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The interrelation between sensorimotor abilities, cognitive performance and individual EEG alpha peak frequency in young children

Andreas Mierau [a,*], Moritz Felsch [b], Thorben Hülsdünker [a], Julia Mierau [a], Pola Bullermann [a], Britta Weiß [a], Heiko K. Strüder [a]

[a] Institute of Movement and Neurosciences, German Sport University Cologne, Germany
[b] Institute of Medical Statistics, Informatics and Epidemiology, University of Cologne, Germany

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H I G H L I G H T S

- Sensorimotor and working memory performance are correlated in young children.
- Brain's global functional architecture (BGFA) correlated with locomotor skills.
- However, BGFA did not significantly correlate with working memory performance.

A B S T R A C T

Objective: The aim of this study was to identify the interrelation between sensorimotor abilities, cognitive performance and individual alpha peak frequency (iAPF), an EEG marker of global architectural and functional properties of the human brain, in healthy preschool children.
Methods: 25 participants completed a one minute eyes-closed EEG recording, two cognitive tests assessing processing speed and visual working memory and a sensorimotor test battery.
Results: We found positive correlations between selective sensorimotor abilities and iAPF; however, no significant correlations were observed between iAPF and cognitive performance. Specifically, locomotor skills correlated with iAPF across all cortical regions, except for the occipital cortex. Furthermore, a close relationship was found between sensorimotor and cognitive performance indicating that children with improved sensorimotor abilities were faster and/or more accurate in cognitive task performance. The cumulative pattern of our results indicates that a close relationship exists between sensorimotor and cognitive performance in young children. However, this relationship is dissociated from the iAPF.
Conclusion: In contrast to adults, in young children the iAPF is related to locomotor skills and not to cognitive processing speed or visual working memory function.
Significance: The global architectural and functional properties of the brain are closely related to locomotor skills during development.

1. Introduction

Numerous experiments have established a close relationship between sensorimotor and cognitive development (Piek et al., 2008; Roebers and Kauer, 2009; Niederer et al., 2011). However, the neurobiological mechanisms underlying this relationship are inadequately studied, and most of the current discussion in this context is based upon extrapolation from studies on children with neurological disorders. This research indicates that neurodevelopmental disorders such as attention-deficit hyperactivity disorder (ADHD) and developmental coordination disorder (DCD) are typically characterised by both, abnormal sensorimotor and cognitive control (Diamond, 2000; Zwicker et al., 2009). It has been argued this co-occurrence of sensorimotor and cognitive deficits in children with developmental problems is highly suggestive of neuropathology of the cerebellum. However, given the heterogeneity of these disorders, other sources such as the basal ganglia, the parietal lobe, the corpus callosum and the prefrontal cortex may also be involved (Diamond, 2000; Zwicker et al., 2009). More recent

* Corresponding author at: Institute of Movement and Neurosciences, German Sport University, 50933 Cologne, Germany. Tel.: +49 221 4982 4060; fax: +49 221 4973454.
E-mail address: mierau@dshs-koeln.de (A. Mierau).

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studies used functional magnetic resonance imaging (fMRI) and diffusion tensor imaging (DTI) to identify the neural correlates of DCD and ADHD. The results of these studies support the existence of both common and distinct neurobiological substrates underlying motor and attention problems. Specifically, it was found that functional connectivity of neural motor networks is disrupted in children with DCD and/or ADHD (McLeod et al., 2014). Furthermore, microstructural alternations in the corpus callosum were associated with difficulties in motor and attention functioning. However, these alternations are functionally and regionally distinct (Langevin et al., 2014).

Notwithstanding the above mentioned evidence, more research is needed addressing the link between sensorimotor and cognitive development using neurobiological measures in both healthy children and those with neurodevelopmental disorders across different ages. However, it is a central problem in research investigating the brain–behaviour relationship during infancy and early childhood that neuroimaging using techniques such as (f)MRI, DTI and positron emission tomography (PET) is limited due to movement restriction and feelings of discomfort. In addition, PET involves the injection of a radioactive isotope. Given these restrictions, electroencephalography (EEG) is probably the most frequently used neuroimaging technique in infants and children, as its application is comparatively unproblematic. Among the quantitative EEG parameters, the individual alpha peak frequency (iAPF) was found to be the best signature of brain maturation (Valdés et al., 1990). The iAPF is the dominant oscillatory frequency in the human EEG during relaxed wakefulness, and it is considered a marker of global architectural and functional properties of the human brain (Grandy et al., 2013a). It increases from infancy to adulthood, then decreases with age analogue to changes in brain architecture and general cognitive abilities (Klimesch, 1999). The iAPF shows large interindividual variability and has been shown to correlate with a range of cognitive tasks in adults. For example, adult individuals with higher iAPF show shorter reaction times (Jin et al., 2006), better working memory scores (Richard Clark et al., 2004; Grandy et al., 2013a) and superior memory performance (Klimesch et al., 1993). Although the iAPF is consistently discussed as a neurophysiological marker of brain maturation, the relationship between iAPF and behaviour during childhood development remains unknown.

The primary aims of the present study are: (1) to establish the relationship between sensorimotor abilities and cognitive performance in young children, (2) to identify how these two domains relate to the iAPF, and (3) when indicated, to analyse whether the relationship between sensorimotor abilities and cognitive performance is mediated by the iAPF. Based on previous research, it was hypothesised that a close relationship exists between sensorimotor abilities and cognitive performance. In addition, both sensorimotor and cognitive performance should correlate with iAPF if the two domains are fundamentally interrelated and develop in parallel (Diamond, 2000). However, given the inconclusive literature about the directional nature of the relationship between sensorimotor and cognitive development, alternative hypotheses (e.g. significant correlation between iAPF and sensorimotor, but not cognitive performance or vice versa) could also be posed.

2. Methods

2.1. Participants and ethical statement

25 children (9 females, 16 males) recruited from a kindergarten in Cologne city centre participated in the study. Eligibility criteria for the participants were age (3–6 years) and "normal" BMI (15th–85th percentile, Kromeyer-Hauschild et al., 2001). In addition, parents had to confirm their child was in good health and did not have any overt medical conditions or a documented history of developmental delays. The children and their parents were informed about the intention and procedure of the study and their verbal (children) and written (parents) consent was obtained. The study was designed in accordance with the Declaration of Helsinki and approved by the Research Ethics Committee of the German Sport University in Cologne.

2.2. Measures

2.2.1. EEG data acquisition and analysis

Each participant's eyes-closed resting state EEG (Brain Products, Munich, Germany) was recorded for 1 min. Children were instructed to sit relaxed with their hands placed on their thighs and to try not to move. Using an elastic cap (ActiCap; Brain Products, Munich, Germany), 20 scalp electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, Oz, O2) were placed according to the international 10:20 system (Jasper, 1958). In addition, one electrooculographic electrode was placed laterally below the right eye to detect eye movement. The electrical reference and the ground electrode were located on position FCz and AFz, respectively. Electrode impedance was kept below 5 kΩ and data was sampled with 256 Hz.

EEG data were analysed using the Brain Vision Analyzer 2 (Brain Products, Germany) software package and scripts based on EEGlab (Delorme and Makeig, 2004). In a first step, data were digitally band pass filtered using an IIR butterworth filter (low pass: 40 Hz, 48 db/oct; high pass: 1 Hz, 48 db/oct) and segmented into 4 s epochs. All segments were baseline corrected and a semiautomatic artefact rejection algorithm (maximal allowed voltage step: 100 μV; maximal allowed voltage difference within 30 ms: 150 μV; maximal/minimal allowed amplitude within each segment: ±200 μV) was applied to detect gross artefacts. Remaining artefacts were corrected applying independent component analysis (ICA). After ICA-based artefact correction, the data were re-referenced to a common average reference. The spectral power of each segment was calculated using fast Fourier transformation (FFT) (resolution: 0.25 Hz; 20% Hanning window) and data were subsequently averaged across segments. The iAPF was defined as the frequency bin displaying the highest power value within the frequency range 5–12.5 Hz and was averaged across electrodes to form the following five regions: frontal (Fp1, Fp2, F7, F3, Fz, F4, F8, FCz), central (C3, Cz, C4), parietal (P3, Pz, P4), occipital (O1, Oz, O2) and temporal (T7, T8, P7, P8). While the iAPF is traditionally defined as the peak power value within the traditional adult alpha frequency range (~7.5–12.5 Hz), in this study the lower boundary was corrected to account for reduced peak frequencies in children when compared to adults (cf. Klimesch, 1999).

2.2.2. Cognitive performance

Cognitive performance was assessed using the computerised Vienna Test System (VTS) for neuropsychological assessment (Schuhfried, Austria, http://www.schuhfried.com/viennatestsystem10/vienna-test-system-vts/). For each child, the first test presentation started with automatic and standardised test instructions, including a practice period in order to ensure the tasks were fully understood. The participants were asked by the examiner to focus on the task and as a reward for attendance allowed their choice from a range of toys or sweets after completion of the tests.

2.2.2.1. Determination test for children (DTC). Processing speed was measured using the children's version of the determination test. The reliability and validity of the determination test has been confirmed in previous studies (Baur et al., 2006; Sommer et al., 2010). The DTC assesses the individual's accuracy and reaction speed

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