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Behavioral and Neural Enhancing Effects of a Summer Treatment Program in Children with Attention Deficit Hyperactivity Disorder

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Abstract

Deficiency in executive functioning is a core symptom of attention deficit hyperactivity disorder (ADHD). The brain part responsible for executive functions is the prefrontal cortex (PFC). Although drug-based interventions can improve PFC activity, reports on PFC activity being improved by behavioral treatment are lacking. We evaluated whether a summer treatment program (STP) administering comprehensive behavioral treatment would increase PFC activity in children with ADHD. We examined behavioral and neural changes in 20 children before and after the STP, conducted over a 2-week period. We asked the parents/guardians to complete the Swanson, Nolan, and Pelham IV scale to assess severity of ADHD. The main task evaluating executive control was the reverse Stroop task. To examine changes in physiological indices, we used near-infrared spectroscopy to measure changes in PFC activity. Subjective assessments by parents/guardians indicated that ADHD symptoms improved significantly. There was also significant improvement in the number of correct responses and interference rates in the reverse Stroop task. Furthermore, post-intervention PFC activity was significantly higher. These results suggest that the STP improved inhibitory control in executive function, which is considered as a key symptom of ADHD. The increase in PFC activity further suggests that the STP improves cognition through neural function.

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Keywords

Attention Deficit Hyperactivity Disorder (ADHD), Inhibitory Control, Prefrontal Cortex, Behavioral Treatment, Reverse Stroop Task, Near-Infrared Spectroscopy

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neuro-developmental disorder whose main symptoms are inattention, hyperactivity, and impulsivity [1]. It has been argued that the core symptom of ADHD is deficiency in executive functioning [2] [3], in which the prefrontal cortex (PFC) has a significant role [4]-[8]. Moreover, secondary disorders, such as personality disorders, tend to occur if there is no timely intervention to address the core symptom of ADHD; therefore, early identification and treatment is critical [9]-[11].

Interventions for ADHD primarily involve medication, behavioral modification treatment, and more recently, neurofeedback. Medication is reported to improve behavior and increase PFC activity [12]-[17]. Behavioral treatment, however, has the advantage that it has no side effects and can be administered relatively safely to children [18]. However, although behavioral treatment reportedly improves behavior, there are few reports on its efficacy in improving neural function. Given that behavioral treatment is useful in early intervention, there is a need to clarify its impact on the PFC, which is deeply related to the core symptom of ADHD.

This study examined the neural and behavioral effects of a behavioral treatment program on PFC activity. We focused on the 2-week Kurume summer treatment program (STP), which was based on Pelham's American STP, administered to children with ADHD every year in Kurume City, Fukuoka, Japan. The Kurume STP provides children with ADHD with a summer camp experience that focuses on improving behavior, motor abilities, and social skills [19]. During the program, behavioral treatment is administered to help the children control their inattention, hyperactivity, and impulsivity, and to learn appropriate behavior [13] [14] [20] [21]. Emphasis is placed on controlling behavior and improving sociability through a point system, daily report card, and group work [13] [14]. To determine from a behavioral and neurofunctional perspective how the ADHD core symptom (PFC syndrome) changes between pre- and post-intervention, we used a reverse Stroop task (RST), which assessed inhibitory control. The RST is widely used as an interference control task, which involves executive function regulated primarily by the PFC [22]-[25]. In a previous study that compared children with ADHD with typically developing children, it was found that RST results reflected the particular characteristics of ADHD, suggesting that it is highly useful as an objective index in intervention studies [3].

2. Material and Methods

2.1. Participants

We recruited children with ADHD who took part in the STP in 2013 and 2014. All of them were born in Fukuoka or Saga prefecture, Japan. ADHD diagnosis was provided by a pediatric neurologist specializing in developmental disorders, and was based on the Diagnostic and Statistical Manual of Mental Disorders Fourth Edition, Text Revised and Fifth Edition (DSM-IV-TR and 5) [1]. Each of the children scored more than 80 on the full intelligence quotient of the Wechsler Intelligence Scale for Children-III (WISC-III) or the WISC-IV [26]. After excluding children for whom the task could not be implemented satisfactorily or whose artifacts were very large (>2 standard deviations), 20 children remained (mean age: 9.72 years old; male children: 17; see **Table 1**). Of these participants, 14 were receiving medication before the intervention, and the same number were receiving medication after intervention. All the participants and their guardians provided written informed consent before the experiment. The protocol was approved by the Ethics Committee of the National Center of Neurology and Psychiatry and Kurume University School of Medicine. The assessments were carried out in accordance with the approved guidelines.

2.2. Psychological Examination

To assess non-verbal intelligence, we administered Raven's Colored Progressive Matrices pre- and post- intervention. To assess reading comprehension, we administered the reading comprehension subtest of the Kaufman

Table 1. Participants' scores on behavioral tests.

	Pre-intervention (n = 20)	Post-intervention (n = 20)	*t* value (*df* = 19)	*p* value
Age	9.72 (1.27)	9.89 (1.27)		
Non-verbal intelligence	27.35 (3.62)	28.45 (5.54)	1.37	0.186
Reading comprehension	17.90 (4.52)	18.30 (4.32)	0.801	0.433
Inattention	16.50 (5.61)	12.85 (5.83)	5.45	<0.001
Hyperactivity /impulsivity	10.00 (6.32)	7.50 (6.17)	3.58	0.002
ODD	9.50 (5.58)	6.90 (5.51)	4.37	<0.001

Mean values of clinical scales. Standard deviations are shown in parentheses.
ODD = Oppositional defiant disorder.

Assessment Battery for Children (K-ABC) pre- and post-intervention [3] [27].

2.3. Rating Scale

To determine the correlation between age and ADHD severity, we asked all the children's parents/guardians to complete the Swanson, Nolan, and Pelham IV scale (SNAP-IV) [28]. The SNAP is a version of the DSM-based ADHD-Rating Scale that includes items for measuring oppositional defiant disorder (ODD).

2.4. Inhibitory Control Task

We administered the RST, which employs color reading interference control as a behavioral index, and measured the interference rate. The procedures for the task and analysis were in accordance with the protocols of Yasumura *et al.* [3]. The participants sat approximately 50 cm in front of a 38-cm (15-inch) liquid crystal display screen with a gray background. The tasks employed a touch panel screen. All words on the screen were displayed in Japanese.

2.5. Recording and Analysis

While the participants performed the RST, neural activity in the PFC was recorded by measuring changes in oxygenated hemoglobin (oxy-Hb) using a multichannel near-infrared spectroscopy (NIRS) system (OEG-16; Spectratech Inc., Tokyo, Japan). The tasks, as well as the procedures for the analysis, were in accordance with the protocols of Yasumura *et al.* [3]. In this system, near-infrared laser diodes with two wavelengths (approximately 770 and 840 nm) were used to emit near-infrared light. The re-emitted light was detected with avalanche photodiodes located 30 mm from the emitters. The temporal resolution of acquisition was 0.65 s. The system measures oxy-Hb at a depth of approximately 30 mm below the scalp. In our system, six emitters and six detectors were placed at alternate points on a 2×6 grid, enabling us to detect signals from 16 channels (**Figure 1**). The center of the probe matrix was placed on Fpz (international 10 - 10 system), and the bottom left and bottom right corners were located around F7 and F8, respectively, following a previous report [3] [29]-[31]. The NIRS signals were sent to a data collection computer. To increase the signal-to-noise ratio, each record was converted to a z-score to compare traces across the participants and channels [32]-[34]. For the analysis, we conducted paired t-tests on the pre- and post-intervention results as behavioral and physiological indices. The level chosen for alpha was 0.05.

3. Results

3.1. Psychological Examination

We did not observe any significant difference in non-verbal intelligence or reading ability between pre- and

post-intervention (t(19) = 1.37, p = 0.19; K-ABC: t(19) = 0.80, p = 0.43).

3.2. Rating Scale

There was significant improvement from pre- to post-intervention in the SNAP subscales of inattention, hyperactivity/impulsivity, and ODD (inattention: t(19) = 5.45, p < 0.001; hyperactivity/impulsivity: t(19) = 3.58, p = 0.002; ODD: t(19) = 4.37, p < 0.001; see **Table 1**).

3.3. Behavior

Regarding the RST results, there was no significant difference in the number of correct responses under the non-incongruent (neutral stimuli) condition. However, under the interference (incongruent stimuli) condition, there was significant improvement between pre- and post-intervention (neutral: t(19) = 0.15, p = 0.88; incongruent: t(19) = 2.11, p = 0.049). There was also a significant improvement in interference rate between pre- and post-intervention (t(19) = 2.16, p = 0.044; **Figure 2** and **Figure 3**).
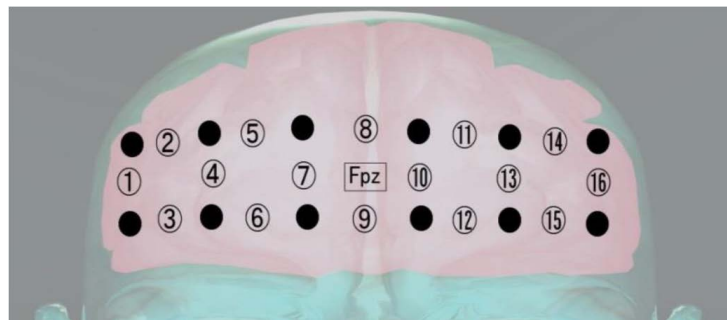

Figure 1. Emitter and probe configuration for the NIRS. The NIRS system was attached to the prefrontal area. The center of the probe matrix was placed on Fpz (International 10 - 10 system).
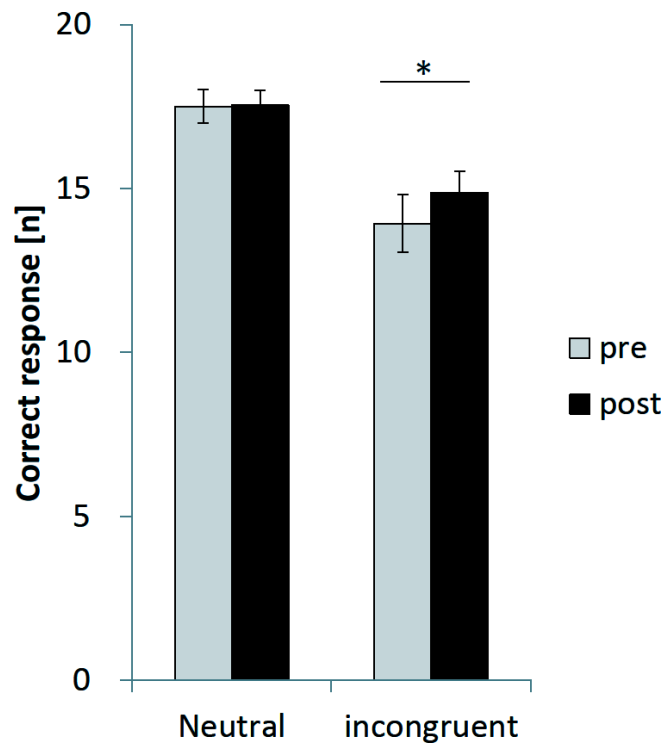

Figure 2. Behavioral results of the reverse-Stroop test. The number of correct responses for each condition during the task. Error bars indicate standard errors. *p < 0.05.
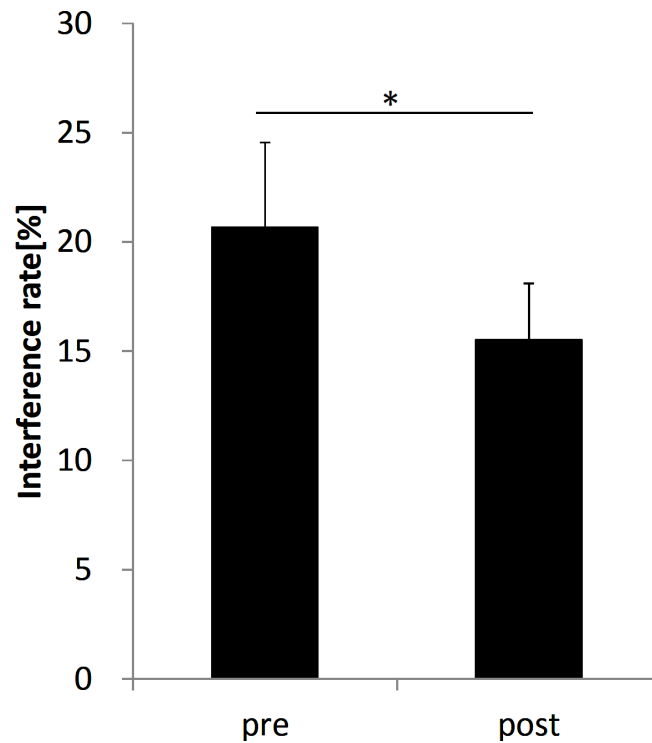
Figure 3. Behavioral results of the reverse-Stroop test. The interference rate for pre- and post-intervention during the task. Error bars indicate standard errors. *p < 0.05.

3.4. Brain Function

We compared each channel pre- and post-intervention and found that activity in the left PFC channel 13 increased significantly (ch13: $t(19) = 2.16$, $p < 0.044$). We also observed a trend for improvement in the right PFC channel 2 (ch2: $t(19) = 1.94$, $p = 0.067$; see **Figure 4**). The other channels did not yield significant changes ($p > 0.1$).

4. Discussion

4.1. Rating Scale

All the SNAP items—inattention, hyperactivity/impulsivity, and ODD—showed an improvement post-intervention. Subjective assessments by parents/guardians indicated that ADHD symptoms improved significantly. Hyperactivity/impulsivity and ODD improved to below their respective cutoff scores of 9 and 8. However, inattention remained approximately 4 points above the cutoff even after intervention, showing inadequate improvement. Given that the scores for hyperactivity/impulsivity and ODD were around 1 point above the cutoff before intervention, the above results were probably due to the presence of participants whose predominant symptom was inattention. Indeed, inattention decreased by around 4 points, making it the symptom that improved the most. Moreover, as inattention is more likely to persist into adulthood than is hyperactivity/impulsivity, the fact that inattention decreased significantly after the program demonstrated the efficacy of the intervention [10] [35].

4.2. Behavior

Regarding the number of correct responses for the RST, we did not observe any improvement between pre- and post-intervention under the non-incongruent/neutral condition; however, we observed a significant improvement between pre- and post-intervention under the incongruent condition. We also observed a significant improvement in interference rates between pre- and post-intervention. This finding suggests that the interference rate in the RST has a particularly close association with the core factor of ADHD—inhibitory control [3] [24] [36]. It should be noted, however, that we did not observe any pre- or post-intervention changes in non-verbal intelli-
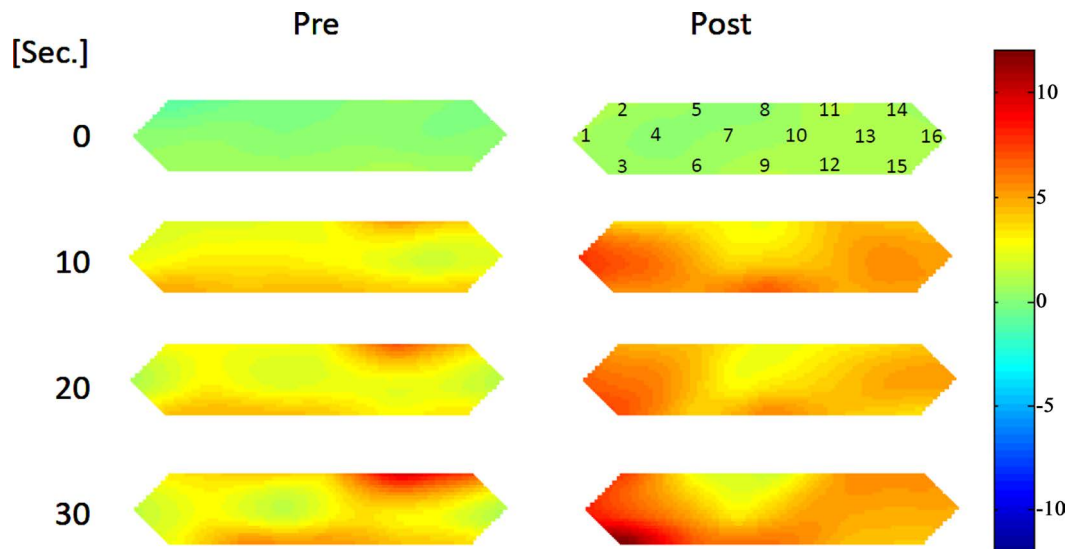
Figure 4. Mean z-score changes in oxygenated hemoglobin (oxy-Hb) measured by near-infrared spectroscopy during the reverse Stroop task. Pseudocolor images plot regional changes in oxy-Hb for pre- and post-intervention during the task. Values on the first row of the first image indicate the channel locations.

gence or reading comprehension. In light of these results, we surmise that interference control, as the core factor of ADHD, improved as a result of the intervention.

4.3. Brain Function

We compared PFC activity pre- and post-intervention and found that PFC activity in the left and right channels were improved after the STP. It has been reported that inhibitory control is strongly related to activity in the right PFC [37]. In the present study, the post-intervention brain topography revealed low activity in the right channels of the PFC. A previous study reported that the severity of the core ADHD symptom is negatively associated with activity in the right PFC [3] (**Figure 4**). The brain topography in the present study also revealed that PFC activity overall improved from pre-intervention, suggesting that the increase in PFC activity post-intervention reflected behavioral improvement, as measured by the inhibitory task (**Figure 4**). A recent study suggested that left PFC activity during an attention-demanding cognitive task was abnormal before treatment but normalized following behavioral treatment for chronic lower back pain [38]. Thus, improvement in the activation of the right and left PFC might be due to the behavioral treatment provided during the STP that, for instance, improved self-monitoring.

This is the first study to report that behavioral treatment improves PFC activity in children with ADHD [15] [16]. The assumption that PFC dysfunction is the core symptom of ADHD implies that neurotransmitters such as dopamine and norepinephrine have a key role [39]. This would also imply that behavioral treatment during the STP brought about a neurophysiological change. Future studies need to clarify connections with brain areas outside the PFC [7] [40]. In addition, another non-drug-based intervention—namely, neurofeedback—has come to be recognized as suitable for children with ADHD. Thus, there is also a need to compare the outcome of behavioral treatment with that of other non-drug-based interventions [12] [17].

5. Limitations

When assessing treatment outcomes, the influence of medication should be considered; however, in the present study, the number of children taking medication was the same pre- and post-intervention, suggesting that medication had a limited effect on the results. In addition, the assessment period was only 2 months long, so participants' development likely had minimal impact on the results [41]. Lastly, this study involved a comparison among a single group; thus, so it would be desirable to compare the results with typically developing children or verify the results with a crossover test. There is also a need to examine the long-term efficacy of the intervention.

6. Conclusion

We verified the efficacy of the 2-week Kurume STP by measuring changes in inhibitory control—an executive function—from a behavioral and physiological perspective. The results revealed improvements in behavior and PFC activity. These results provide neurological evidence for the efficacy of behavioral treatment that, unlike medication, has no concerning side effects.

Acknowledgments

Conflict of Interest

The authors declare that they have no conflict of interest.

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