1175-80.
[24] Brummer V, Schneider S, Vogt T, Struder H, Carnahan H, Askew CD, et al. Coherence between brain cortical function and neurocognitive performance during changed gravity conditions. Journal of visualized experiments : JoVE. 2011.
[25] Schneider S, Abeln V, Askew CD, Vogt T, Hoffman U, Denise P, et al. Changes in brain hemodynamics during parabolic flight. J Appl Physiol. 2012;submitted.
[26] Schneider S, Askew CD, Abel T, Mierau A, Struder HK. Brain and exercise: a first approach using electrotomography. Med Sci Sports Exerc. 2010;42:600-7.
[27] Schneider S, Abeln V. Neuroimaging in Space. Planetary and Space Science. 2012;invited.
[28] Martin JH. The collective electrical behavior of cortical neurons: The electroencephalogram and the mechanisms of epilepsy. In: Kandel JH, Schwartz, T.M. Jessel, editor. Principles of Neuroscience, London: Prentice-Hall; 1991. p. 777-91.
[29] Jasper HH. The ten-twenty electrode system of the international Federation. Electroencephalogr Clin Neurophysiol Suppl. 1958;35:371-5.
[30] Buhl EH, Tamas G, Fisahn A. Cholinergic activation and tonic excitation induce persistent gamma oscillations in mouse somatosensory cortex in vitro. J Physiol. 1998;513 (Pt 1):117-26.
[31] Borgers C, Epstein S, Kopell NJ. Background gamma rhythmicity and attention in cortical local circuits: a computational study. Proc Natl Acad Sci U S A. 2005;102:7002-7.
[32] Steriade M, Amzica F, Contreras D. Synchronization of fast (30-40 Hz) spontaneous cortical rhythms during brain activation. J Neurosci. 1996;16:392-417.

[33] Mecklinger A, Boesel R. Veränderungen im EEG-Frequenzspektrum bei verschiedenen Phasen mentaler Belastung. Z Exp Angew Psychol. 1989;XXXVI:453-75.
[34] Gray CM, Singer W. Stimulus-specific neuronal oscillations in orientation columns of cat visual cortex. Proc Natl Acad Sci U S A. 1989;86:1698-702.
[35] Bai X, Towle VL, He EJ, He B. Evaluation of cortical current density imaging methods using intracranial electrocorticograms and functional MRI. Neuroimage. 2007;35:598-608.
[36] Ogawa S, Lee TM, Nayak AS, Glynn P. Oxygenation-sensitive contrast in magnetic resonance image of rodent brain at high magnetic fields. Magn Reson Med. 1990;14:68-78.
[37] Pascual-Marqui RD. Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. Methods and findings in experimental and clinical pharmacology. 2002;24 Suppl D:5-12.
[38] Pascual-Marqui RD, Esslen M, Kochi K, Lehmann D. Functional imaging with low-resolution brain electromagnetic tomography (LORETA): a review. Methods and findings in experimental and clinical pharmacology. 2002;24 Suppl C:91-5.
[39] Pascual-Marqui RD, Lehmann D, Koenig T, Kochi K, Merlo MC, Hell D, et al. Low resolution brain electromagnetic tomography (LORETA) functional imaging in acute, neuroleptic-naive, first-episode, productive schizophrenia. Psychiatry Res. 1999;90:169-79.
[40] Naatanen R. Implications of ERP data for psychological theories of attention. Biol Psychol. 1988;26:117-63.
[41] Farwell LA, Donchin E. Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. Electroencephalogr Clin Neurophysiol. 1988;70:510-23.
[42] Falkenstein M, Hohnsbein J, Hoorman J. Analysis of mental workload with ERP indicators of processing stages. Perspectives of Event-Related Potentials Research. 1995;suppl. 44:280-6.
[43] Kok A. Event-related-potential (ERP) reflections of mental resources: a review and synthesis. Biol Psychol. 1997;45:19-56.
[44] Folstein JR, Van Petten C. Influence of cognitive control and mismatch on the N2 component of the ERP: a review. Psychophysiology. 2008;45:152-70.
[45] Correa A, Lupianez J, Madrid E, Tudela P. Temporal attention enhances early visual processing: a review and new evidence from event-related potentials. Brain Res. 2006;1076:116-28.
[46] Sutton S, Braren M, Zubin J, John ER. Evoked-Potential Correlates of Stimulus Uncertainty. Science. 1965;150:1187-8 ->2192.
[47] Donchin E. The P300 as a metric for mental workload. Electroencephalogr Clin Neurophysiol Suppl. 1987;39:338-43.
[48] Polich J. Updating P300: an integrative theory of P3a and P3b. Clin Neurophysiol. 2007;118:2128-48.
[49] Nieuwenhuis S, De Geus EJ, Aston-Jones G. The anatomical and functional relationship between the P3 and autonomic components of the orienting response. Psychophysiology. 2010.
[50] Tomporowski PD. Physical activity, cognition, and aging: A review of reviews. In: L. W. Poon WJC-Z, P.D. Tomporowski, editor. Active living, cognitive functioning, and aging, Champaign, IL: Human Kinetics; 2006. p. 15-32.

[51] Kirkendall DR. Effect of physical activity on intellectual development and academic performance. In: M. Lee HME, & G.A. Stull editor. Effects of physical activity on children: A special tribute to Mabel Lee, Champaign, IL: Human Kinetics; 1986. p. 49-63.
[52] Spirduso WW. Physical fitness, aging, and psychomotor speed: a review. J Gerontol. 1980;35:850-65.
[53] Etnier JR, Salazar W, Landers DM, Petruzzello SJ, Han M, (1997) NP. The influence of physical fitness and exercise upon cognitive functioning: a meta analysis. J Sport Exerc Psychol. 1997;19:249–77.
[54] Kramer AF, Colcombe S, Erickson K, Belopolsky A, McAuley E, Cohen NJ, et al. Effects of aerobic fitness training on human cortical function: a proposal. J Mol Neurosci. 2002;19:227-31.
[55] Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: a meta-analytic study. Psychol Sci. 2003;14:125-30.
[56] Tomporowski P, Ellis N. Effects on Exercise on Cognitve Prosess. A Review. Psychol Bull. 1986;99 338-46.
[57] Vaynman S, Gomez-Pinilla F. Revenge of the "sit": how lifestyle impacts neuronal and cognitive health through molecular systems that interface energy metabolism with neuronal plasticity. J Neurosci Res. 2006;84:699-715.
[58] Etnier JL, Karper WB, Park SY, Shih CH, Piepmeier AT, Wideman L. Motivating Mature Adults to be Physically Active. Journal of aging and physical activity. 2017;25:325-31.
[59] Karp A, Paillard-Borg S, Wang HX, Silverstein M, Winblad B, Fratiglioni L. Mental, physical and social components in leisure activities equally contribute to decrease dementia risk. Dementia and geriatric cognitive disorders. 2006;21:65-73.
[60] Wilson RS, Mendes De Leon CF, Barnes LL, Schneider JA, Bienias JL, Evans DA, et al. Participation in cognitively stimulating activities and risk of incident Alzheimer disease. Jama. 2002;287:742-8.
[61] Dietrich A. Transient hypofrontality as a mechanism for the psychological effects of exercise. Psychiatry Res. 2006;145:79-83.
[62] Kahnemann D. Attention and Effort. New Jersey: Prentice-Hall; 1993.
[63] Dietrich A. Functional neuroanatomy of altered states of consciousness: the transient hypofrontality hypothesis. Conscious Cogn. 2003;12:231-56.
[64] Boecker H, Hillman CH, Scheef L, Strüder HK. Functional Neuroimaging in Exercise and Sport Sciences. Heidelberg, New York: Springer; 2012.
[65] McKlveen JM, Morano RL, Fitzgerald M, Zoubovsky S, Cassella SN, Scheimann JR, et al. Chronic Stress Increases Prefrontal Inhibition: A Mechanism for Stress-Induced Prefrontal Dysfunction. Biol Psychiatry. 2016;80:754-64.
[66] Csikszentmihalyi M, Rathunde K. The measurement of flow in everyday life: toward a theory of emergent motivation. Nebraska Symposium on Motivation 1992;40:57-97.
[67] Dietrich A. Neurocognitive mechanisms underlying the experience of flow. Conscious Cogn. 2004;13:746-61.
[68] Dietrich A, Haider H. A Neurocognitive Framework for Human Creative Thought. Front Psychol. 2016;7:2078.
[69] Ekkekakis P, Petruzzello SJ. Acute aerobic exercise and affect: current status, problems and prospects regarding dose-response. Sports Med. 1999;28:337-74.

[70] Schneider S, Askew CD, Diehl J, Mierau A, Kleinert J, Abel T, et al. EEG activity and mood in health orientated runners after different exercise intensities. Physiol Behav. 2009;96:709-16.
[71] Schneider S, Brummer V, Abel T, Askew CD, Struder HK. Changes in brain cortical activity measured by EEG are related to individual exercise preferences. Physiol Behav. 2009;98:447-52.
[72] Albery WB, Goodyear C. The effect of noise or acceleration stress on human mental work load and performance. Aviation, Space, and Environmental Medicine. 1988:487.
[73] Hockey G. Stress and fatigue in human performance. Chichester: Wiley; 1983.
[74] Lieberman H, Tharion W, Shukitt-Hale B, Speckman K, Tulley R. Effects of caffeine, sleep loss, and stress on cognitive performance and mood during U.S. Navy SEAL training. Sea-Air-Land. Psychopharmacologia. 2002;164:250-61.
[75] Grigoriev AJ, Polyakov VV, Bogomolov VV, Egorov AD, Pestov ID, Kozlovskaya IB. Medical Results of the Fourth Prime Expedition on the Orbital Station MIR. Proc of the Fourth European Symposium on Life Sciences Res in Space, Trieste, Italy, ESA SP-307. 1990:19-22.
[76] Kozlovskaya IB, Kreidich YV, Oganov VS, Koserenko OP. Pathophysiology of motor functions in prolonged manned space flights. Acta Astronautica. 1981;8:1059-72.
[77] Berger M, Mescheriakov S, Molokanova E, Lechner-Steinleitner S, Seguer N, Kozlovskaya I. Pointing Arm Movements in Short- and Long-Term Spaceflights. Aviat Space Environ Med. 1997;68:781-7.
[78] Bock O, Fowler B, Comfort D. Human sensorimotor coordination during spaceflight: An analysis of pointing and tracking responses during the "Neurolab" Space Shuttle mission. Aviat Space Environ Med. 2001;72:877-83.
[79] Heuer H, Manzey D, Lorenz B, Sangals J. Impairments of manual tracking performance during spaceflight are associated with specific effects of microgravity on visuomotor transformations. Ergonomics. 2003;46:920-34.
[80] Watt DGD. Pointing at memorized targets during prolonged microgravity. Aviat Space Environ Med. 1997;68:99-103.
[81] Semjen A, Leone G, Lipshits M. Motor timing under microgravity. Acta Astronautica. 1998;42:303-21.
[82] Pattyn N, Migeotte P, Demaesselaer W, Kolinsky R, Morais J, Zizi M. Investigating human cognitive performance during spaceflight. J Gravit Physiol. 2005;12:P39-P40.
[83] Lackner JR. Human sensory-motor adaptation to the terrestrial force enviroment. Brain mechanisms and spacial vision. 1985:175-209.
[84] Roll JP, Popov K, Gilhodes JC, Roll R, Gurfinkel V, Quoniam C, et al. Changes in Human Proprioceptive Functions in Weightlessness. Arcachon, France1993. p. 351-5.
[85] Manzey D, Lorenz B. Mental performance during short-term and long-term spaceflight. Brain Res Rev. 1998;28:215 - 21.
[86] Manzey D, Lorenz B, Poljakov V. Mental performance in extreme environments: results from a performance monitoring study during a 438-day spaceflight. Ergonomics. 1998;41:537-59.
[87] Lorenz B, Lorenz J, Manzey D. Performance and brain electrical activity during prolonged confinement. Adv Space Biol Med. 1996;5:157-81.

[88] Schneider S, Abeln V, Askew CD, Vogt T, Hoffmann U, Denise P, et al. Changes in cerebral oxygenation during parabolic flight. Eur J Appl Physiol. 2013;113:1617-23.
[89] Palinkas LA, Suedfeld P. Psychological effects of polar expeditions. Lancet. 2008;371:153-63.
[90] Pagel JI, Chouker A. Effects of isolation and confinement on humans-implications for manned space explorations. J Appl Physiol (1985). 2016;120:1449-57.
[91] Jacubowski A, Abeln V, Vogt T, Yi B, Chouker A, Fomina E, et al. The impact of long-term confinement and exercise on central and peripheral stress markers. Physiol Behav. 2015;152:106-11.
[92] Schneider S, Brummer V, Carnahan H, Kleinert J, Piacentini MF, Meeusen R, et al. Exercise as a countermeasure to psycho-physiological deconditioning during long-term confinement. Behav Brain Res. 2010;211:208-14.
[93] Abeln V, MacDonald-Nethercott E, Piacentini MF, Meeusen R, Kleinert J, Strueder HK, et al. Exercise in isolation--a countermeasure for electrocortical, mental and cognitive impairments. PLoS One. 2015;10:e0126356.
[94] Cheron G, Leroy A, De Saedeleer C, Bengoetxea A, Lipshits M, Cebolla A, et al. Effect of gravity on human spontaneous 10-Hz electroencephalographic oscillations during the arrest reaction. Brain Res. 2006;1121:104-16.
[95] Angelakis E, Lubar JF, Stathopoulou S, Kounios J. Peak alpha frequency: an electroencephalographic measure of cognitive preparedness. Clin Neurophysiol. 2004;115:887-97.
[96] Angelakis E, Stathopoulou S, Frymiare JL, Green DL, Lubar JF, Kounios J. EEG neurofeedback: a brief overview and an example of peak alpha frequency training for cognitive enhancement in the elderly. The Clinical neuropsychologist. 2007;21:110-29.
[97] Pletser V, Quadens O. Degraded EEG response of the human brain in function of gravity levels by the method of chaotic attractor. Acta Astronaut. 2003;52:581-9.
[98] Schneider S, Brummer V, Carnahan H, Dubrowski A, Askew CD, Struder HK. What happens to the brain in weightlessness? A first approach by EEG tomography. Neuroimage. 2008;42:1316-23.
[99] Faw B. Pre-frontal executive committee for perception, working memory, attention, long-term memory, motor control, and thinking: a tutorial review. Conscious Cogn. 2003;12:83-139.
[100] Miller EK, Cohen JD. An integrative theory of prefrontal cortex function. Annu Rev Neurosci. 2001;24:167-202.
[101] Watenpaugh DE. Analogs of microgravity: head-down tilt and water immersion. J Appl Physiol (1985). 2016;120:904-14.
[102] Montano D, Hoven H, Siegrist J. A meta-analysis of health effects of randomized controlled worksite interventions: does social stratification matter? Scand J Work Environ Health. 2014;40:230-4.
[103] Tucker P. The impact of rest breaks upon accident risk, fatigue and performance. International Journal of Work, Health & Organisations. 2003;17:123-37.
[104] Carriker CR. Components of Fatigue: Mind and Body. J Strength Cond Res. 2017;31:3170-6.

[105] Kurth BM, Schaffrath Rosario A. Die Verbreitung von Übergewicht und Adipositas bei Kindern und Jugendlichen in Deutschland. Bundesgesundheitsbl - Gesundheitsforsch - Gesundheitsschutz 2007. 2007;50:736–43.
[106] Reichert FF, Baptista Menezes AM, Wells JC, Carvalho Dumith S, Hallal PC. Physical activity as a predictor of adolescent body fatness: a systematic review. Sports Med. 2009;39:279-94.
[107] Shultz SP, Anner J, Hills AP. Paediatric obesity, physical activity and the musculoskeletal system. Obesity reviews : an official journal of the International Association for the Study of Obesity. 2009;10:576-82.
[108] Lavie CJ, Milani RV, Ventura HO. Obesity and cardiovascular disease: risk factor, paradox, and impact of weight loss. J Am Coll Cardiol. 2009;53:1925-32.
[109] Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, et al. Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review. Med Sci Sports Exerc. 2016;48:1197-222.
[110] Marques A, Santos DA, Hillman CH, Sardinha LB. How does academic achievement relate to cardiorespiratory fitness, self-reported physical activity and objectively reported physical activity: a systematic review in children and adolescents aged 6-18 years. Br J Sports Med. 2018;52:1039.
[111] Chaddock-Heyman L, Weng TB, Kienzler C, Erickson KI, Voss MW, Drollette ES, et al. Scholastic performance and functional connectivity of brain networks in children. PLoS One. 2018;13:e0190073.
[112] Kao SC, Westfall DR, Parks AC, Pontifex MB, Hillman CH. Muscular and Aerobic Fitness, Working Memory, and Academic Achievement in Children. Med Sci Sports Exerc. 2017;49:500-8.
[113] Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. Nature reviews Neuroscience. 2008;9:58-65.
[114] Hillman CH, Biggan JR. A Review of Childhood Physical Activity, Brain, and Cognition: Perspectives on the Future. Pediatric exercise science. 2017;29:170-6.
[115] Booth JN, Leary SD, Joinson C, Ness AR, Tomporowski PD, Boyle JM, et al. Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort. Br J Sports Med. 2013.
[116] Schneider S, Vogt T, Frysch J, Guardiera P, Struder HK. School sport--a neurophysiological approach. Neurosci Lett. 2009;467:131-4.
[117] Gopalakrishnan R, Genc KO, Rice AJ, Lee SM, Evans HJ, Maender CC, et al. Muscle volume, strength, endurance, and exercise loads during 6-month missions in space. Aviat Space Environ Med. 2010;81:91-102.
[118] LeBlanc A, Schneider V, Shackelford L, West S, Oganov V, Bakulin A, et al. Bone mineral and lean tissue loss after long duration space flight. Journal of musculoskeletal & neuronal interactions. 2000;1:157-60.
[119] NASA. Science Strategy. 2018.
[120] ESA. ESA's SciSpacE programme. 2018.
[121] Ellis S. Collisions in space. Ergonomics in Design. 2000;8:4-9.
[122] WHO. Depression in Europe: facts and figures. 2013 ed: World Health Organisation; 2013.

[123] Maslach C, Schaufeli WB, Leiter MP. Job burnout. Annu Rev Psychol. 2001;52:397-422.
[124] Schaufeli WB, Greenglass ER. Introduction to special issue on burnout and health. Psychol Health. 2001;16:501-10.
[125] Slesina W. [Workplace health promotion in the Federal Republic of Germany]. Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz. 2008;51:296-304.
[126] Richter P, Hacker W. Belastung und Beanspruchung. Heidelberg: Asanger; 1998.
[127] Ulich E. Arbeitspsychologie: Schäffer-Poeschel Verlag; 2005.
[128] Graf O. Die Arbeitspause in Theorie und Praxis. Psychologische Arbeiten. 1927;9:563-681.
[129] Allmer H. Erholung und Gesundheit Grundlagen, Ergebnisse, Maßnahmen. Göttingen: Hogrefe; 1996.
[130] Marschak ME. Experimentelle Untersuchungen über den Einfluss der aktiven Erholung auf die Arbeitsfähigkeit des Menschen. Eur J Appl Physiol Occup Physiol. 2012:664-80.
[131] Bös K, Brehm W. Handbuch Gesundheitssport. Schorndorf: Hofmann; 2006.
[132] Byrne A, Byrne DG. The effect of exercise on depression, anxiety and other mood states: a review. J Psychosom Res. 1993;37:565-74.
[133] Folkins CH, Sime WE. Physical fitness training and mental health. Am Psychol. 1981;36:373-89.
[134] Ransford CP. A role for amines in the antidepressant effect of exercise: a review. Med Sci Sports Exerc. 1982;14:1-10.
[135] Petruzzello SJ, Landers DM, Hatfield BD, Kubitz KA, Salazar W. A meta-analysis on the anxiety-reducing effects of acute and chronic exercise. Outcomes and mechanisms. Sports Med. 1991;11:143-82.
[136] Brisswalter J, Collardeau M, Rene A. Effects of acute physical exercise characteristics on cognitive performance. Sports Med. 2002;32:555-66.
[137] Anish EJ. Exercise and its effects on the central nervous system. Curr Sports Med Rep. 2005;4:18-23.
[138] Lo Bue-Estes C, Willer B, Burton H, Leddy JJ, Wilding GE, Horvath PJ. Short-term exercise to exhaustion and its effects on cognitive function in young women. Percept Mot Skills. 2008;107:933-45.
[139] Mierau A, Schneider S, Abel T, Askew C, Werner S, Struder HK. Improved sensorimotor adaptation after exhaustive exercise is accompanied by altered brain activity. Physiol Behav. 2009;96:115-21.
[140] Frith C, Dolan R. The role of the prefrontal cortex in higher cognitive functions. Brain Res Cogn Brain Res. 1996;5:175-81.
[141] Vogt T, Schneider S, Anneken V, Struder HK. Moderate cycling exercise enhances neurocognitive processing in adolescents with intellectual and developmental disabilities. Research in developmental disabilities. 2013;34:2708-16.
[142] Schneider S, Struder HK. Monitoring effects of acute hypoxia on brain cortical activity by using electromagnetic tomography. Behav Brain Res. 2009;197:476-80.
[143] Kashihara K, Maruyama T, Murota M, Nakahara Y. Positive effects of acute and moderate physical exercise on cognitive function. J Physiol Anthropol. 2009;28:155-64.

[144] Norton K, Norton L, Sadgrove D. Position statement on physical activity and exercise intensity terminology. J Sci Med Sport. 2010;13:496-502.
[145] Brickenkamp R. Bickenkamp Handbuch psychologischer und pädagogischer Tests. Göttingen Bern Toronto Seattle: Hogrefe; 2002.
[146] Brickenkamp R, Schmidt-Atzert L, Liepmann D. Attention- and Concentration Test d2 - revised version. Göttingen: Hogrefe Verlag für Psychologie; 2010.
[147] Schneider S, Abeln V, Popova J, Fomina E, Jacubowski A, Meeusen R, et al. The influence of exercise on prefrontal cortex activity and cognitive performance during a simulated space flight to Mars (MARS500). Behav Brain Res. 2013;236:1-7.
[148] Dorval M, Pepin M. Effect of playing a video game on a measure of spatial visualization. Percept Mot Skills. 1986;62:159-62.
[149] Schaefer PD, Thomas J. Difficulty of a spatial task and sex difference in gains from practice. Percept Mot Skills. 1998;87:56-8.
[150] Kirschstein T, Kohling R. What is the source of the EEG? Clinical EEG and neuroscience. 2009;40:146-9.
[151] Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev. 1999;29:169-95.
[152] Klimesch W, Sauseng P, Hanslmayr S. EEG alpha oscillations: the inhibition-timing hypothesis. Brain research reviews. 2007;53:63-88.
[153] Kleinert J. Adjektivliste zur Erfassung der wahrgenommenen körperlichen Verfassung (WKV): Skalenkonstruktion und erste psychometrische Befunde [Adjective list for assessing Perceived Physical State (PEPS). Scale construction and psychometric results]. Zeitschrift für Sportpsychologie. 2006;13:156-64.
[154] Cohen J. Statistical Power Analysis for the Behavioral Sciences, Cohen (1988). Oxon: Psychology Press; 1988.
[155] Best JR. Effects of Physical Activity on Children's Executive Function: Contributions of Experimental Research on Aerobic Exercise. Dev Rev. 2010;30:331-551.
[156] Hillman CH, Kramer AF, Belopolsky AV, Smith DP. A cross-sectional examination of age and physical activity on performance and event-related brain potentials in a task switching paradigm. Int J Psychophysiol. 2006;59:30-9.
[157] Ridderinkhof KR, van den Wildenberg WP, Segalowitz SJ, Carter CS. Neurocognitive mechanisms of cognitive control: the role of prefrontal cortex in action selection, response inhibition, performance monitoring, and reward-based learning. Brain Cogn. 2004;56:129-40.
[158] Deslandes A, Moraes H, Ferreira C, Veiga H, Silveira H, Mouta R, et al. Exercise and mental health: many reasons to move. Neuropsychobiology. 2009;59:191-8.
[159] Penedo FJ, Dahn JR. Exercise and well-being: a review of mental and physical health benefits associated with physical activity. Curr Opin Psychiatry. 2005;18:189-93.
[160] Fox KR. The influence of physical activity on mental well-being. Public Health Nutr. 1999;2:411-8.
[161] Berger BG. Psychological benefits of an active lifestyle: What we know and what we need to know. Quest. 1996;48:330-53.

[162] Chmura J, Nazar K, Kaciuba-Uscilko H. Choice reaction time during graded exercise in relation to blood lactate and plasma catecholamine thresholds. Int J Sports Med. 1994;15:172-6.
[163] McMorris T, Keen P. Effect of exercise on simple reaction times of recreational athletes. Percept Mot Skills. 1994;78:123-30.
[164] Vogt T, Abeln V, Struder HK, Schneider S. Artificial gravity exposure impairs exercise-related neurophysiological benefits. Physiol Behav. 2014;123:156-61.
[165] Ohsugi H, Ohgi S, Shigemori K, Schneider EB. Differences in dual-task performance and prefrontal cortex activation between younger and older adults. BMC Neurosci. 2013;14:10.
[166] Vogt T, Schneider S, Brummer V, Struder HK. Frontal EEG asymmetry: the effects of sustained walking in the elderly. Neurosci Lett. 2010;485:134-7.
[167] Dababneh AJ, Swanson N, Shell RL. Impact of added rest breaks on the productivity and well being of workers. Ergonomics. 2001;44:164-74.
[168] Galinsky TL, Swanson NG, Sauter SL, Hurrell JJ, Schleifer LM. A field study of supplementary rest breaks for data-entry operators. Ergonomics. 2000;43:622-38.
[169] Salmon P. Effects of physical exercise on anxiety, depression, and sensitivity to stress: a unifying theory. Clin Psychol Rev. 2001;21:33-61.
[170] McMorris T, Davranche K, Jones G, Hall B, Corbett J, Minter C. Acute incremental exercise, performance of a central executive task, and sympathoadrenal system and hypothalamic-pituitary-adrenal axis activity. Int J Psychophysiol. 2009;73:334-40.
[171] McMorris T, Swain J, Smith M, Corbett J, Delves S, Sale C, et al. Heat stress, plasma concentrations of adrenaline, noradrenaline, 5-hydroxytryptamine and cortisol, mood state and cognitive performance. Int J Psychophysiol. 2006;61:204-15.
[172] Ashby FG, Casale MB. The cognitive neuroscience of implicit category learning. In: Jiménez L, editor. Attention and implicit learning Amsterdam & Philadelphia: John Benjamins Publishing Company; 2002. p. 109–41.
[173] Dehaene S, Naccache L. Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework. Cognition. 2001;79:1-37.
[174] Jackson SA. Toward a conceptual understanding of the flow experience in elite athletes. Res Q Exerc Sport. 1996;67:76-90.
[175] Schneider S, Kleinert J, Steinbacher A, Brümmer V, Strüder HK. The effect of parabolic flight on perceived physical, motivational and psychological state in men and women: correlation with neuroendocrine stress parameters and electrocortical activity. Stress. 2008;Nov 13.
[176] Jackson SA, Martin AJ, Eklund RC. Long and short measures of flow: the construct validity of the FSS-2, DFS-2, and new brief counterparts. J Sport Exerc Psychol. 2008;30:561-87.
[177] Csikszentmihalyi M. Flow: The psychology of optimal experience. New-York: Harper and Row; 1990.
[178] Martin AJ, Tipler DV, Marsh HW, Richards GE, Williams MR. Assessing multidimensional physical activity motivation, assessing multidimensional physical activity motivation: a construct validity study of high-school students. . Journal of Sport & Exercise Psychology. 2006;28:171-92.

[179] Jackson SA, Marsh HW. Development and validation of a scale to measure optimal experience: The flow state scale. Journal of Sport and Exercise Psychology. 1996;18:17-35.
[180] Jackson SA. Joy, fun, and flow state in sport. In: Hanin Y, editor. Emotions in sport, Champaign, IL: Human Kinetics; 1999. p. 135-55.
[181] Vogel EK, Luck SJ. The visual N1 component as an index of a discrimination process. Psychophysiology. 2000;37:190-203.
[182] Omoto S, Kuroiwa Y, Otsuka S, Baba Y, Wang C, Li M, et al. P1 and P2 components of human visual evoked potentials are modulated by depth perception of 3-dimensional images. Clin Neurophysiol. 2010;121:386-91.
[183] Karageorghis CI, Jones L. On the Stability and Relevance of the Exercise Heart Rate - Music-Tempo Preference Relationship. Psychology of Sport and Exercise. 2014;15:299-310.
[184] Millet GY, Lepers R. Alterations of neuromuscular function after prolonged running, cycling and skiing exercises. Sports Med. 2004;34:105-16.
[185] Roelands B, De Pauw K, Meeusen R. Neurophysiological effects of exercise in the heat. Scand J Med Sci Sports. 2015;25 Suppl 1:65-78.
[186] Bachasson D, Temesi J, Gruet M, Yokoyama K, Rupp T, Millet GY, et al. Transcranial magnetic stimulation intensity affects exercise-induced changes in corticomotoneuronal excitability and inhibition and voluntary activation. Neuroscience. 2016;314:125-33.
[187] Grego F, Vallier JM, Collardeau M, Rousseu C, Cremieux J, Brisswalter J. Influence of exercise duration and hydration status on cognitive function during prolonged cycling exercise. Int J Sports Med. 2005;26:27-33.
[188] Parker SM, Erin JR, Pryor RR, Khorana P, Suyama J, Guyette FX, et al. The effect of prolonged light intensity exercise in the heat on executive function. Wilderness Environ Med. 2013;24:203-10.
[189] Moore RD, Romine MW, O'Connor P J, Tomporowski PD. The influence of exercise-induced fatigue on cognitive function. J Sports Sci. 2012;30:841-50.
[190] Jonas S, Phillips EM. ACSM's Exercise is Medicine™: A Clinician's Guide to Exercise Prescription. Philadelphia: Lippincott, Wiliams and Wilkins; 2009.
[191] Castelli DM, Hillman CH, Buck SM, Erwin HE. Physical fitness and academic achievement in third- and fifth-grade students. J Sport Exerc Psychol. 2007;29:239-52.
[192] Coe DP, Pivarnik JM, Womack CJ, Reeves MJ, Malina RM. Effect of physical education and activity levels on academic achievement in children. Med Sci Sports Exerc. 2006;38:1515-9.
[193] Hillman CH, Pontifex MB, Raine LB, Castelli DM, Hall EE, Kramer AF. The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. Neuroscience. 2009;159:1044-54.
[194] Booth JN, Leary SD, Joinson C, Ness AR, Tomporowski PD, Boyle JM, et al. Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort. Br J Sports Med. 2014;48:265-70.
[195] Grech R, Cassar T, Muscat J, Camilleri KP, Fabri SG, Zervakis M, et al. Review on solving the inverse problem in EEG source analysis. J Neuroeng Rehabil. 2008;5:25.

[196] Miller R. Theory of the normal waking EEG: from single neurones to waveforms in the alpha, beta and gamma frequency ranges. Int J Psychophysiol. 2007;64:18-23.
[197] Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. Nat Rev Neurosci. 2008;9:58-65.
[198] Simons-Morton BG. Implementing health-related physical education. In: Pate RR, Hohn RC, editors. Health and Fitness Through Physical Education, Champaign, IL: Human Kinetics; 1994. p. 137-46.
[199] Kaur H, Hyder ML, Poston WS. Childhood overweight: an expanding problem. Treat Endocrinol. 2003;2:375-88.
[200] Sharma M. School-based interventions for childhood and adolescent obesity. Obes Rev. 2006;7:261-9.
[201] Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, et al. Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review. Med Sci Sports Exerc. 2016;48:1223-4.
[202] Fowler B, Manzey D. Summary of research issues in monitoring of mental and perceptual-motor performance and stress in space. Aviat Space Environ Med. 2000;71:A76-7.
[203] Manzey D. Monitoring of mental performance during spaceflight. Aviat Space Environ Med. 2000;71:A69-A75.
[204] Heuer H, Manzey D, Lorenz B, Sangals J. Impairments of manual tracking performance during spaceflight are associated with specific effects of microgravity on visuomotor transformations. Ergonomics. 2003;46:920-34.
[205] Bock O, Fowler B, Comfort D. Human sensorimotor coordination during spaceflight: an analysis of pointing and tracking responses during the "Neurolab" Space Shuttle mission. Aviat Space Environ Med. 2001;72:877-83.
[206] Bock O, Abeele S, Eversheim U. Sensorimotor performance and computational demand during short-term exposure to microgravity. Aviat Space Environ Med. 2003;74:1256-62.
[207] Jüngling S, Bock O, Girgenrath M. Speed-accuracy trade-off of grasping movements during microgravity. Aviat Space Environ Med. 2002;73:430-5.
[208] Hermsdörfer J, Marquardt C, Philipp J, Zierdt A, Nowak D, Glasauer S, et al. Grip forces exerted against stationary held objects during gravity changes. Experimental Brain Research. 1999;126:205-14.
[209] Hermsdörfer J, Marquardt C, Philipp J, Zierdt A, Nowak D, Glasauer S, et al. Moving Weightless objects: Grip force control during microgravity. Exp Brain Res. 2000;132:52-64.
[210] Augurelle AS, Penta M, White O, Thonnard JL. The effects of a change in gravity on the dynamics of prehension. Exp Brain Res. 2003;148:533-40.
[211] Money KE, Cheung BS. Alterations of proprioceptive function in the weightless environment. J Clin Pharmacol. 1991;31:1007-9.
[212] Bock O, Howard IP, Money KE, Arnold KE. Accuracy of aimed arm movements in changed gravity. Aviat Space Environ Med. 1992;63:994-8.
[213] Lackner JR, DiZio P. Gravitoinertial force level affects the appreciation of limb position during muscle vibration. Brain Res. 1992;592:175-80.
[214] Cheron G, Leroy A, Palmero-Soler E, De Saedeleer C, Bengoetxea A, Cebolla AM, et al. Gravity influences top-down signals in visual processing. PLoS One. 2014;9:e82371.

[215] Messerotti Benvenuti S, Bianchin M, Angrilli A. Effects of simulated microgravity on brain plasticity: a startle reflex habituation study. Physiol Behav. 2011;104:503-6.
[216] Koppelmans V, Erdeniz B, De Dios YE, Wood SJ, Reuter-Lorenz PA, Kofman I, et al. Study protocol to examine the effects of spaceflight and a spaceflight analog on neurocognitive performance: extent, longevity, and neural bases. BMC neurology. 2013;13:205.
[217] Fuchs M, Kastner J, Wagner M, Hawes S, Ebersole JS. A standardized boundary element method volume conductor model. Clin Neurophysiol. 2002;113:702-12.
[218] Jurcak V, Tsuzuki D, Dan I. 10/20, 10/10, and 10/5 systems revisited: their validity as relative head-surface-based positioning systems. Neuroimage. 2007;34:1600-11.
[219] Talairach J, Tournoux, P. Co-Planar Stereotaxic Atlas of the Human Brain. Stuttgart: Thieme; 1988.
[220] Nichols TE, Holmes AP. Nonparametric permutation tests for functional neuroimaging: a primer with examples. Hum Brain Mapp. 2002;15:1-25.
[221] Ciesielski KT, French CN. Event-related potentials before and after training: chronometry and lateralization of visual N1 and N2. Biol Psychol. 1989;28:227-38.
[222] Manzey D, Lorenz B, Schiewe A, Finell G, Thiele G. Behavioral aspects of human adaption to space: analyses of cognitive and psychomotor performance in space during an 8-day space mission. Clinical Investigator. 1993;71:725-31.
[223] Bock O. Problems of sensorimotor coordination in weightlessness. Brain Res Brain Res Rev. 1998;28:155-60.
[224] Schneider S, Brummer V, Gobel S, Carnahan H, Dubrowski A, Struder HK. Parabolic flight experience is related to increased release of stress hormones. Eur J Appl Physiol. 2007;100:301-8.
[225] Strewe C, Feuerecker M, Nichiporuk I, Kaufmann I, Hauer D, Morukov B, et al. Effects of parabolic flight and spaceflight on the endocannabinoid system in humans. Reviews in the neurosciences. 2012;23:673-80.
[226] Schneider S, Askew CD, Brummer V, Kleinert J, Guardiera S, Abel T, et al. The effect of parabolic flight on perceived physical, motivational and psychological state in men and women: correlation with neuroendocrine stress parameters and electrocortical activity. Stress. 2009;12:336-49.
[227] Luck SJ, Kappenman ES. The Oxford Handbook of Event-Related Potential Components. Oxfor, New York et al.: Oxford University Press; 2012.
[228] Mangun GR, Hillyard SA. Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. J Exp Psychol Hum Percept Perform. 1991;17:1057-74.
[229] Herdman AT, Takai O. Paying attention to orthography: a visual evoked potential study. Frontiers in human neuroscience. 2013;7:199.
[230] Luck SJ, Hillyard SA. Electrophysiological correlates of feature analysis during visual search. Psychophysiology. 1994;31:291-308.
[231] Ho HT, Schroger E, Kotz SA. Selective Attention Modulates Early Human Evoked Potentials during Emotional Face-Voice Processing. J Cogn Neurosci. 2014:1-21.

[232] Stevenson RA, Bushmakin M, Kim S, Wallace MT, Puce A, James TW. Inverse effectiveness and multisensory interactions in visual event-related potentials with audiovisual speech. Brain Topogr. 2012;25:308-26.
[233] Saradjian AH, Paleressompoulle D, Louber D, Coyle T, Blouin J, Mouchnino L. Do gravity-related sensory information enable the enhancement of cortical proprioceptive inputs when planning a step in microgravity? PLoS One. 2014;9:e108636.
[234] Wollseiffen P, Vogt T, Abeln V, Struder HK, Askew CD, Schneider S. Neuro-cognitive performance is enhanced during short periods of microgravity. Physiol Behav. 2016;155:9-16.
[235] Ogoh S, Hirasawa A, Raven PB, Rebuffat T, Denise P, Lericollais R, et al. Effect of an acute increase in central blood volume on cerebral hemodynamics. Am J Physiol Regul Integr Comp Physiol. 2015;309:R902-11.
[236] Marusic U, Meeusen R, Pisot R, Kavcic V. The brain in micro- and hypergravity: the effects of changing gravity on the brain electrocortical activity. Eur J Sport Sci. 2014;14:813-22.
[237] Aaslid R, Markwalder TM, Nornes H. Noninvasive transcranial Doppler ultrasound recording of flow velocity in basal cerebral arteries. Journal of neurosurgery. 1982;57:769-74.
[238] Willie CK, Colino FL, Bailey DM, Tzeng YC, Binsted G, Jones LW, et al. Utility of transcranial Doppler ultrasound for the integrative assessment of cerebrovascular function. Journal of neuroscience methods. 2011;196:221-37.
[239] Skow RJ, MacKay CM, Tymko MM, Willie CK, Smith KJ, Ainslie PN, et al. Differential cerebrovascular CO(2) reactivity in anterior and posterior cerebral circulations. Respiratory physiology & neurobiology. 2013;189:76-86.
[240] van Lieshout JJ, Toska K, van Lieshout EJ, Eriksen M, Walloe L, Wesseling KH. Beat-to-beat noninvasive stroke volume from arterial pressure and Doppler ultrasound. European journal of applied physiology. 2003;90:131-7.
[241] Bartels SA, Bezemer R, de Vries FJ, Milstein DM, Lima A, Cherpanath TG, et al. Multi-site and multi-depth near-infrared spectroscopy in a model of simulated (central) hypovolemia: lower body negative pressure. Intensive Care Med. 2011;37:671-7.
[242] Truijen J, Bundgaard-Nielsen M, van Lieshout JJ. A definition of normovolaemia and consequences for cardiovascular control during orthostatic and environmental stress. European journal of applied physiology. 2010;109:141-57.
[243] Griffiths PD. Vascular supply of the brain. In: Standring S, editor. Gray's Anatomy, Churchill Livingstone Elsevier; 2008.
[244] Pascual-Marqui RD, Michel CM, Lehmann D. Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain. Int J Psychophysiol. 1994;18:49-65.
[245] Wollseiffen P, Vogt T, Abeln V, Struder HK, Askew CD, Schneider S. Neuro-cognitive performance is enhanced during short periods of microgravity. Physiol Behav. 2015;155:9-16.
[246] Lawley JS, Petersen LG, Howden EJ, Sarma S, Cornwell WK, Zhang R, et al. Effect of gravity and microgravity on intracranial pressure. J Physiol. 2017;595:2115-27.

[247] Norsk P, Damgaard M, Petersen L, Gybel M, Pump B, Gabrielsen A, et al. Vasorelaxation in space. Hypertension. 2006;47:69-73.
[248] Kohn FPM, Ritzmann R. Gravity and neuronal adaptation, in vitro and in vivo-from neuronal cells up to neuromuscular responses: a first model. Eur Biophys J. 2018;47:97-107.
[249] Kohn FPM. High Throughput Fluorescent Screening of Membrane Potential and Intracellular Calcium Concentration Under Variable Gravity Conditions. Microgravity Sci Technol. 2013;25:113-20.
[250] Kim KH, Kim JH, Yoon J, Jung KY. Influence of task difficulty on the features of event-related potential during visual oddball task. Neurosci Lett. 2008;445:179-83.
[251] Efron B, Stein C. The Jackknife Estimate of Variance. The Annals of Statistics. 1981;9:586-96.
[252] Wollseiffen P, Vogt T, Abeln V, Struder HK, Askew CD, Schneider S. Neuro-Cognitive Performance Is Enhanced During Short Periods Of Microgravity: 3020 Board #85 June 3, 2: 00 PM - 3: 30 PM. Med Sci Sports Exerc. 2016;48:853.
[253] Justen C, Herbert C. Snap Your Fingers! An ERP/sLORETA Study Investigating Implicit Processing of Self- vs. Other-Related Movement Sounds Using the Passive Oddball Paradigm. Frontiers in human neuroscience. 2016;10:465.
[254] Justen C, Herbert C. The spatio-temporal dynamics of deviance and target detection in the passive and active auditory oddball paradigm: a sLORETA study. BMC Neurosci. 2018;19:25.
[255] Raney GE. Monitoring changes in cognitive load during reading: an event-related brain potential and reaction time analysis. J Exp Psychol Learn Mem Cogn. 1993;19:51-69.
[256] Klein T, Wollseiffen P, Sanders M, Claassen J, Carnahan H, Abeln V, et al. The influence of microgravity on cerebral blood flow and electrocortical activity. Exp Brain Res. 2019.
[257] Kozlowska K, Melkonian D, Spooner CJ, Scher S, Meares R. Cortical arousal in children and adolescents with functional neurological symptoms during the auditory oddball task. Neuroimage Clin. 2017;13:228-36.
[258] Caldwell HG, Coombs GB, Tymko MM, Nowak-Fluck D, Ainslie PN. Severity-dependent influence of isocapnic hypoxia on reaction time is independent of neurovascular coupling. Physiol Behav. 2018;188:262-9.
[259] Handtke W, Schluhe W. Planar lipid bilayers: methods and applications. Oxford: Academic Press 1993.
[260] Grigoriev AJ, Polyakov VV, Bogomolov VV, Egorov AD, Pestov ID, Kozlovskaya IB. Medical Results of the Fourth Prime Expedition on the Orbital Station MIR. Proceedings of the Fourth European Symposium on Life Sciences Research in Space, Trieste, Italy, ESA SP-307. 1990:19-22 ->910.
[261] WHO. Global Recommendations on Physical Activity for Health. Geneva Switzerland: World Health Organisation Press; 2010.
[262] Ekkekakis P, Hall EE, VanLanduyt LM, Petruzzello SJ. Walking in (affective) circles: can short walks enhance affect? J Behav Med. 2000;23:245-75.
[263] Salmon P. Effects of physical exercise on anxiety, depression, and sensitivity to stress: a unifying theory. Clin Psychol Rev. 2001;21:33-61.

[264] Kamdar D, Van Dyne L. The joint effects of personality and workplace social exchange relationships in predicting task performance and citizenship performance. J Appl Psychol. 2007;92:1286-98.
[265] Coco M, Perciavalle V, Cavallari P, Perciavalle V. Effects of an Exhaustive Exercise on Motor Skill Learning and on the Excitability of Primary Motor Cortex and Supplementary Motor Area. Medicine (Baltimore). 2016;95:e2978.
[266] Coco M, Alagona G, Rapisarda G, Costanzo E, Calogero RA, Perciavalle V, et al. Elevated blood lactate is associated with increased motor cortex excitability. Somatosens Mot Res. 2010;27:1-8.
[267] Meeusen R, Watson P, Hasegawa H, Roelands B, Piacentini MF. Brain neurotransmitters in fatigue and overtraining. Appl Physiol Nutr Metab. 2007;32:857-64.
[268] Pageaux B, Marcora SM, Rozand V, Lepers R. Mental fatigue induced by prolonged self-regulation does not exacerbate central fatigue during subsequent whole-body endurance exercise. Front Hum Neurosci. 2015;9:67.
[269] Cheron G. How to Measure the Psychological "Flow"? A Neuroscience Perspective. Front Psychol. 2016;7:1823.
[270] Dietrich A. Transient hypofrontality as a mechanism for the psychological effects of exercise. Psychiatry Res. 2006;145:79-83.
[271] Kahneman D. Attention and Effort. Prentice-Hall series in experimental psychology. Library of Congress Cataloging in Publication Data ed. Englewood Cliffs New Jersey: Prentice-Hall; 1993.
[272] Ellis SR. Collision in space. Ergon Des. 2000;8:4-9.
[273] Organization WH. Global recommendations on physical activity for health. 20 Avenue Appia, 1211 Geneva 27, Switzerland: WHO Press; 2010.
[274] Gur RE, Gur RC. Gender differences in aging: cognition, emotions, and neuroimaging studies. Dialogues Clin Neurosci. 2002;4:197-210.

Acknowledgments

I would like to extend my sincere thanks and gratitude for excellent scientific and personal guidance as well as collegial assistance and friendship to

Univ.-Prof Dr. Heiko Strüder,

Prof. Dr. Dr. Stefan Schneider,

Jun. Prof. Dr. Tobias Vogt,

Dr. Vera Abeln,

For their constant support and collegial guidance, I would like to thank

Prof. Dr. Thomas Abel, Prof. Dr. Kirsten Albracht, Dr. Volker Anneken, Prof. Dr. Chris Askew, Anna Berger, Univ.-Prof. Dr. Otmar Bock, Dr. Björn Braunstein, Dr. Marc Dalecki, Sebastian Dern, Prof. Dr. Arne Dietrich, Dr. Tina Foitschik, Univ.-Prof. Dr. Albert Gollhofer, Arghan Ghadiri, Ilka Staub, Prof. Dr. Rainer Herpers, Hannelore Holl, Amrei Jacubowski, Dr. Gerard King, Timo Klein, Dr. Axel Knicker, Dr. Helge Knigge, Dr. Axel Kupfer, Prof. Dr. Andreas Mierau, Dr. Julia Mierau, Dr. Anja Paul, Dr. Nora Peters, Prof. Dr. Theo Peters, Dr. Anna-Maria Platschek, Dr. Wolfgang Ritzdorf, PD Dr. Dr. Sandra Rojas Vega, Stefanie Rüdiger, PD Dr. Dr. Thorsten Schiffer, André Scholz, Regina Schüler, Dr. Stefanie Schulte, Tim Stuckenschneider, Jan Weber, Dr. Susen Werner, Vanja Zander

I would also like to thank the many participants, children, parents and teachers from Cologne, staff and students from the German Sport University as well as from the University of applied science Bonn Rhein-Sieg and the University of the Sunshine Coast who conducted the data in the studies whether in the primary school or in space.

and for my family – so glad to have them.

PHD Curriculum

PEER-REVIEWED PUBLICATIONS

(Chronologically listed as of 9th of March 2019, IF as of publication date)

1. Neuro-Cognitive Performance Is Enhanced During Short Periods Of Microgravity – part 2, ***Wollseiffen, P.***, ***Klein, T.***, *Vogt, T., Abeln, V., Strüder, H. K., Sanders, M., Claassen, J., Askew, C. D., Carnahan, H., Schneider, S.,* (2019) Physiology & Behavior under revision 05.02.2019

2. The influence of microgravity on cerebral blood flow and electrocortical activity, ***Klein, T., Wollseiffen, P.***, *Sanders, M., Claassen, J., Carnahan, H., Abeln, V., Vogt, T., Strüder, H. K., Schneider, S*., Experimental Brain Research. (2019) DOI 10.1007/s00221-019-05490-6 Impact: 1.87

3. Distraction versus Intensity: The Importance of Exercise Classes for Cognitive Performance in School, ***Wollseiffen, P***., *Vogt, T., Strüder, H. K. & Schneider, S.* Medical Principles and Practice. (2018) DOI 10.1159/000486281, Impact: 1.536

4. Hemodynamic and neuroendocrinological responses to artificial gravity, *Schneider, S., Zander, V., Vogt, T., Abeln, V., Strüder, H. K. Jacubowski, A., Carnahan, H.,* ***Wollseiffen, P.*** Gravitational and Space Research. (2017) 5, 2, S. 80-88. Impact: .62

5. The Effect of 6 h of Running on Brain Activity, Mood, And Cognitive Performance, ***Wollseiffen, P***., *Schneider, S., Martin, L. A., Kerhervé, H. A., Klein, T. & Solomon, C.,* Experimental brain research. (2016) DOI 10.1007/s00221-016-4587-7, Impact: 2.036

6. Neuro-Cognitive Performance Is Enhanced During Short Periods Of Microgravity, ***Wollseiffen, P***., *Vogt, T., Abeln, V., Strüder, H. K. & Schneider, S.* Physiology & Behavior. (2015) DOI 10.1016/j.physbeh.2015.11.036, Impact: 2.976

7. Short Bouts Of Intensive Exercise During The Workday Have A Positive Effect On Neuro-Cognitive Performance, ***Wollseiffen, P***., *Ghadiri, A., Scholz, A., Strüder, H. K., Herpers, R., Peters, T. & Schneider, S.*, Stress and Health. (2015) DOI 10.1002/smi.2654, Impact: 1.814

8. Localisation of exercise induced changes in brain cortical activity using a distributed source localization algorithm, *Schneider S., Brümmer V., Askew C.D.,* ***Wollseiffen, P.***,

Strüder, H. K. Medicine & Science in Sports & Exercise. (2009) DOI: 10.1249/01.mss.0000353279.09561.11, Impact: 1.93

PRESENTATIONS

Poster Presentation at the *Neuroscience 2018 annual meeting of the Society for Neuroscience* in San Diego, CA, USA, 4th November, 2018: "The role of physical education on academic performance in primary school".

Oral presentation at the *23th annual congress of the European College of Sport Science* in Dublin, Ireland, 5th of July, 2018: "Distraction versus Intensity: The importance of non-major subjects on academic performance in school"**.**

Oral Presentation at the *annual meeting of Australian Sports Medicine* in Langkawi, Malaysia, 26th of October, 2017:" Train like an astronaut – the effects of exercise on neurocognitive performance".

Poster Presentation at the *annual meeting of the American College of Sports Medicine 2016* in Boston, MA, USA, 3rd of June, 2016: "Neurocognitive performance is enhanced during short periods of microgravity".

Oral Presentation at the *20th annual congress of the European College of Sport Science* Malmö, Sweden, 25th of June, 2015: "The effect of prolonged Exercise on brain activity mood and effort".

Oral Presentation at the *18th European College of Sports Science* in Barcelona, Spain, 28th of June, 2013: "Exercise at the office: How to maintain working performance of employees".

VISITED CONFERENCES

Neuroscience 2018 annual meeting of the Society for Neuroscience. San Diego, CA, USA, November 3-7, 2018.

23th annual congress of the European College of Sport Science – Sport science at the cutting edge. Dublin, Ireland, July 4-7, 2018.

Annual conference of Asics Sports Medicine Australia. Langkawi, Malaysia, October 25-28, 2017.

2016 Annual Meeting of the American College of Sports Medicine – Advancing health through science, education and medicine. Boston, MA, USA, May 31-June 4, 2016.

20th annual congress of the European College of Sport Science – Sustainable sport. Malmö, Sweden, June 24-27, 2015.

18th annual congress of the European College of Sports Science – Unifying sport science. Barcelona, Spain June 26-29, 2013.