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Brain Games as a Potential Nonpharmaceutical Alternative for the Treatment of ADHD

Stacy C. Wegrzyn
Kennesaw State University

Doug Hearrington
Augusta State University

Tim Martin and Adriane B. Randolph
Kennesaw State University

Abstract

*Attention deficit hyperactivity disorder (ADHD) is the most commonly diagnosed childhood neurobehavioral disorder, affecting approximately 5.5 million children, of which approximately 66% take ADHD medication daily. This study investigated a potential nonpharmaceutical alternative to address the academic engagement of 5th through 11th grade students (*n *= 10) diagnosed with ADHD. Participants were asked to play "brain games" for a minimum of 20 minutes each morning before school for 5 weeks. Engagement was measured at three points in time using electroencephalogram, parent and teacher reports, researcher observations, and participant self-reports. An analysis of the data supports the hypothesis that daily use of brain games can help strengthen focusing ability and executive functioning in adolescents with ADHD. The results provide hope for those searching for an alternative or supplement to medication as a means of helping students with ADHD engage in the classroom. (Keywords: ADHD, brain games, engagement, focus, executive functioning, EEG)*

Attention deficit hyperactivity disorder (ADHD) is the most commonly diagnosed childhood neurobehavioral disorder, affecting approximately 5.5 million children between the ages of 4 and 17 (CDC, 2010). Children with this disorder typically exhibit behaviors that are spurred by inattentiveness, hyperactivity, or a combination of both. Subtypes based on these characteristics are utilized in the diagnosis of those with ADHD. Although it is not considered a learning disability, the effects of ADHD can make learning more challenging for students (Samuels, 2005). As a result, approximately 66% of children diagnosed with ADHD take daily medication to treat the symptoms (CDC, 2010). Many of the medications available for the treatment of ADHD are of the stimulant variety. The theory behind these medications is that they adhere to important neurotransmitters, dopamine and norepinephrine, which are typically in short supply in students with ADHD. The medications then activate these neurotransmitters to stimulate the prefrontal cortex (Szegedy-Maszak, 2002). There is abundant research supporting the theory that ADHD is caused by dysfunction in this part of the brain (Barkley, 1997; Brennan & Arnsten, 2008; Dickstein, Bannon, Xavier Castellanos, & Milham, 2006; Dige & Wik, 2005). As a result, children with ADHD do not perform as well as controls in tests of their executive functions, which are the mental processes that control thinking, emotions, and behavior (Adler, Spencer, Stein, & Newcorn, 2008; Halperin & Schulz, 2006; Mares, McLuckie, Schwartz, & Saini, 2007). Unfortunately, 20% of childhood ADHD patients do not respond to stimulant medication (Fox, Tharp, & Fox, 2005) and are therefore in a constant search for alternative treatments.

One relatively new genre of research that is not highly recognized in the literature about ADHD is that of brain games. Based on the research of Ryuta Kawashima and associates (2005), which indicates that activities such as rapid mathematical calculations and reading aloud can increase activity in the prefrontal cortex, companies such as Nintendo have created a new line of brain games. For example, the Nintendo DS game Brain Age (NDSBA) allows users to participate in 10 different games that are modeled after those in Kawashima's studies (Crecente, 2006). Although Kawashima's studies showed the benefits of brain games in geriatric patients with dementia, there has been no published research in the area of using these games to help students with ADHD. However, based on the literature, it seemed feasible that playing brain games such as NDSBA could stimulate the prefrontal cortex of students with ADHD, simulating the effects of stimulant medication, thus helping these students improve their ability to engage in classroom activities and perform tasks of executive function.

We used the executive dysfunction framework (Johnson, Wiersema, & Kuntsi, 2009) and engagement versus disaffection framework (Skinner & Belmont, 1993) as guides for this study. The executive dysfunction framework is based on the premise that the symptoms of ADHD are caused by a reduced level of executive control, which is the ability of the brain to regulate cognitive, emotional, and behavioral processes (Johnson et al., 2009). According to this framework, the reduced level of executive control is caused by structural and chemical abnormalities in the prefrontal cortex of the brain. Executive functions are instrumental in focusing, switching focus, and dividing attention (Johnson et al., 2009). Students with a deficit in these areas find ignoring distractions difficult and managing learning strategies a struggle (Brown, 2009). This framework is therefore most suitable for studying symptoms of ADHD that are related to inattention and lack of focus (Johnson et al., 2009).

Engagement, as described by Skinner and Belmont (1993), involves both a student's behavior and his or her emotions. When comparing engagement to disaffection, the level of a student's intensity and emotion, associated with the initiation and fulfillment of a learning activity, should be evaluated. Through this lens, prolonged behavioral participation along with a positive emotional attitude is indicative of engagement. Conversely, students who are passive and show little effort are considered disaffected. Because this study ultimately sought to identify a strategy that would help students with ADHD maintain focus, and thus increase their achievement in the classroom, the engagement versus disaffection framework was the most suitable of those reviewed.

The purpose of this study was to add to the research on potential non-pharmaceutical alternatives for the treatment of ADHD. Since many have theorized that ADHD is caused by lack of activity in the prefrontal cortex of the brain (Abraham, Windmann, Siefen, Daum, & Gunturkun, 2006; Szegedy-Maszak, 2002), and studies have shown that brain games can stimulate and increase blood flow to this region (Kawashima et al., 2005), this study sought to determine if daily use of brain games such as NDSBA can increase classroom engagement of students with ADHD. To help determine if there was a relationship between the participants' use of brain games and their level of classroom engagement, the following six questions were addressed:

1. What effect does daily use of NDSBA have on theta/beta ratios of the ongoing electroencephalograms (EEG) of students with ADHD?
2. What effect does daily use of NDSBA have on self-reported engagement of students with ADHD, as measured by the Student's Achievement-Relevant Actions in the Classroom (SARAC), participant journals, and participant interviews?
3. What effect does daily use of NDSBA have on teacher-reported engagement of students with ADHD, as measured by the teacher-report component of the SARAC (TSARAC)?
4. What effect does daily use of NDSBA have on parent-reported observance of ADHD symptoms, as measured by parent questionnaires?
5. What effect does daily use of NDSBA have on researcher-observed engagement of students with ADHD?
6. What effect does daily use of NDSBA have on the executive functioning of students with ADHD, as measured by the Frontal Assessment Battery (FAB), Video/Question (VQ), and Read/Question (RQ)?

Methods

Participants

We chose the 10 participants for this study from a purposive sample of 5th through 11th grade students with ADHD whose parents had responded to an ad in the local newspaper. We reviewed the students' ADHD diagnoses and selected only those with ADHD, predominantly inattentive type or combined type. Five participants were taking stimulant ADHD medication at the time of the study. Table 1 (p. 110) illustrates the demographics of the participants.

Table 1. Participant Demographics

Participant	Gender	Age	Race	ADHD Type	Meds
Jane	F	16	Caucasian	Inattentive	No
John	M	12	Asian	Combined	No
Aaron	M	15	African American	Combined	Yes
Blake	M	12	African American	Combined	Yes
Caleb	M	10	Caucasian	Combined	Yes
Dante	M	13	Caucasian	Combined	Yes
Eli	M	12	Caucasian	Combined	Yes
Fynn	M	17	African American	Inattentive	No
Galen	M	10	African American	Inattentive	No
Hayden	M	16	Caucasian	Combined	No

Instrumentation

An EEG is a test in which electrodes are placed on the scalp to read the brain's electrical activity (Nemours, 2010). EEG is considered a reliable and valid source of brain activity data in many disciplines. As modern studies of ADHD diagnosis and symptoms have included EEG data, often looking at the theta/beta ratios of participants (Clarke, Barry, Bond, McCarthy, & Selikowitz, 2002; Clarke, Barry, McCarthy, & Selikowitz, 2002; Leins et al., 2007; Monastra, Lubar, & Linden, 2001), this study also included EEG as a means of data collection. For this study, we recorded EEG activity using BioSemi ActiveTwo equipment (BioSemi B.V., 2011). Using the International 10-20 system of electrode placement (Jasper, 1958), eight channels covering the frontal lobe of the brain were activated: Fp1, Fp2, F3, FZ, F4, C3, CZ, and C4. CMS was used as the ground. Because the ActiveTwo is a monopolar device, it does not have a reference. We therefore used common average reference. Low- and high-pass filter settings were 0.1 and 70 Hz, respectively, and the EEG sampling was set at 256 Hz. Impedance measurements were not necessary due to the fact that the ActiveTwo system has a preamplifier stage on the electrodes and can correct for high impedances in the range of 100 kΩ.

We recorded frontal beta and theta activity using BCI2000 software (Schalk et al., 2004). Beta waves are the fast, irregular brainwaves (12.5–25 HZ) (Clarke, Barry, McCarthy et al., 2002) associated with a state of mental or physical activity (Andreassi, 2000), which are often at decreased levels in children with ADHD (Loo & Barkley, 2005). Theta waves are the slow brainwaves (3.5–7.5 HZ) (Clarke, Barry, McCarthy et al., 2002) associated with a state of drowsiness (Andreassi, 2000), which are often more prevalent in children with ADHD (Cantor & Chabot, 2009; Clarke, Barry, McCarthy, et al., 2002; Dupuy, Clarke, Barry, McCarthy, & Selikowitz, 2011; Leins et al., 2007; Loo & Barkley, 2005). People with ADHD have also been found to have a higher theta/beta ratio than those without ADHD (Clarke, Barry, Bond, et al., 2002; Clarke, Barry, McCarthy, et al., 2002; Monastra et al., 2001). Since this study sought to evaluate the overall increase and decrease in theta and beta activity, we used theta/beta ratio.

The Student's Achievement-Relevant Actions in the Classroom (SARAC) is a student self-report of engagement versus disaffection (Skinner, Kindermann, & Furrer, 2009). We used this instrument, which is based on the engagement versus disaffection framework used in this study (Skinner & Belmont, 1993), to collect data on the participants' perceptions of their own engagement in the classroom. The SARAC consists of 20 statements such as, "In class, I work as hard as I can," which are rated using a 4-point Likert-type scale. We also used the teacher-report component (TSARAC), which mirrors the format of the student-report component.

Skinner et al. (2009) determined the validity of both the student-report and teacher-report components of the SARAC by involving 1,018 third through sixth graders in a 4-year longitudinal study about student motivation. Fifty-three of the students' teachers also participated in the study. The researchers used data from the fall and spring administrations of Year 3. When comparing engagement versus disaffection, correlations between student reports and teacher reports were significant in both the fall ($r = .41$, $p < .01$) and spring ($r = .42$, $p < .01$). Based on Cohen's effect size criteria (Cohen, 1992), these results suggest a medium to large relationship between student and teacher reports (r^2 values of .17 and .18 respectively), which strengthens the concurrent validity of the instruments. Correlation between the four components of the engagement versus disaffection framework showed that emotion and behavior were positively correlated (average $r = .60$, $p < .001$), whereas engagement and disaffection were negatively correlated (average $r = -.52$, $p < .001$). These relationships provide construct validity for the SARAC. For this study, the same researcher administered and evaluated the SARAC for all of the participants to eliminate any concern regarding inter-rater reliability.

Dubois, Slachevsky, Litvan, and Pillon (2000) created the Frontal Assessment Battery (FAB) to assess the functions of the frontal lobe of the brain to help diagnose executive dysfunction. Because we used the executive dysfunction framework (Johnson et al., 2009) in this study, we chose this instrument to help assess the participants' executive functioning. It consists of six verbal prompts that test a participant's conceptualization, mental flexibility, programming, sensitivity to interference, inhibitory control, and environmental autonomy.

Dubois et al. (2000) determined the reliability of the FAB by administering the FAB as well as the Mattis Dementia Rating Scale (DRS) and Mini-Mental State Examination (MMSE) to 121 patients with varying degrees of frontal lobe dysfunction and 42 controls with no neurologic or psychiatric history. The researchers also administered the Wisconsin Card Sorting Test (CST) to 86 of the participants with frontal lobe dysfunction. They found a correlation between the FAB and DRS scores in 121 patients ($r = 0.82$, p

< 0.001). Based on Cohen's effect size criteria (Cohen, 1992), these results suggest a medium to large relationship between student and teacher reports (r^2 values of .17 and .18 respectively). The DRS scores and number of criteria achieved in the CST also accounted for 79% of variance in the FAB, $F(2,82) = 152.9$; $p < 0.001$; $r^2 = 0.79$. These results helped establish concurrent validity. An ANCOVA showed that the FAB discriminated between controls and patients after adjusting for age as a covariate, $F(1,131) = 17.24$; $p < 0.001$ (Dubois et al., 2000). Additionally, the FAB showed considerable inter-rater reliability based on the comparison of results from two independent evaluators, for a subset of 17 patients ($k = 0.87$, $p < 0.001$). The Cronbach's coefficient alpha between the items of the FAB of 121 patients was 0.78, which suggests good internal consistency.

To elicit information regarding the participants' focus and behavior at school, participants kept a daily electronic journal for the duration of the study. We designed prompts, such as, "How did you feel about school during school today? (i.e. enthusiastic, bored, interested, disinterested, satisfied, angry, etc.)," based on Skinner and Belmont's engagement versus disaffection framework (1993), and participants used these to guide their writing. To eliminate any concern regarding inter-rater reliability, the same researcher evaluated all of the journal entries. As an additional guard against bias, the other three researchers reviewed the interpretations.

At the pretreatment session, participants completed a Participant Pre-session Questionnaire so that we could collect data about outside factors, such as caffeine consumption and physical activity, which might affect their mental processing and focus. We interviewed participants during the post-treatment and follow-up sessions. Interview questions were primarily directed at determining whether or not the participants had followed the protocol of the study, and whether or not they could tell a difference in their school performance or ability to focus during the treatment and follow-up periods. To eliminate concern about inter-rater reliability, the same researcher conducted all interviews and evaluated all questionnaire and interview responses. To further guard against bias, the remaining researchers from this study reviewed the interpretations. When possible, participants were asked directly about the researcher's interpretations in order to increase the trustworthiness of the data.

Parents completed a pretreatment questionnaire to gather historical information regarding the participant's experience with ADHD. The survey requested information such as when they were diagnosed and what treatments they had used up to that point. Additionally, the parents completed post-treatment and end-of-study questionnaires. Prompts on these questionnaires were largely intended to elicit parental views on how well their children had followed the protocols of the study and whether or not they had seen any difference in their ability to focus or perform at school. The same researcher evaluated all parent questionnaires to eliminate any concern regarding inter-rater reliability. The other researchers confirmed interpretations to further guard against bias. To increase the trustworthiness of the data, when possible, the reserachers asked parents directly about the researcher's interpretations.

During all three sessions, a researcher recorded any observance of the indicators of engagement and disaffection using a checklist based on Skinner and Belmont's engagement versus disaffection framework (1993). The researcher also recorded general field notes. The inclusion of researcher data added to the trustworthiness of the data from participant journal entries and interview responses. To reduce concern about inter-rater reliability, the same researcher utilized the checklist and recorded field notes throughout the study. The other researchers validated interpretations of this data to help minimize bias.

During the EEG sessions, participants watched two 4-minute segments from *The Voyage of the Mimi* (Bank Street College of Education, 1984), which was an educational television series that many states used in the 1980s as part of the middle school science curriculum. We chose this video because its age and lack of current usage seemed to increase the likelihood that participants had not previously viewed it. Participants also read two short selections from *Incredible Animal Adventures* (George, 1999), a book of nonfictional short stories written for a sixth grade reading level. We followed each of the four tasks with a series of five questions. We used scores from these tasks as an indicator of executive function, as they showed participants' ability to focus on details, switch tasks, and tune out distractions. Allowing the same researcher to evaluate all question responses eliminated any concern regarding inter-rater reliability.

We retrieved the following data from the NDSBA device of each participant: dates Brain Age was played, number of days at least three games were played, and how many times each individual game was played during the treatment period. We used data collected from the participants' Nintendo DS units to confirm or refute the information provided in the individual participant journals and interviews.

Procedure

During each lab session, participants completed two sets of tasks while connected to the EEG. For one set of tasks, participants watched a video while the EEG was collecting data. Then the EEG and video were paused, and we gave them five questions to answer about the video. The EEG and video were resumed, and a researcher provided extraneous stimuli in the form of a pen clicking or other common classroom sounds. The purpose of adding the distraction for the second half of the activity was to evaluate the participants' ability to tune out distractions and see if there was any EEG evidence of the distraction. We again paused the EEG and video and gave the participants five questions to answer about the second half of the video. We collected

EEG data only during the actual viewing of the video, not during the answering of the questions. The purpose of the question and answer check was to ensure that participants were actually paying attention to the video and hopefully attending closely enough to answer questions about what they saw. For the remainder of this study, this set of activities will be referred to as Video/Question (VQ).

The second set of activities was completed in the same manner as the VQ, except that instead of watching a video, the participants read short stories. For the remainder of this study, this set of activities will be referred to as Read/Question (RQ).

In addition to the EEG and VQ/RQ data, during the pretreatment lab, we collected session data in the form of researcher observations as well as administration of the FAB, SARAC, participant presession questionnaire, and parent pretreatment questionnaire. At the end of the first session, we assigned participants a Nintendo DS unit and a copy of the Brain Age software (Nintendo, 2005) and instructed them how to use it. This software includes a combination of computation, reading, and memory games. We asked them to play a minimum of 20 minutes each morning before school but told them they could play longer if they noted it in their daily journal. Treatment continued for 5 weeks.

During the post-treatment lab session, we collected data in the form of researcher observations and from administration of the FAB, SARAC, EEG, participant post-treatment interview, parent post-treatment questionnaire, and VQ/RQ. We also collected pretreatment and post-treatment TSARAC forms from participants. At the close of the session, participants returned their Nintendo DS unit and Brain Age software to us. We asked that they not play any kind of brain game during the next three weeks, which included spring break and two weeks of school. We retrieved usage data from the units during the three weeks that the participants did not have them. This allowed us to verify the frequency and duration of utilization.

During the follow-up lab session, we collected data in the form of researcher observations and from administration of the SARAC, EEG, participant follow-up interview, parent follow-up questionnaire, and VQ/RQ. We also collected follow-up TSARAC forms. We collected supplementary data during the treatment and post-treatment periods in the form of participant journals, which the participants submitted to us at the follow-up lab session. Before leaving, we gave each participant his or her Nintendo DS unit and Brain Age software to keep.

Analysis

For analysis of the quantitative data, we used MATLAB (MathWorks, 2009) and SPSS (IBM, 2008). We exported the EEG data from the BCI2000 software (Schalk et al., 2004) in ASCII format. We completed

Table 2. Effect Size Criteria for Comparing Two Means (adapted from Huck, 2008, p. 246)

Effect Size Measure	Small	Medium	Large
Cohen's *d* (*d*)	.20	.50	.80
Partial eta squared ($\eta^2 p$)	.01	.06	.14

a fast Fourier transform (FFT) in MATLAB to establish pretreatment, post-treatment, and follow-up theta and beta levels for each of the 12 activities that each participant completed. We computed theta/beta ratios in SPSS and analyzed them with a repeated-measures ANOVA. We used a multivariate approach to repeated measures (Maxwell & Delaney, 2000) as well as a priori test of within-subjects contrasts, with Bonferroni corrected $\alpha = 0.025$.

Each participant had pretreatment and post-treatment FAB scores of 0–18. We ran a paired samples *t*-test in SPSS to determine if there was a significant difference between these scores across participants.

Because the statements of the SARAC are presented in both positive and negative formats, the scoring required an extra step. We coded positive statements, representing behavioral and emotional engagement, from 1 through 4. We reverse-coded negative statements, representing behavioral and emotional disaffection, from 4 through 1. Each participant had pretreatment, post-treatment, and follow-up SARAC scores of 20–80. We ran a repeated-measures ANOVA in SPSS to determine if there was a significant difference between these scores across participants. We completed scoring of the TSARAC in the same manner as the student SARAC.

We scored the five video questions and five reading questions (VQ/RQ) from each session. This elicited a participant VQ/RQ total of 0–10 points for each session. We ran a repeated-measures ANOVA in SPSS to determine if there was a significant difference in pretreatment, post-treatment, and follow-up VQ/RQ scores across participants. We also ran a post hoc pairwise comparison because the ANOVA indicated significance ($p <. 05$).

We used an alpha level of .05 to determine the significance of all *t*-tests and ANOVAs. In addition to significance values and test statistics, we calculated and reported effect sizes for each statistically significant result. We calculated Cohen's *d* (*d*) for the significant *t*-test results and calculated partial eta squared ($\eta^2 p$) for the significant ANOVA results. Table 2 illustrates the criteria for determining the strength of effect sizes.

We used a variety of methods to analyze the qualitative data for this study. Because we were using the engagement versus disaffection framework, the primary analytical categories were already established. For this reason, we analyzed student journal entries through deductive reasoning (Marshall & Rossman, 2006) by organizing them in a chart based on the journal prompts and aggregating data regarding participants' feelings and behaviors while at school as well as factors affecting their engagement.

Table 3. Mean Scores and Standard Deviations for Pretreatment, Post-Treatment, and Follow-Up Sessions

	Pretreatment (n = 10)		Post-Treatment (n = 10)		Follow-Up (n = 10)	
Instrument	*M*	*SD*	*M*	*SD*	*M*	*SD*
SARAC	53.50	9.372	56.90	11.050	55.90	11.733
T-SARAC	51.30	7.558	53.00	8.511	52.10	8.672
FAB	14.80	2.936	16.40	2.011	n/a	n/a
Theta/Beta*	7.829	1.511	5.754	0.455	7.749	1.142
VQ/RQ	10.70	2.003	14.40	3.340	14.70	2.214

Note. *Theta/beta ratio is calculated by dividing the power of the theta band by the power of the beta band. Decreased theta/beta ratio indicates a more alert and focused mental state.

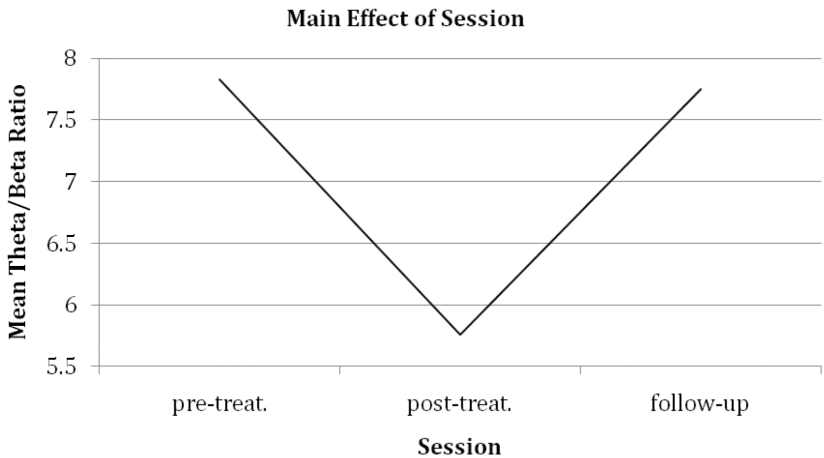

Figure 1. An ANOVA of the theta/beta ratios indicated a significant effect of session, $F(2,8) = 5.275$, $p = .035$, $\eta^2 p = 569$. The mean theta/beta ratio of the post-treatment session was significantly lower than the pretreatment and follow-up mean theta/beta ratios.

We used deductive analysis to analyze the data from participant post-treatment and follow-up interviews by organizing them in a chart separating data by session. We used a manual highlighting system to code information and find patterns regarding participants' feelings and behaviors while at school as well as factors affecting engagement. We used direct interpretation to analyze any data that was outside of the categories stipulated by the engagement versus disaffection framework.

We used inductive reasoning (Marshall & Rossman, 2006) and direct interpretation (Stake, 1995) in the analysis of the parent pretreatment, post-treatment, and follow-up questionnaires, as well as the researcher observations and participant pretreatment questionnaires. We aggregated all of this data in a chart separating information by data collection instrument and lab session. This process is similar to that used in grounded theory (Strauss & Corbin, 1990).

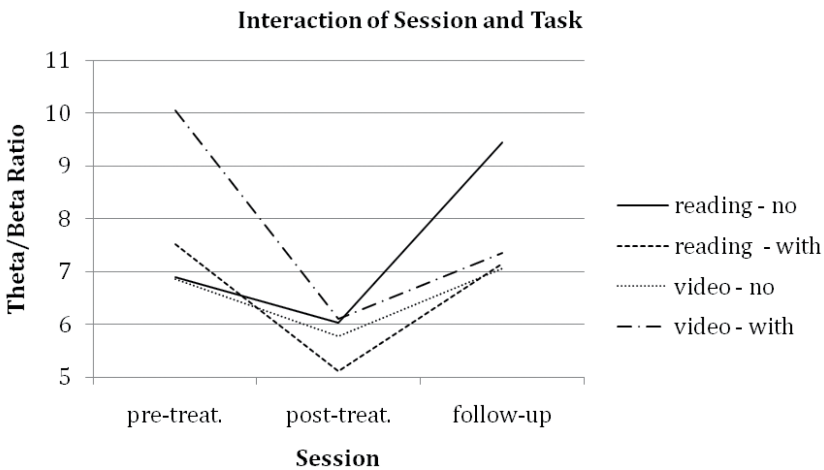

Figure 2. An ANOVA of the theta/beta ratios indicated a significant interaction between session and task, $F(6,4) = 10.405$; $p = .020$; $\eta^2 p = .940$. All of the tasks followed the same pattern of decreased mean theta/beta ratio at the post-treatment session and increased mean theta/beta ratio at the follow-up session.

We organized data collected from the participants' Nintendo DS units in a chart that illustrated the number of times participants played each game and the average number of games they played each day, among other details. We used this data to confirm or refute the information provided in the participant journals and interviews.

Results

Table 3 reports the mean scores and standard deviations for the five quantitative instruments used during this study. Data are presented for all three sessions.

Research Question 1

What effect does daily use of NDSBA have on theta/beta ratios of the ongoing EEG of students with ADHD? An ANOVA of the theta/beta ratios revealed there was a significant effect of session, $F(2,8) = 5.275$, $p = .035$, $\eta 2p = 569$, meaning that the mean theta/beta ratio of the post-treatment session was significantly lower than the pretreatment and follow-up mean theta/beta ratios. Figure 1 illustrates the relationship between session and theta/beta ratio.

There was also a significant interaction between session and task, $F(6,4) = 10.405$, $p = .020$, $\eta 2p = .940$, meaning that all of the tasks followed the same pattern of decreased mean theta/beta ratio at the post-treatment session, and increased mean theta/beta ratio at the follow-up session. Figure 2 shows this relationship.

Research Question Two

What effect does daily use of NDSBA have on self-reported engagement of students with ADHD? Findings from an ANOVA of the SARAC showed that

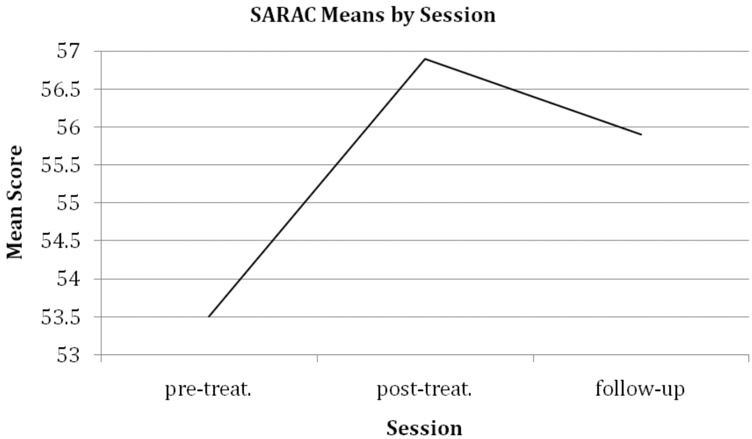

Figure 3. An ANOVA of the SARAC indicated there was not a significant effect of session, $F(2,18) = .932$, $p = .412$. The increase in mean scores from pretreatment to post-treatment was not significant.

there was not a significant effect of session, $F(2,18) = .932$, $p = .412$, meaning that the increase in the mean scores from pretreatment to post-treatment was not significant. Figure 3 shows mean SARAC scores by session.

Analysis of participant journals revealed that six of the nine participants who kept journals showed patterns of increased engagement during the treatment period and decreased engagement during the follow-up period. Two of the other participants tended to write negative comments about school throughout the study, whereas the remaining participant wrote mostly positive comments about school for the duration of the study.

During participant interviews, nine participants indicated that they had noticed a positive difference in their ability to focus, pay attention, concentrate, or engage in class during the treatment period. The follow-up interviews revealed that, since they had stopped playing the games, seven participants were less focused and having a harder time paying attention in class.

Research Question Three

What effect does daily use of NDSBA have on teacher-reported engagement of students with ADHD? Results from an ANOVA of the TSARAC showed that there was not a significant effect of session, $F(2,18) = .965$, $p = .40$, meaning that the increase in scores from pretreatment to post-treatment, and decrease in scores from post-treatment to follow-up were not significant. Figure 4 shows the mean TSARAC scores by session.

Research Question Four

What effect does daily use of NDSBA have on parent-reported observance of ADHD symptoms? Analysis of the parent questionnaires revealed that 9 out of 10 parents saw an improvement in one or more symptoms of their child's ADHD during the treatment period. Additionally, on the follow-

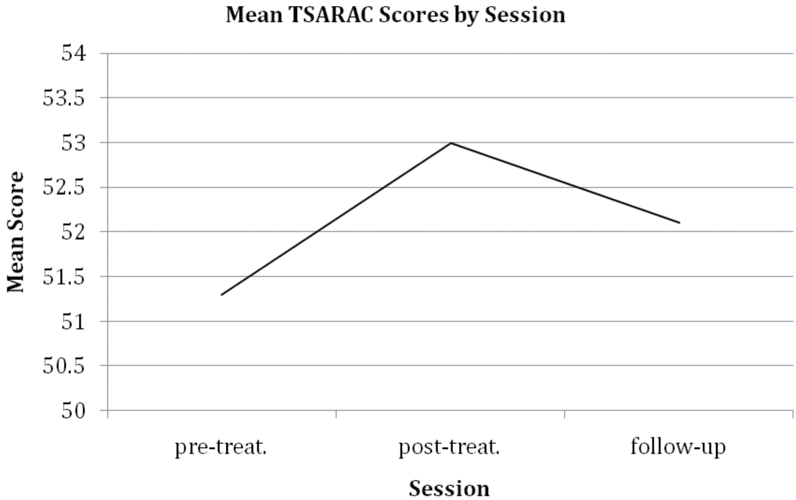

Figure 4. An ANOVA of the TSARAC indicated there was not a significant effect of session, $F(2,18) = .965$, $p = .40$. The increase in scores from pretreatment to post-treatment, and decrease in scores from post-treatment to follow-up were not significant.

Table 4. Researcher Observation Checklist Data

	Pretreatment			Post-Treatment			Follow-Up	
	Dis.	Eng.	Δ	Dis.	Eng.	Δ	Dis.	Eng.
Jane	3	1	6	0	4	--	0	4
John	6	1	4	2	1	4	0	3
Aaron	0	4	--	0	4	-1	0	3
Blake	1	2	2	1	4	--	1	4
Caleb	4	2	3	2	3	-1	2	2
Dante	4	1	1	3	1	-4	6	2
Eli	0	3	-1	1	3	-6	5	1
Fynn	1	1	3	1	4	-3	2	2
Galen	1	2	1	0	2	2	0	4
Hayden	0	3	--	0	3	-2	1	2
Total	20	20		10	29		17	27

Note. "Δ" represents the change in engagement between the two sessions on either side of the Δ column. Negative Δ numbers represent an overall decrease in engagement, increase in disaffection, or both. The opposite is true for positive Δ numbers.

up questionnaire, 8 out of 10 parents revealed that they had seen a negative change in one or more of their child's symptoms of ADHD since they had stopped treatment.

Research Question Five

What effect does daily use of NDSBA have on researcher-observed engagement of students with ADHD? Findings from the researcher observations (see Table 4) revealed four of the participants showed a large increase in

Table 5. Mean Scores and Standard Deviations for FAB Prompts

	Pretreatment (n = 10)		Post-treatment (n = 10)	
Prompt	M	SD	M	SD
Conceptualization	2.0	0.471	2.2	0.919
Mental flexibility	2.6	0.699	3.0	0.0
Programming	2.3	0.949	2.8	.0422
Sensitivity to interference	2.3	1.059	2.5	0.972
Inhibitory control	2.6	0.699	2.9	0.316
Environmental autonomy	3.0	0.0	3.0	0.0

engagement level from pretreatment to post-treatment, and three other participants showed a smaller increase. Additionally, two participants reported no change, and a negative change was observed in one. During the follow-up sessions, many indicators of engagement were still present. However, for some of the participants, the indicators of disaffection had increased.

Research Question Six

What effect does daily use of NDSBA have on the executive functioning of students with ADHD? A paired sample t-test of the FAB revealed that there was a significant increase in scores from pretreatment (M = 14.80, SD = 2.936) to post-treatment (M = 16.40, SD = 2.011), $t(9)$ = -2.516, p = .033, with a medium to large effect size (d = .67). Table 5 (p. 120) provides the means and standard deviations for each of the six prompts on the FAB.

An ANOVA of VQ/RQ scores revealed there was a significant effect of session, $F(2, 18) = 8.12$; p = .003; $\eta^2 p = .474$. A pairwise comparison with Bonferroni correction showed that the significant difference was between the scores for the pretreatment and follow-up sessions (p = .02). Figure 5 shows the Mean VQ/RQ scores by session.

Discussion

Abundant research supports the theory that ADHD is caused by dysfunction in the brain's prefrontal cortex (Barkley, 1997; Brennan & Arnsten, 2008; Dickstein et al., 2006; Dige & Wik, 2005), and a growing number of studies accredit brain games with the ability to stimulate this area of the brain (Crecente, 2006; Kawashima et al., 2005), which provided a strong scaffold for this study. However, until this study, the research tying these two variables together was remarkably scant and inconclusive. The objective of this study was to explore whether daily use of brain games such as NDSBA could increase the engagement of students with ADHD, thus providing a possible alternative or complement to medication for its treatment.

There was a significant decrease in the mean theta/beta ratio from pretreatment to post-treatment, which supports the hypothesis that post-treatment

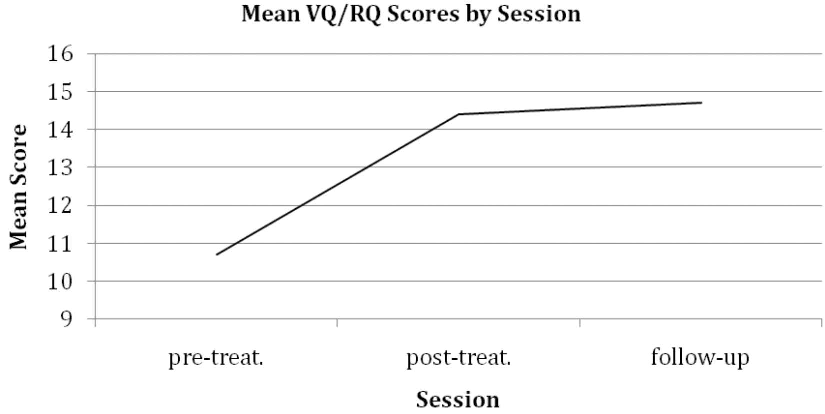

Figure 5. An ANOVA of VQ/RQ scores indicated there was a significant effect of session, $F(2, 18) = 8.12$, $p = .003$, $\eta^2 p = .474$. A pairwise comparison with Bonferroni correction showed that the significant difference was between the scores for the pretreatment and follow-up sessions ($p = .02$).

theta/beta ratios would be significantly lower than the pretreatment theta/beta ratios. Bear in mind that a decrease in theta/beta ratio suggests a more alert and focused mental state. Additionally, the ratios for all four activities followed the same pattern—a decrease at post-treatment and an increase at the follow-up—but to different degrees. These data strengthen the value of the results in that they indicate the improvement in theta/beta ratio did not discriminate by task. Furthermore, the mean theta/beta ratio decreased by 2.075 from pretreatment to post-treatment and then increased by 1.995 from post-treatment to follow-up, meaning that it had almost returned to the pretreatment level. An increased theta/beta ratio suggests a decrease in alertness and focus. This suggests that if there had been any residual effects from the brain game use, they had diminished greatly by the follow-up assessment, and that continued use of the brain games is most likely necessary for maintaining the benefits of their use.

Although the SARAC scores increased from pretreatment to post-treatment, and decreased from post-treatment to follow-up, neither one of these changes was significant. Considering the positive results of the qualitative instruments used for this research question, it is possible that the small sample size was at fault for lack of significance in SARAC scores. It should also be kept in mind that students' ability to accurately assess their own thinking and behavior varies (Assor & Connell, as cited in Chapman, 2003). Another downfall of the SARAC is that it provides a "snapshot" of a participant's feelings at one moment in time. If a participant happened to have had an exceptionally good or abnormally bad day at school on the day they completed the SARAC, it is possible that they could have been influenced to answer differently than they would have on just an average school day.

Out of the nine participant journals that were completed, six showed some sort of pattern or evidence of increased engagement from the pre-treatment to the post-treatment period and decreased engagement during the follow-up period. This supports the idea that sustained use of the brain games is most likely required for maintaining the benefits of their use. Although the overall consistency and thoroughness of the journal entries was less than desired, it appeared that the entries were honest. For instance, if they misbehaved, they confessed to their behavior in their journals. This assessment increased the trustworthiness of the entries.

During the post-treatment interviews, seven participants stated that they had noticed a positive difference in their ability to focus, pay attention, concentrate, or engage in class. Various participants also reported feeling more awake, better behaved in class, and/or more successful in math class. It is possible that the games helped students feel more confident in math class, as they allowed them to practice their basic math facts and skills on a regular basis. Only one participant stated that he did not notice any difference in his symptoms of ADHD during the treatment period.

During the follow-up interviews, seven participants indicated that, since they had stopped playing the games, they were less focused and having a harder time paying attention in class. Various participants also reported having worse classroom behavior, being more fidgety, feeling more bored, and/or seeing a drop in grades since stopping the treatment. This information supports the idea that for the benefits of brain games to be uninterrupted, game play must continue. Of particular interest to the researchers was the fact that four participants also indicated they felt they were getting angrier faster and more easily since stopping the games. Although this was not one of the foci of the study, it was fascinating, considering that a quick temper is sometimes associated with ADHD (Marcus & Mattiko, 2007). This finding suggests that perhaps the use of brain games can help treat symptoms of ADHD other than those specified in this study. The same participant who stated he did not notice any differences during the treatment period was also the only one who stated that he could not tell a difference after stopping the games.

Although the mean TSARAC was slightly higher than pretreatment at post-treatment and slightly lower than post-treatment at follow-up, a repeated-measures ANOVA indicated that the difference in scores was not significant. Two unfortunate factors were noted that could have had a negative effect on the results of this data. First of all, there was no TSARAC data for Blake and Fynn, who were the two participants who reported the greatest improvement during treatment, and greatest regression during the follow-up period. It is probable, considering the level of success noted by these participants and their parents, that their teachers would have observed a notable improvement as well. Additionally, for several of the remaining participants, there seemed to be a lack of effort on the part of the teachers to provide thoughtful responses. It is also possible that after 5 weeks of treatment, the participants were feeling a difference in their ability to focus, but that it was just not enough time for the improvement to carry over to the classroom.

Seven out of ten parents reported that, during the treatment period, their children had increased their grades or were generally doing better in school. Two more parents, although not specifically referencing school, stated that, during the treatment period, they had seen improvement in either their child's calmness or ability to focus and remember things. There is always the possibility that the parents felt obligated to provide some kind of positive results because of the time the researchers had put into this study. However, they were reminded to be honest in their responses. Only one parent indicated that she did not notice any change in her child's symptoms of ADHD. On the follow-up questionnaires, four parents reported a decrease in their child's school performance, or more specifically a drop in grades, since the treatment period had ended. Three parents indicated that their child's behavior had gotten worse, and two others stated that their child's organization was not as good. Two reported that their child seemed less focused. As mentioned in the discussion of the other methods, this pattern of increased engagement during the treatment period and regression during the follow-up period suggests that continuous benefits likely require continuous use of the games.

The researchers observed a large positive change from pretreatment to post-treatment in four of the participants and a smaller positive change in three more of them. It might be speculated that the participants' increased comfort with the researchers at the post-treatment session could have accounted for the increase in engagement. However, the fact that engagement decreased for six of the participants at the follow-up session suggests that it had more to do with the use of, and then the cessation of, the games.

A paired sample *t*-test of pretreatment and post-treatment FAB scores revealed a significant increase from one to the other. This suggests that the executive functioning of the participants was stronger during the post-treatment session. It is not likely that a practice effect was the reason for the increase in scores. With 5 weeks between administrations and no indication of pretreatment FAB results having been given to participants, it seems probable that this instrument legitimately helped evaluate their levels of executive functioning.

A pairwise analysis of ANOVA results revealed a significant increase in VQ/RQ scores from pretreatment to follow-up treatment. Although the post-treatment mean was higher than the pretreatment mean, the follow-up mean was even slightly higher. This suggests that there could have still been some residual effects from the treatment during the follow-up period or possibly that the brain was still adjusting in some way to the prior use of the games. These data support the findings of Kawashima and his team that brain games can help improve executive functions, which can be observed in the improved performance of cognitive tasks (2005).

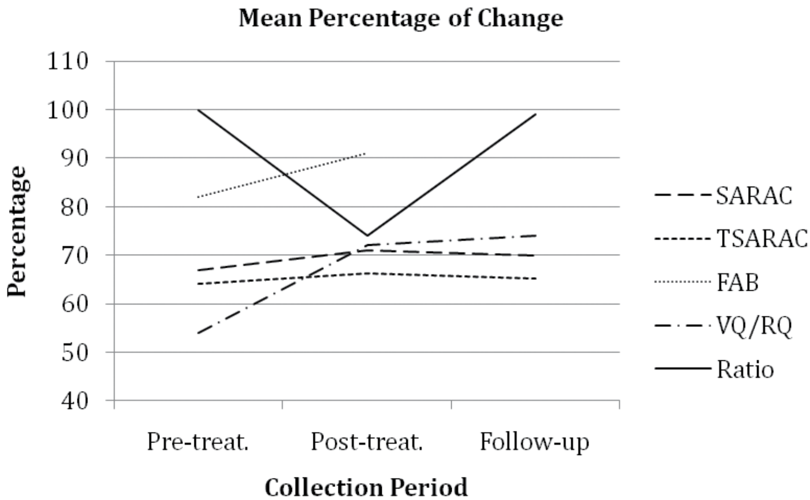

Figure 6. Results from all instruments showed a pattern of improvement from pretreatment to post-treatment. The theta/beta ratios as well as SARAC and TSARAC scores showed a pattern of regression from post-treatment to follow-up. Although the analyses from the SARAC and TSARAC did not indicate statistical significance, the cumulative pattern of data suggests that, for any benefit derived from the brain games to be uninterrupted, continuous use of the games is likely required.

Figure 6 summarizes the results of the study by depicting the pattern of participant engagement across multiple forms of assessment. The mean change in percentage of possible points scored for the SARAC, TSARAC, FAB, and VQ/RQ is illustrated. Additionally, the mean changes in post-treatment and follow-up theta/beta ratios are presented as percentages of the mean pretreatment ratio. Improvement from pretreatment to post-treatment was indicated by all five measures, but to varying degrees. Participant and parent reports also supported these data, adding credibility to the idea that brain games could be a potential alternative intervention for students with ADHD. Furthermore, along with participant and parent reports, theta/beta ratios indicated a decrease in alertness and focus at the follow-up session. This suggests that, for brain games to have a prolonged effect, they will likely need to be a part of a daily long-term regimen.

Implications for Practice

The findings of this study suggest that the use of brain games such as NDSBA could be a possible alternative, or complementary treatment, for ADHD. Specifically, this study focused on how these games affect the theta/beta ratio and related levels of classroom engagement and executive functioning of 5^{th} through 11^{th} grade students with primarily inattentive type or combined type ADHD. The overall results of this study suggest that, for the specified population, it is possible the use of brain games could help decrease theta/beta ratios, which can translate into increased engagement and improved executive functioning.

For parents of children with ADHD, this information suggests a potential nonpharmaceutical alternative to ADHD medication that is affordable. As with medication or any other treatment, not every child will see an improvement with the use of brain games. However, considering the high cost of medication and other alternative treatments, an approximate $80 for a used Nintendo DS unit and copy of the Brain Age software sounds like an option worth exploring. Others may wish to try NDSBA in addition to the medication their child is already taking. As one participant explained, he felt his medication took care of the big picture, whereas the brain games seemed to help with the little details.

Practitioners can reference the results of this study when providing parents with options for their children. Many parents prefer to try nonpharmaceutical treatments first, and this study gives practitioners a new method to suggest. Additionally, as children tend to be engaged by electronic formats that provide instantaneous feedback (Wegrzyn, 2008), this treatment would probably be more positively received by patients, and therefore parents, than many other options that are available at this time.

This form of treatment could also provide support for teachers. Brain games are a form of treatment that could be kept within the school or even within the classroom. Teachers could allow struggling students to play the games each morning during homeroom, lunchtime, or recess. Then they could evaluate the games' usefulness in increasing each student's ability to focus. Liability is not an issue, considering that, even if the games did not help the child's engagement, they would at least provide the educational benefit of practicing basic math facts, memorization, and reading skills.

Even though this study focused on a specific subset of those with ADHD, the absence of risks makes this a potential option for anyone with the disorder. Several of the mothers in the study said they were going to try playing the games themselves, even though they did not have ADHD. As some sort of positive outcome is practically inevitable, it is possible that brain games, as a form of treatment, could become one of the most favored forms of ADHD treatment available.

Limitations and Recommendations for Future Research

Data analysis revealed many significant findings in relation to the research questions. Although the overall results were supportive of the researchers' hypotheses, there are several limitations.

Improvements for the design of future studies. It is suggested that future research involve enough participants to have a control group, so that a more experimental design can be utilized. With a much larger number of participants, they could also be subcategorized by gender, age, type of ADHD, and medication status. The older participants in this study were able to articulate their feelings and observances much better than the younger ones, so it is advised that participants be in at least the seventh grade if self-report is going to be used in collecting data.

It is possible that after 5 weeks of treatment, the participants were feeling a difference in their ability to focus, but it was just not enough time for the improvement to carry over to the classroom. Researchers interested in conducting similar studies should consider using the 6-month timeline used by Kawashima and his associates (2005). Additionally, researchers should ask participants not to make any major changes, such as diet, physical activity, and mental activity other than the treatment, during the course of the study.

Another limitation to this study was the threat of hypothesis guessing (Trochim, 2006). In the future, measures should be taken to limit the information provided to participants to only that which is required by the International Review Board. Future studies should also be double blind so that researcher data collection and interaction with participants is minimized. This would help reduce any personal bias in the data analysis and formation of conclusions.

An ideal research design would allow the research team access to the participants while they were at school. It would be advisable to have a researcher administer the treatment to the participants each morning. This would increase the consistency of the treatment by eliminating external distractions and ensuring that the participants completed the treatment in the same manner, for the same length of time each day.

Because we did not follow the preceding suggestions for design in this particular study, generalizability of the findings is restricted. Therefore, we do not intend to generalize these findings or imply causality, but we believe that the findings do warrant further research in this area.

Improvements for the instrumentation of future studies. The thoughtfulness and detail of participant journal responses appeared to deteriorate over time. If this study had been 6 months in length, as in Kawashima's study (2005), the negative impact on journal entries would likely have been even more pronounced. If the suggested timeline of 6 months is used, it is probable that a weekly, rather than daily, journal entry would capture the needed information without causing an exorbitant amount of work for the participants. Another option would be to administer the SARAC every week or 2 weeks in lieu of a participant journal.

As most teachers do not have the time to observe the behaviors of individual students or fill out weekly reports about their behaviors, researcher observations of participants in their school settings would be extremely valuable. While at the schools, the researchers could also administer the SARAC to ensure that it was completed at specified intervals throughout the study.

In an ideal situation, funding would provide for an adequate research team and resources. Taking this into consideration, along with the recommendation for a 6-month study, we suggest that the number of EEG sessions be increased. They could be conducted once per week and involve a variety of activities, including closed-eye relaxation and playing NDSBA. This would allow researchers to better track any changes in theta/beta ratios.

New directions for related studies. There are many directions that new studies about brain game treatment for ADHD could take. Many of these would focus on the differences in the treatment's effect, based on the demographics of the participants. For instance, does the onset of puberty change the effects of brain game use? Would elementary school children, higher education students, or even older adults see a reduction in ADHD symptoms with the use of this treatment? Is this kind of treatment more helpful or less helpful for a particular age group, gender, ethnicity, or ADHD subtype? Do students without ADHD benefit from brain game use? Do those who have had some sort of head trauma respond differently to the treatment?

Another line of possible future studies revolves around the use of stimulant medication. Is brain game treatment less, more, or as effective for ADHD patients who take stimulant medication versus those who do not? One participant's mother reported that her son, who also has oppositional defiant disorder, appeared to have a resurgence of serious behavioral problems within 2 days of stopping the brain games. Based on this information, a future study could focus on whether the use, and then cessation, of brain games can cause withdrawal effects similar to those that can occur when stimulant use is terminated.

Other variables to consider in future studies are the time and frequency of use. For instance, do the games have to be played first thing in the morning to be helpful? A study comparing morning use only to morning and lunchtime use would provide more guidance as to the number of times the games should be played each day for the best possible results. Other questions that could be studied are: Is it necessary to play the games every day? What is the optimal length of play for each session? Does including weekend play improve the results? Do the treatment effects remain consistent over months or years of use?

As participants in this study seemed to favor some of the brain games over others, it would be helpful to know if certain types of games within the brain game genre are more effective than others. Are other forms of brain games, such as pencil and paper, as effective? Do results differ based on whether the games are played in a secluded location with no distraction, versus a more distracting location? Do those who choose to play of their own will see different results than those who are forced to play by their parents?

Conclusions

The findings of this study bridge the gap between prior research on the frontal lobe's connection to ADHD and the studies that have indicated brain games can stimulate this area of the brain. Based on the compilation of data, there is hope for ADHD patients searching for an alternative to medication. Data from seven of the nine instruments used in this study support the overarching hypothesis that daily use of brain games can help decrease the theta/beta ratio of those with ADHD while improving their ability to focus and strengthening their executive functioning ability. Our hope is that those who read this study will share its findings with individuals affected by ADHD, and that the use of brain games will prove to be a monumental aid for treating the ADHD symptoms of the millions affected by this disorder.

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Author Notes

Stacy C. Wegrzyn is an adjunct professor in the Department of Instructional Technology and Department of Secondary and Middle Grades at Kennesaw State University. Her research interests focus on the use of instructional technology in the classroom, specifically as it applies to helping students with ADHD. Please address correspondence concerning this article to Stacy Wegrzyn, Adjunct Professor, Department of Instructional Technology, Kennesaw State University, 1000 Chastain Road, Box 0127, Kennesaw, GA 30144. E-mail: swegrzyn@kennesaw.edu

Doug Hearrington is an associate professor of educational research and technology in the Department of Educational Leadership, Counseling, and Special Education at Augusta State University. His research interests focus on virtual and augmented reality, simulations, the effects of technology on cognitive and affective processing, and the teaching of educational research.

Tim Martin is an assistant professor in the Department of Psychology at Kennesaw State University. His research interests focus on dynamic attention and stroke recovery.

Adriane B. Randolph is an assistant professor in the Department of Information Systems and director of the BrainLab at Kennesaw State University. Her research interests focus on understanding human mental processes through the use of brain–computer interfaces, which allow humans to control computers and devices using just their thoughts.

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