

Efficacy of a combined neurofeedback, biofeedback, and go/no-go training intervention for ADHD: a randomized controlled trial

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Introduction

There is a need for evidence-based non-pharmacological treatments for attention-deficit/hyperactivity disorder (ADHD)¹. EEG-based neurofeedback (NF) is a promising potential therapy, and several randomized controlled trials have found neurofeedback to reduce ADHD symptoms in children^{2,3}. Go/no-go training games may also improve attention and impulse-control in human subjects⁴.

NeuroPlus is a novel digital intervention that incorporates EEG neurofeedback, go/no-go training, and a novel motion/muscle biofeedback protocol aimed at reducing inattention, impulsivity, and hyperactivity in children with ADHD.

The NeuroPlus system is used at home without the need for clinician/adult supervision. It incorporates a wireless, dry EEG headset and adaptive game-like software that customizes a unique training program for each user.

A randomized, controlled trial was conducted to measure the efficacy of this system in reducing inattention, impulsivity, and hyperactivity in children with ADHD. To our knowledge, this is the first study to examine the effects of combining neurofeedback with go/no-go tasks and/or motion-biofeedback for ADHD. It is also the first study to look at a neurofeedback intervention in an unsupervised home environment.

Methods

A total $n = 57$ ADHD subjects ages 8-13 were randomized to either a NeuroPlus treatment group (NP) or a treatment as usual (TAU) control group.

The NP group completed 30 minutes of training, 3 times per week, for 10 weeks. Subjects wore an EEG headband with an embedded accelerometer and were given feedback on their brain activity, muscle tension, and body movement through a game-based computer program, *NeuroPlus: Axon*.

- Subjects were rewarded for amplifying the ratio of EEG beta activity to theta activity through movement of a game avatar (neurofeedback).
- Subjects were penalized for excessive body movement or muscle tension through point deductions and other penalties (biofeedback).
- Subjects were also asked to respond rapidly with a button press to target stimuli and ignore similar distractor stimuli (go/no-go training).

The TAU control subjects maintained their existing treatment regimen, keeping medication use, therapy sessions, and other treatments consistent during the 10 week study period.

Conners 3-Parent and Quotient ADHD System assessments were completed at a baseline visit at Week 1 and at a follow-up visit at Week 12.

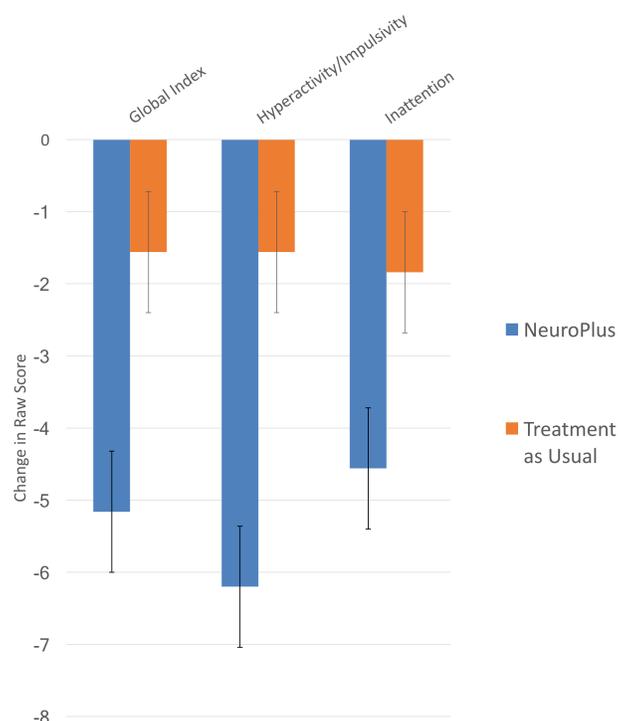
Results

Week 1 and Week 12 assessment data from $n = 50$ subjects were analyzed, after 7 subjects were lost to follow-up or withdrew before completing any training. A two-sample t-test was used to discern significance of differences in average values between the groups. An alternative analysis (ANCOVA) was also performed and found comparable results to the above.

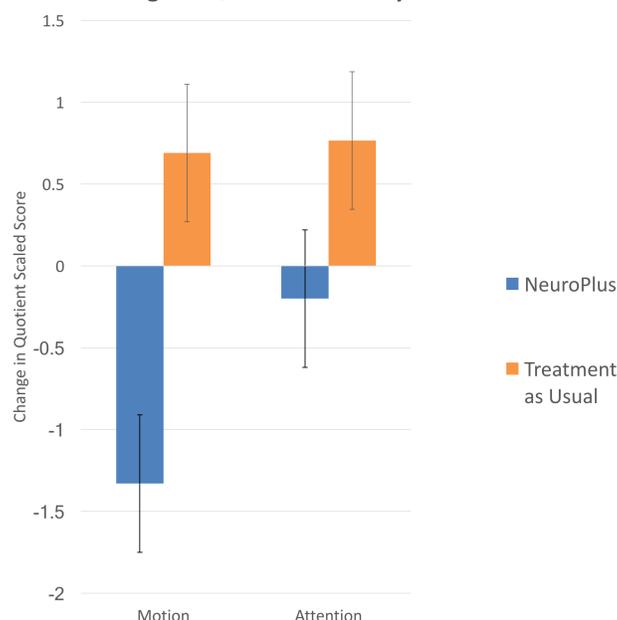
Subjects undergoing NP treatment significantly improved relative to TAU controls in all assessments, with particularly large improvements seen in the Conners Global Index ($p = .004$, Cohen's $d = .85$), Conners Hyperactivity/Impulsivity ($p = .002$, Cohen's $d = .94$), and Quotient Motion ($p = .026$, Cohen's $d = 1.12$).

Results are summarized in graphs below and Table 1.

Change in Conners 3-Parent Raw Scores



Change in Quotient ADHD System Scores



p-values **Cohen's d**

Conners 3-Parent

| | | |
|---------------------------|-------|------|
| Conners Global Index | 0.004 | 0.85 |
| Inattention | 0.026 | 0.65 |
| Hyperactivity/Impulsivity | 0.002 | 0.94 |

Table 1

Quotient ADHD System

| | | |
|-----------|-------|------|
| Motion | 0.026 | 1.12 |
| Attention | 0.002 | 0.45 |

Discussion

Participants receiving the combined neurofeedback, biofeedback, and go/no go training intervention showed significant improvements in symptoms of inattention, hyperactivity, and impulsivity, relative to those continuing current treatment. Improvements were significant for both the parent-reported Conners-3 measures and the objective Quotient ADHD System.

Future studies should investigate whether these improvements are maintained long-term, and should introduce a comparator game to control for non-specific training effects.

Since subjects completed the training without adult supervision, there were several instances of improper use of the equipment and deliberate poor performance on training tasks. Enforcing proper training via improved automated monitoring and in-game feedback and/or parent notifications may result in larger reductions in ADHD symptoms and will be implemented for future research.

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