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Moderate cycling exercise enhances neurocognitive processing in adolescents with intellectual and developmental disabilities

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ABSTRACT

Research has shown that physical exercise enhances cognitive performance in individuals with intact cognition as well as in individuals diagnosed with intellectual and developmental disabilities. Although well identified in the field of health (for example, the transient hypofrontality theory), the underlying neurocognitive processes in intellectual and developmental disabilities remain widely unclear and thus characterize the primary aim of this research. Eleven adolescents with intellectual and developmental disabilities performed moderate cycling exercise and common relaxation. Cross-over designed, both 10-min meetings were randomly allocated at the same time of day with 24-h time lags in between. Conditions were embedded in ability-modified cognitive performance (decision-making processes). Participants' reaction times and their equivalent neurophysiological parameters were recorded using standard EEG and analyzed (spatial activity, N2). Exercise revealed a decrease in frontal electrocortical activity, most pronounced in the medial frontal gyrus (10%). To that effect, reaction time ($p < 0.01$) was decreased and mirrored in decreased N2 latency ($p < 0.01$) after exercise. In contrast, relaxation revealed no significant changes. Results of this research suggest exercise temporarily enhances neuronal activity in relation to cognitive performance for adolescents with intellectual and developmental disabilities; further research is needed to explore possible future effects on enhancing neurocognitive development.

1. Introduction

Today, exercise is recommended to maintain physical and mental health in humans (Brisswalter, Collardeau, & René, 2002; Hagen et al., 2012). Numerous neurophysiological and behavioral research studies address the duration, intensity, and – more recently – individual exercise preferences in relation to well-being and cognitive performance (Schneider, Brümmer, Abel, Askew, & Strueder, 2009). Although this research covers an extensive span of life and class of population, little is known about exercise-induced neurocognitive processes in intellectual and developmental disabilities (IDD).

According to the American Association on Intellectual and Developmental Disabilities (AAIDD), IDD is characterized by limited intellectual functioning; e.g. learning, reasoning, and problem solving, as well as adaptive behavior; e.g. conceptual, social and practical skills that originate in adolescence. Adolescence is a time of considerable neurocognitive and behavioral

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development (Blakemore & Choudhury, 2006; Blakemore, 2012; Hartman, Houwen, Scherder, & Visscher, 2010). Hence, research focuses on beneficial processes to improve neurocognitive behavior in IDD during adolescence (Leggett, Jacobs, Nation, Scerif, & Bishop, 2010; Silver et al., 2008). Recently, a first attempt at using exercise to specifically benefit neural behavior in IDD has been suggested (Vogt, Schneider, Abeln, Anneken, & Strüder, 2012). To that effect, increased social acceptance and participation further underline the needs to broaden the understanding of exercise-induced changes on cognitive performance in IDD. While relaxation setups ('snoezelen'; Mertens, 2008) are commonly used in rehabilitation facilities to improve concentration in IDD (Hogg, Cavet, Lambe, & Smeddle, 2001), additional research suggests moderate exercise to contribute to general well-being and cognitive performance in IDD (Cervantes & Porretta, 2010; Hutzler & Korsensky, 2010). However, underlying neurocognitive processes are mainly disregarded (Temple, Frey, & Stanish, 2006) or are not considered in IDD-modified assessments of cognitive performance (Vogt et al., 2012).

While commonly used in the field of clinical and cognitive neuroscience to explore IDD, electroencephalography (EEG) is still a relatively new method to record brain cortical activity in exercise physiology. However, recent technological developments enable the use of EEG in exercise setups, combining enhanced temporal and spatial resolution with a reduction of moving artifacts. To that effect, traditional EEG recordings enable low-resolution brain electromagnetic tomography (LORETA). The LORETA method (University Hospital of Psychiatry, Zurich, Switzerland) has previously been described and validated in clinical (Fuchs, Kastner, Wagner, Hawes, & Ebersole, 2002; Jurcak, Tsuzuki, & Dan, 2007; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002; Pascual-Marqui, 2002) and exercise research (Schneider, Brümmer, et al., 2009; Schneider, Vogt, Frysch, Guardiera, & Struder, 2009; Vogt et al., 2012). This research indicates that cognitive processes relate to specific electrocortical activity patterns, particularly in frontal brain areas that are fundamental for cognitive performance. During exercise, the transient hypofrontality theory (Dietrich, 2006) suggests a shift of cortical resources away from brain areas that are rather negligible for movement processing but for cognitive performance. Neurocognitive research indicates that essential areas of the frontal lobe associate to sensory information processing (superior frontal gyrus, SuFG), motor control and movement processing (precentral gyrus, PrG and inferior frontal gyrus, InFG) and executive functions (medial frontal gyrus, MeFG), including decision-making processes such as go/no-go tasks (Chouinard & Paus, 2006; Könönen et al., 2005; Liakakis, Nickel, & Seitz, 2011; Talati & Hirsch, 2005). In addition, EEG recordings enable analyses and interpretation of event-related potential waveforms, sensitive to stimulus probability in amplitude and latency. Generally associated with cognitive control, the N2 component, as an event-related potential component, covers a concept of strategic monitoring and control of movement responses (Folstein & van Petten, 2008). Developments of cognitive control are reflected by decreases in the N2 amplitude and latency, indicating better cognitive performance (Lamm, Zelazo, & Lewis, 2006). Following stimulus onset in the averaged EEG waveform, the N2 peaks negatively between 200 and 350 ms. Its visual modality is prominent in occipital electrode sites. In order to modulate and assess neural responses of cognitive performance, previous research suggests the use of expected and unexpected sensory stimuli (Mangun, 1995). The consistent temporal modulation of N2 is suggested to indicate both an attentional preparation of decision-making, as well as early motor processing (Correa, Lupiáñez, Madrid, & Tudela, 2006). Recent clinical research suggests that N2 latency in particular shows a correlation between cognitive performance and IDD (Papaliagkas, Kimiskidis, Tsolaki, & Anogianakis, 2011).

1.1. Hypotheses

Accordingly, the primary aim of this research is to explore exercise-induced neurocognitive changes compared to common relaxation in adolescents with IDD. It is hypothesized that: (1) frontal electrocortical activity decreased after 10 min of moderate cycling exercise compared to 10 min of relaxation; (2) reaction time is improved after exercise compared to relaxation and (3) coinciding with neural responses of cognitive control – particularly in the N2 latency.

2. Materials and methods

2.1. Participants

Approved by the University's Human Research Ethics Committee, eleven right-handed adolescents (6 males, 5 females) volunteered to participate in this research (16 ± 1.34 years, 167.27 ± 10.01 cm, 69.36 ± 7.80 kg). According to the AAIDD definition (Schalock et al., 2010), previously published characterizations (Vogt et al., 2012; World Health Organization, 1997) as well as medical records and school reports, participants were classified as adolescents with intellectual and developmental disabilities. Furthermore, participants were excluded if they were unable to differentiate between colors and shapes. Prior to involvement, participants attended an informatory meeting, including medical screening and familiarization with the experimental procedures. On agreement, legal guardians provided written informed consent. All participants were familiar with exercising–cycling, in particular. All procedures were in compliance with the Declaration of Helsinki for human participants.

2.2. Design

This research was conducted in cooperation with schools for special needs education, focusing on intellectual and learning disabilities. Each participant attended two experimental meetings, differing in exercise and relaxation conditions.