Selected neurocognitive deficits in attention deficit hyperactivity disorder in children: Characteristic, measurement, and intervention using motivational methods and hemoencephalographic neurofeedback

Structural and functional abnormalities in the prefrontal cortex (PFC) of children with attention deficit hyperactivity disorder (ADHD) have been linked to cognitive impairment (Bush, 2011). One method of brain activation in this area is hemoencephalographic (HEG) neurofeedback using near-infrared spectroscopy. Neurofeedback with virtual reality (VR) is believed to be more effective in improving cognitive functioning compared to two-dimensional training. VR technology provides an environment that attracts attention and increases concentration ability (Blume et al., 2017). In addition, the use of motivational techniques seems to be of interest in cognitive therapy, as it has been widely proven that motivational deficits cooccur in ADHD. This dissertation consists of a series of five publications (research reports). The purpose of the first study was to assess cortical activity, dimensions of motivation as per the self-determination theory (Deci & Ryan, 2008) and the influence of extrinsic motivation on selected aspects of attention in children with ADHD. As a result of the recruitment, 30 children with ADHD and 30 neurotypical children aged 9 to 13 years were qualified to participate. Children with ADHD exhibited a higher theta/beta power ratio in the midline and lower regional cerebral blood oxygenation ($rCBO_2$) in the PFC compared to neurotypical children. Children with ADHD were more likely to perform activity under the pressure of external stimuli and exhibited attention deficits (vigilance, visual search, and divided attention). The prospect of earning a reward reduced intergroup differences in attention, indicating that motivation may reduce cognitive deficits in children with ADHD. The purpose of the second study was to assess vigilance, inhibitory control and $rCBO_2$ in the PFC across ADHD presentation types. The study involved 150 children with ADHD and 51 neurotypical children aged 9–12. Children with ADHD showed impaired vigilance and inhibitory control, different $rCBO_2$ patterns in the PFC, and lower cortical activation in the cognitive task. Differences are discussed, including three types of ADHD presentations (predominantly hyperactive-impulsive presentation, predominantly inattentive presentation, and combined presentation). The purpose of the third study was to evaluate the efficacy of HEG neurofeedback in PFC in ADHD and neurotypical children, as well as to determine psychological predictors of gain in HEG neurofeedback. Individuals (120 children aged 9–15, including 60 with ADHD) participated in ten HEG neurofeedback or physical activity training sessions. Children with ADHD exhibited lower cognitive capacity in terms of vigilance, visual search, multitasking, inhibitory control, and working memory compared to neurotypical children. The scores among children with ADHD

and neurotypical children regarding controlled cognitive functions improved with HEG neurofeedback, and the effects of the intervention were maintained at one-month naturalistic follow-up (physical activity training did not affect scores). Intrinsic motivation, internal locus of control, and positive mood were found to be significant predictors of gain in HEG neurofeedback. The data obtained indicate that HEG neurofeedback may be an effective method to treat symptoms of ADHD and cognitive development in neurotypical children. The purpose of the fourth study was to evaluate the effect of placebo expectation on gain in HEG neurofeedback. Individuals (33 children with ADHD aged 9–14) were assigned to one of two groups (standard active training instruction or placebo-related instruction) and subjected to five HEG neurofeedback sessions. Children with standard instruction exhibited a higher increase in $rCBO_2$ at the PFC during the session, as well as better results in cognitive tests (vigilance and visual search) at the end of the experiment compared to children with placebo-related instruction. The data obtained highlight the difficulty in designing studies that evaluate the efficacy of neurofeedback, as the expectation of placebo may negatively affect treatment outcomes in children with ADHD. The purpose of the fifth study was to evaluate the effects of HEG neurofeedback with VR on vigilance and divided attention in children with ADHD. Participants (87 children aged 9–15) were assigned to one of three groups (standard HEG neurofeedback in the laboratory, VR HEG neurofeedback with limited visual scene, VR HEG neurofeedback with complex visual scene) and subjected to ten training sessions. Children in VR groups exhibited better performance in cognitive tests following the experiment compared to children who participated in standard training. The data obtained suggest that VR HEG neurofeedback may have a more beneficial effect in treating attention deficits compared to standard laboratory training. It seems that the strong effects of VR HEG neurofeedback stem from the increased commitment and motivation of individuals, rather than from manipulation with regard to the complexity of the visual scene.

Keywords: ADHD, neurofeedback, biofeedback, cognitive deficits, hemoencephalography, near-infrared spectroscopy.