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The Impact of Fidget Spinners on Fine Motor Skills in Individuals with and without ADHD: An Exploratory Analysis

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Abstract

Fidget spinners have been marketed as repetitive motion devices that improve attention and motor performance, and as such, they have become quite appealing to individuals with Attention Deficit Hyperactive Disorder (ADHD). To date, no studies have explored changes in brain activity that may occur due to fidgeting in ADHD. Our aim was to use functional Near-Infrared Spectroscopy (fNIRS) to examine the prefrontal cortex (PFC) during the performance of a standardized fine motor skills test after using a fidget spinner. Eight right-handed adults with ADHD and eight age and gender matched adults without ADHD (4F/4M, 4 control/4 fidget) performed the Purdue Pegboard Test (PPT) while their brain oxygenation was monitored using fNIRS. Relative neural efficiency (RNE) and involvement (RNI) were calculated and analyzed for all subtasks of PPT including the less cognitively demanding fine motor subtasks and more complex assembly tasks. The fidget spinner improved both task performance and RNE in the ADHD group but not the non-ADHD group for the less cognitively demanding subtasks. Our results indicate Fidget spinners may improve both relative neural efficiency and fine motor performance in adults with ADHD for less cognitively demanding tasks.

Keywords

Fidget Spinners, fNIRS, ADHD, Executive Function, Motor Skill

1. Introduction

Attention Deficit Hyperactive Disorder (ADHD) is one of the most prevalent

Attention Deficit Hyperactive Disorder (ADHD) is one of the most prevalent chronic health conditions affecting school-aged children, with a recent 2016 national parent survey estimating a 9.4% prevalence rate in the US [1]. ADHD, as defined by the most recent edition of the American Psychiatric Association's DSM-V, is a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development [2]. Symptoms of inattention can manifest as wandering off the task or having trouble maintaining focus while hyperactivity can be noticed as excessive motor behaviors such as fidgeting, tapping, or talkativeness [3]. Individuals with ADHD describe symptoms of inner restlessness, talkativeness, and fidgeting in places where an individual is expected to sit still such as in lectures or meetings [4]. These symptoms of fidgeting and impulsiveness, in addition to both motor and cognitive deficiencies associated with ADHD, can have negative effects on both academic [5] and vocational performance [6].

Although the exact cause of ADHD is still unknown, one prominent theory that provides a reason for the dysfunction of cognitive control and executive function associated with ADHD places an emphasis on top-down, controlled processing deficits [7]. Executive function (EF) involves top-down cognitive processes that allow for complex behavior through accurate process selection [8]. EF is often used in daily functioning when one is regulating attention, behavior, and actions. The prefrontal cortex (PFC) plays an important role in higher order controlled processing, which suggests ADHD may have associated deficits within this brain region such as reduced activity [8] [9].

1.1. Motor Deficiencies with ADHD

In addition to the general symptomology used to diagnose ADHD, various motor deficits are also often associated with the disorder [10] [11] [12]. Researchers have found that individuals with ADHD have associated decreases in fine motor performance that requires manual dexterity [10] [11] [12] [13] [14]. These studies suggest problems with attention may be the underlying cause of motor deficits in individuals with ADHD, in which attention is constantly being maintained through cognitive processes during such executive functions.

1.2. Fidgeting and ADHD

Fidgeting is defined as the repetitive motion of small movements caused by nervousness or impatience, and hyperactivity in ADHD is often associated with some sort of fidgeting and restlessness [2]. Various studies have investigated the possible relationship between fidgeting and attention. Anecdotal reports of increased random fidgeting movements during spontaneous mind wandering or inattentiveness were investigated in a scientific study that found a strong association between the two, specifically that an increase in fidgeting was reported as soon as unintentional mind wandering occurred [15]. However, it is possible that fidgeting may modulate attention rather than only represent a manifestation of its reduction. Two recent studies [16] [17] investigated this possibility in hyperactive and typically developing children (TD) by asking them to perform cognitive working memory tasks while monitoring their levels of activity. Both studies found a positive correlation between an increased activity level and task performance in the hyperactive ADHD group but not in the TD group. These findings suggest that excessive fidgeting may be a compensatory mechanism employed by those with ADHD, where it may help them to modulate attention and cognitive control as well as stimulate CNS arousal. A recent model of ADHD suggests that these individuals appear "hypo-aroused" in terms of cortical activation on attentionally demanding tasks [18]. In addition, studies have shown that optimal levels of cortical arousal are needed to maintain certain attentional demands [8] [19] and therefore it is possible that the compensatory activity of fidgeting could act as a mechanism used by individuals with ADHD to improve attention and optimize their level of arousal. Considering the widespread use of fidget spinners and scant scientific evidence on their effectiveness, further neuroimaging studies are required to test this hypothesis.

1.3. Fidget Spinners

Fidget spinners have recently surged to high demand in the public as both an exciting new toy as well as a therapeutic device with enticing purported benefits to improving focus and attention. In fact, advocacy organizations such as Children and Adults with Attention Deficit/Hyperactivity Disorder (CHADD) suggest their use [20]. However, a dearth of scientific evidence for these fidget spinner claims has led to a controversy over the efficacy of these benefits. In fact, schools are even banning the device from being used in classrooms because their use supposedly distracts others in the classroom from focusing on their own work even though anecdotal reports insist it is helping the individual using it to focus [21]. One such study investigating the effects of fidget spinner use on young children with ADHD in a classroom setting suggests that use can lead to more attentional distractions for the child using it, however, they found them to have no negative effect on others' attentional functioning in the classroom [22]. Two other studies have found potential negative effects of using fidget spinners on memory processes [23] [24]. On the other hand, supporters of the device argue that the act of spinning helps them to concentrate better and focus for longer on their work [21]. In a 2017 review study, authors found no evidence to support the purported benefits of fidget spinners [25]. Despite all of the contradictory claims, there is a clear lack of scientific evidence in relation to fidget spinners and their claimed benefits and/or hindrance to individuals who use them.

The fidget spinner itself comes in many colors, is quite simple in nature, and is very easy to use, all of which make it quite appealing to the general population.

Most designs are composed of an outer three-winged shell that rotates around a central axis when a torque is applied (**Figure 1**). The idea is to hold it in one hand, with the thumb and index finger, and then use the other hand to spin it,

Figure 1. A fidget spinner used in this research study. Individuals grasp the spinner between the thumb and index finger of one hand and use their opposite hand to "spin" it.

creating a continuous rotating motion. Furthermore, a ball bearing is placed in the center of the device to help reduce overall friction and increase the duration of the spin. As so, the use of the fidget spinner can be seen as mimicking the act of fidgeting. Fidget spinners have been promoted to have benefits in autism and PTSD [26], ADHD, anxiety and sensory issues [25] but scientific evidence on the effectiveness of this device in any of these conditions is lacking.

Two experimental studies were recently published on the effects of fidget spinners on motor control and executive functions [22] [27]. One comes from Cohen in 2017 [27] measures the short-term effects of fidget spinners on fine motor control. In a simple spiral tracing task, typical college aged students were asked to trace a spiral, then either spin the fidget spinner, hold it (sham), or do nothing (control) for a minute, then re-trace the same spiral immediately following the intervention. Based on error analysis, an overall improvement was found in both the fidget and sham groups but not the control group, which suggests an improvement in fine motor control may have been due to the manipulation of the fidget spinner. In 2020, Graziano and colleagues [22] did a systematic analysis of fidget spinner intervention, through an A-B-A-B design on 60 children diagnosed with ADHD. They tested the children on gross motor activity levels, behavior, and attentional functioning in the classroom after an eight-week, intensive, evidence-based, multimodal intervention for children diagnosed with ADHD. Graziano *et al.*'s [22] findings were contrary to the evidence in that there were reduced gross motor activity levels and reduced classroom attention. Since effective motor control relies on an underlying attentional component [28] [29], other than Graziano *et al.*, these findings are consistent with similar studies that found the manual manipulation of other commonly used fidgeting tools, such as stress balls [30] and doodling [31], help to improve overall attention and concentration. To our knowledge, there are no neuroimaging studies that have utilized neuroimaging to understand the neural basis and potential benefits of fidget spinners in ADHD. Only one neuroimaging study exists on the effect of fidget spinners in healthy adults on fine motor tasks, in this study the authors found that using fidget spinners may lead to decreased activity in the left dorsolateral prefrontal cortex (DLPFC) during a challenging fine motor task [32]. We hypothesized that fidget spinners may affect neural and fine motor performance differently between neurotypical and ADHD subjects. We explored the effects a fidget spinner may have on cognitive effort and fine motor performance in individuals with and without ADHD using functional near infrared spectroscopy (fNIRS) to examine how the use of the fidget spinner affected the activation of the prefrontal cortex (PFC).

2. Materials and Methods

2.1. Participants

A total of sixteen individuals (N = 16) were recruited for this research study from around the Newark, DE area, and University of Delaware community. All testing occurred in the Developmental Motor Control laboratory at the University of Delaware Research protocol was approved by the University of Delaware IRB and all participants read and signed an informed consent form prior to initiating the study.

Eight right-handed adults with a clinical diagnosis of ADHD were recruited for the ADHD group and eight age and gender matched individuals were recruited for the group without ADHD. Inclusion criteria for the healthy participants were 1) age between 18 - 55 years old. 2) Healthy with no diagnosis of mental/psychiatric disorders. 3) Right-handed and naïve to the task. Inclusion criteria for ADHD subjects were 1) age between 18 - 55 years old, 2) Self-reported clinically diagnosed ADHD adults who have no diagnosis of mental/psychiatric disorders, and 3) Right-handed and naïve to the task. Exclusion criteria were: 1) Head injuries such as concussion within the past twelve months; 2) visual impairments that restrict the ability to perform tasks; 3) open wound to the forehead; 4) a seizure disorder; 5) allergic to rubbing alcohol; and 6) any neurological or orthopaedical condition that has affected the hand fine motor function. Participants of both test conditions were then pseudorandomized and placed into either the fidget or non-fidget intervention groups, totaling four groups (**Table 1**). Participants from all groups were matched based on the task order. These individuals were recruited by word of mouth and were given a fidget spinner for completing the study.

2.2. Research Design

Participants performed three identical trial blocks. Within each block, participants in the fidget groups used the fidget spinner continuously for 60 seconds,

Table 1. Depicts four experimental groups used in study with demographic information.

Group	Male/Female	Mean Age ± St. Dev.
Typical - Control (TC)	2M/2F	22.00 ± 1.87 yrs.
Typical - Fidget (TF)	1M/3F	22.00 ± 1.00 yrs.
ADHD - Control (AC)	2M/2F	20.50 ± 0.50 yrs.
ADHD - Fidget (AF)	2M/2F	20.25 ± 0.43 yrs.

while participants in the control group sat quietly with their hands facing down in front of them. This was followed by the performance of the five subtasks (**Figure 2**). The first four subtasks (right, left, bimanual, and a rest period) lasted 30 seconds and were randomly presented for each participant. The goal of the PPT non-assembly tasks was to place as many pegs as possible within the thirty second period. The assembly subtask lasted 60 seconds and always appeared last in the trial sequence. The goal of the assembly subtask was to create as many assembles within 60 seconds. These task-related time intervals were selected because they correspond with intervals used in the PPT test. The time between subtasks was jittered between 12–18 seconds to minimize hemodynamic changes in anticipation of the task [33]. Each period in the experiment was prompted on the monitor with a visual cue and an auditory beep to begin and end the task. A custom PsychoPy code was used for stimulus presentation and triggering the fNIRS device [34].

2.3. Instrumentation

2.3.1. Purdue Pegboard Test

The Purdue Pegboard Test (PPT) provides a measure of manual dexterity and fine motor control ability [35] [36] and consists of a board with two perpendicular lines of 25 holes each spaced evenly and pieces including pins, washers, and bearings (**Figure 3**). There are four standardized subtasks. Three of the subtasks (right, left, bimanual) require placing pins in the board. For the right subtask, participants used the right hand to pick up a pin from the righthand dish and place it in the most proximal open hole on the right side of the board. This process was continued for 30 seconds, with the objective of placing as many pins in holes as possible for the allotted time.

The left subtask follows similarly, except using the left hand, dish, and board. The bimanual subtest utilizes both hands in unison. The assembly subtask requires that the participants assemble a specific combination of one pin, two washers, and one collar using both hands and alternating had used. The objective of this subtask is to complete as many assemblies as possible during a 60 second timeframe. Scores from the PPT include the number of pins inserted for the

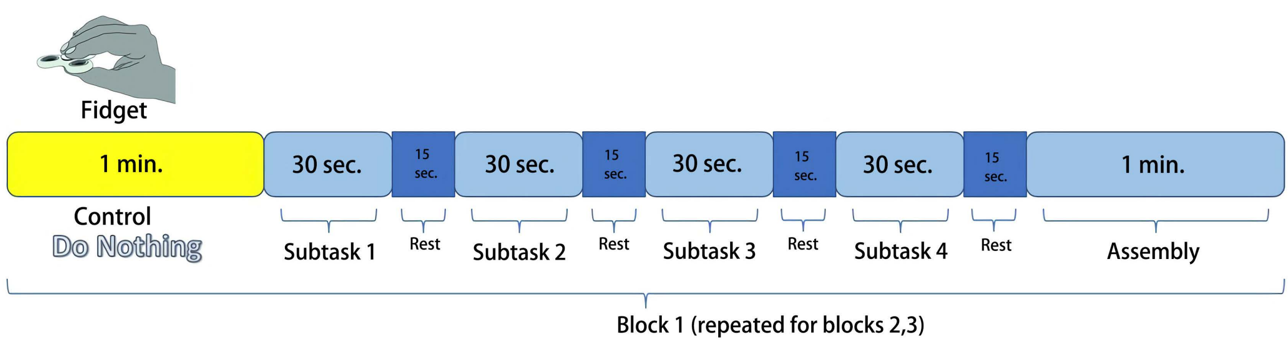


Figure 2. Research protocol for one block of trials. In the first minute of data collection, control groups sat quietly with their hands face down in front of them, while the fidget groups used the fidget spinner continuously. This was followed by a block of thirty second trials that included three non-assembly tasks presented in a random order followed by a sixty second trial of the assembly task. This sequence was repeated three times.

Figure 3. The Purdue peg test (PPT). The test consists of a peg board with two perpendicular lines of twenty-five evenly spaced holes, with cups of pins, washers, and collars at the top. Participants place either single pins or assemblies in the holes for a prescribed amount of time.

right and left subtask, the total number of pairs of pins inserted for the bimanual task, and the number of assembled parts for the assembly task. An additional sum score for the non-assembly tasks (Left, Right, Bimanual) is utilized as a 5th subtest to measure one's overall gross movement performance of the Purdue Pegboard Test [37]. Performance scores were converted to Z-scores to facilitate comparison across tasks. Participants sat at a desk with the Purdue Pegboard test directly in front of them; behind the PPT was a computer monitor used to provide trial prompts. Participants practiced the PPT for 15 - 20 seconds per subtest. In addition, participants in the fidget group participants were given instruction and practice holding the fidget device (**Figure 4(B)**). Data collection took approximately 40 minutes.

2.3.2. Functional Near Infrared Spectroscopy

Hemodynamic data from the prefrontal cortex (PFC) was collected using a 16-channel continuous-wave functional near-infrared device (fNIRS Device LLC, Potomac, MD, USA) sensor band was secured to the participants' forehead while they performed the PPT (**Figure 4(A)** & **Figure 4(B)**). The band consisted of sixteen measurement locations (optodes) established by 10 photo detectors and 4 light emitters that released light within the 730 - 850 nm wavelength window. The detectors were separated by 2.5 cm which resulted in a penetrating depth of approximately 1.2 cm. Placement of the fNIRS sensor band aligned the center of both the horizontal and vertical axes of the head with those of the band. Specifically, the sensor's vertical axis was placed in the Fp1 and Fp2 locations delineated in the international 10 - 20 system of cerebral electrode placement [38].

2.4. Data Acquisition and Processing

2.4.1. Data Acquisition

Data collected with the fNIRS device were sampled at 2 Hz, acquired through Cognitive Optical Brain Imaging (COBI) studio software, and processed using

(A) (B)

Figure 4. (A) A participant wearing an fNIRS sensor pad positioned for data collection. B) A participant holding the fidget spinner in the right hand and spinning it with the left-hand during data collection.

fNIRSoft Software (Version 4.9). Signal acquisition was optimized by 1) cleaning the participants' forehead with an alcohol swab prior to positioning the sensor band; 2) excluding any hair between the sensor and the participants' forehead; 3) adjusting gain and LED current until raw wavelength signal was verified to be between 40 - 4000 mV; and 4) reducing the ambient light in the testing room. The device was then initiated, and the first 10 seconds of recording were set as a baseline. During this period, the participant remained still and focused on a cross located on a computer screen in front of the participant.

2.4.2. Data Processing

Researchers visually inspected raw light intensities and individual optodes, which were rejected when data did not reflect hemodynamic activity due to lack of proper contact between the sensors and the forehead or inevitable placement on top of the hair in smaller-sized foreheads.

Next, a finite impulse response (FIR) filter (20th order, Hamming window) to low pass filters the raw light intensity data at 0.1 Hz was used to remove input from physiological signals, such as respiration and heartbeat. Data were subsequently converted to changes in concentration through the modified Beer-Lambert law [39]. From the available biomarkers, we used oxygenated hemoglobin ΔHbO. Finally, the detrending filter was applied to data characterizing changes in concentration to remove drift in the data using linear parameters that convert the slope of the baseline to zero.

To determine relative neural efficiency (RNE) and relative neural involvement (RNI) metrics, we used oxygenated hemoglobin (ΔHbO) as a measure of cognitive effort and subtask scores from the PPT as a measure of performance. First, these values were converted to Z-scores, which were used in the following way. The RNE metrics calculations are based on [40] [41], and RNI metrics are based on applications with subjective effort and instructional motivation by Paas [40]. We used the inverse of PPT performance and the cognitive effort (CE) measure – inverse mean ΔHbO to account for the appropriate interpretation of the measures. That is, a shorter distance indicates a better performance than a longer distance. RNE represents the perpendicular distance of the standardized performance score relative to the standardized cognitive effort scores (see Equations (1) and (2)). Then RNE and RNI (see Equations (3) and (4)) are plotted as cartesian coordinates for each participant group.

$$P_z = \frac{\frac{1}{\text{PPT}_i} - \frac{1}{\text{PPT}_{\text{GM}}}}{\frac{1}{\text{PPT}_{\text{SD}}}} \tag{1}$$

$$\text{CE}_z = \frac{\frac{1}{\Delta\text{HbO}_i} - \frac{1}{\Delta\text{HbO}_{\text{GM}}}}{\frac{1}{\Delta\text{HbO}_{\text{SD}}}} \tag{2}$$

$$\text{RNE} = \frac{P_z - \text{CE}_z}{\sqrt{2}} \tag{3}$$

$$\text{RNI} = \frac{P_z + \text{CE}_z}{\sqrt{2}} \tag{4}$$

2.5. Statistical Analysis

Prior to analysis, the data were assessed to see if they met the assumption of normality (Shapiro-Wilkes) and homogeneity of variance (Levine's). Dependent measures included relative changes in mean ΔHbO across the entire PFC region as well as corresponding PPT scores from the (right, left, bimanual) (non-assembly) and assembly subtasks. All analyses were divided into non-assembly and assembly tasks to differentiate between just motor and motor-cognitive tasks. All statistics were calculated using JMP Pro 15.2. Two-way factorial ANOVAs were used to determine the effects of group (TD, ADHD) and condition (fidget, control) on relative overall performance, ΔHbO, RNE, and RNI. The significance criterion for all tests was set at $\alpha = 0.05$.

3. Results

3.1. PPT Performance Scores

A 2-way factorial ANOVA on non-assembly tasks revealed a main effect for condition ($F(1, 44) = 7.35$, $p = 0.010$), and a group by condition interaction ($F(1, 44) = 6.99$, $p = 0.011$), with group effect approaching significance ($F(1, 44) = 4.09$, $p = 0.052$). There was also a group by condition interaction (**Figure 5**). Post-hoc analysis for the group by condition interaction revealed the ADHD-Control to be significantly lower than all the other groups, which did not differ from each other. A 2-way factorial ANOVA on the assembly tasks revealed no significant main effects or interactions (**Figure 6**).

3.2. ΔHbO

A 2-way factorial ANOVA on the non-assembly tasks revealed no significant main effects or interactions (**Figure 7**). Subtasks for ADHD Control (AC), ADHD

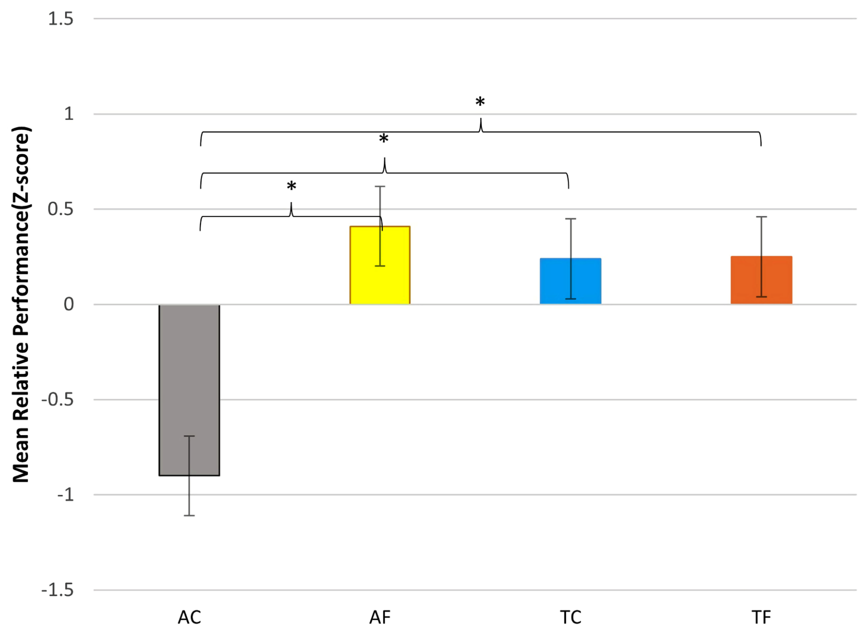


Figure 5. Mean relative PPT performance between groups and conditions in the non-assembly subtasks for. ADHD Control (AC), ADHD Fidget (AF), Typical Control (TC) Typical Fidget (TF). * indicates significantly different at $p < 0.05$.

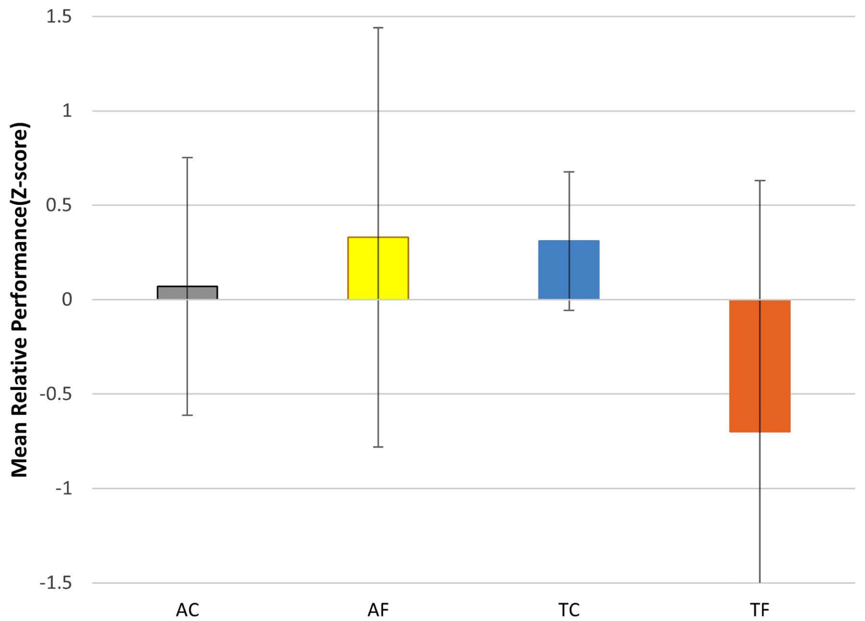


Figure 6. Mean relative PPT performance for all groups and conditions in the assembly subtask for ADHD Control (AC), ADHD Fidget (AF), Typical Control (TC) Typical Fidget (TF). No significant differences existed among the groups.

Fidget (AF), Typical Control (TC) Typical Fidget (TF). No significant differences existed. A 2-way factorial ANOVA on the assembly task revealed no significant main effects, and a group by condition interaction that approached significance ($F(1, 12) = 4.52$, $p = 0.055$). Post hoc analysis did not reveal any significant comparisons (**Figure 8**).

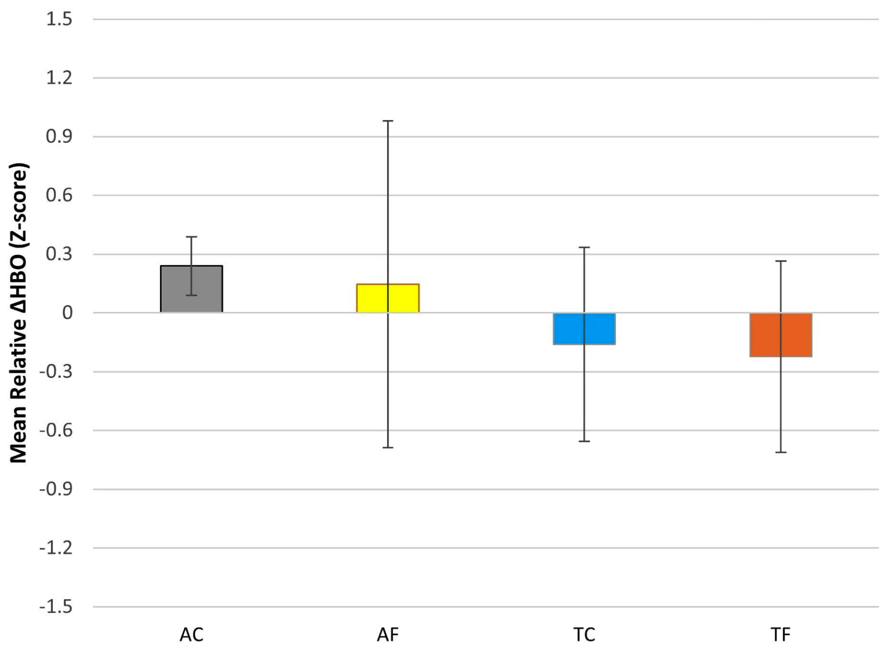


Figure 7. Mean relative ΔHBO for all groups and conditions in the non-assembly subtask for ADHD Control (AC), ADHD Fidget (AF), Typical Control (TC) Typical Fidget (TF). No significant differences existed.

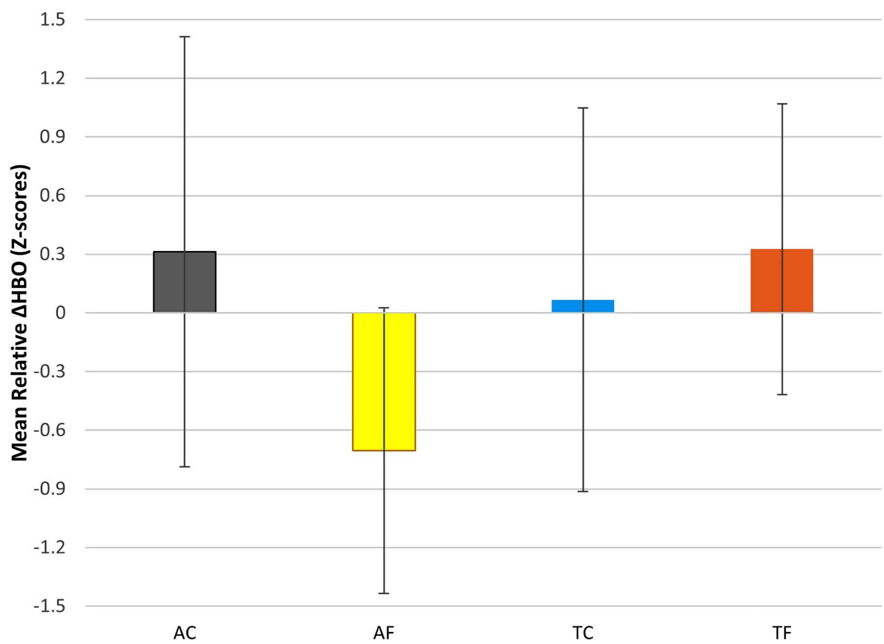


Figure 8. Mean relative ΔHBO for all groups and conditions in the assembly subtask for ADHD Control (AC), ADHD Fidget (AF), Typical Control (TC) Typical Fidget (TF). No significant differences existed.

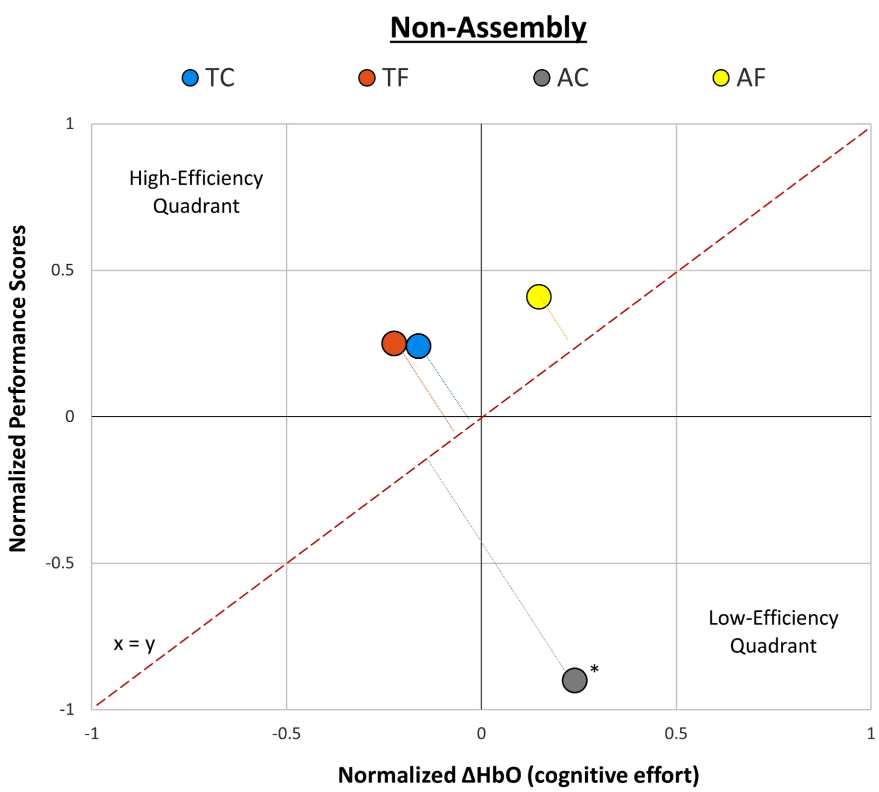
3.3. Relative Neural Efficiency (RNE)

For the non-assembly tasks, there was a group main effect, in which the ADHD group had a lower mean RNE compared to the Typical group ($F(1, 45) = 5.50$, $p < 0.05$). The ADHD group's low RNE represents high cognitive effort for a weaker performance on the non-assembly tasks when compared to the typical group overall RNE. For condition, the main effect was approaching significance ($F(1, 45) = 3.87$, $p = 0.055$), with Fidgets appearing to have a greater RNE than Controls. In addition, a group by condition interaction was approaching significance ($F(1, 45) = 3.16$, $p = 0.082$) in which post-hoc t-tests revealed there were significant differences between the RNE of ADHD-Control and those of the ADHD-Fidget ($p < 0.02$), Typical-Control ($p < 0.01$), and Typical-Fidget ($p < 0.01$). Furthermore, there were no significant differences between Typical-Control, Typical-Fidget, and ADHD-Fidget ($p > 0.05$). There were no significant group or condition main effects or interactions ($p > 0.05$) (See **Figure 9(A)** and **Figure 9(B)**).

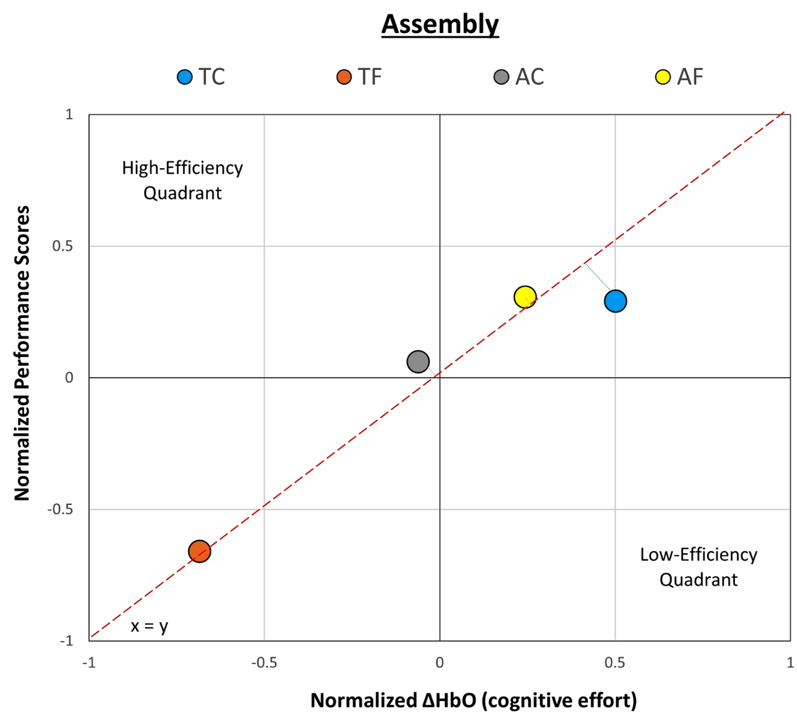
3.4. Relative Neural Involvement (RNI)

In the non-assembly tasks, a group by condition interaction approached significance ($F(1, 45) = 2.92$, $p = 0.09$) with post-hoc t-tests revealing the AF group had a significantly different RNI than the AC ($p < 0.05$; **Figure 10(A)**). No further significant differences were found between groups, specifically the typical groups in which the fidget spinner had no effect on neural involvement.

In the assembly task, a significant group by condition interaction was found ($F(1, 15) = 7.41$, $p < 0.02$) with post-hoc t-tests revealing the RNI of the TF group was significantly different from that of the TC and AF groups (**Figure 10(B)**).

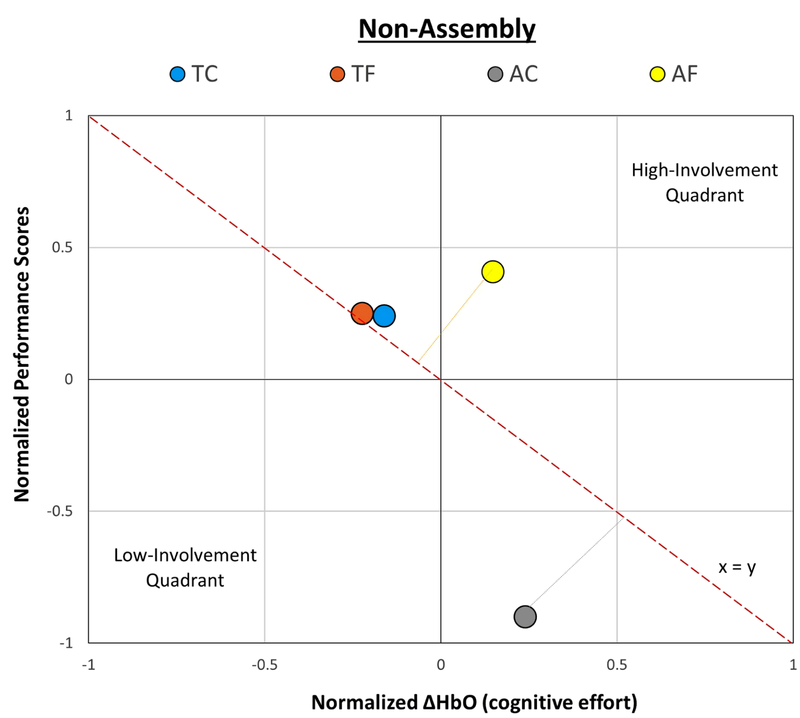


(A)

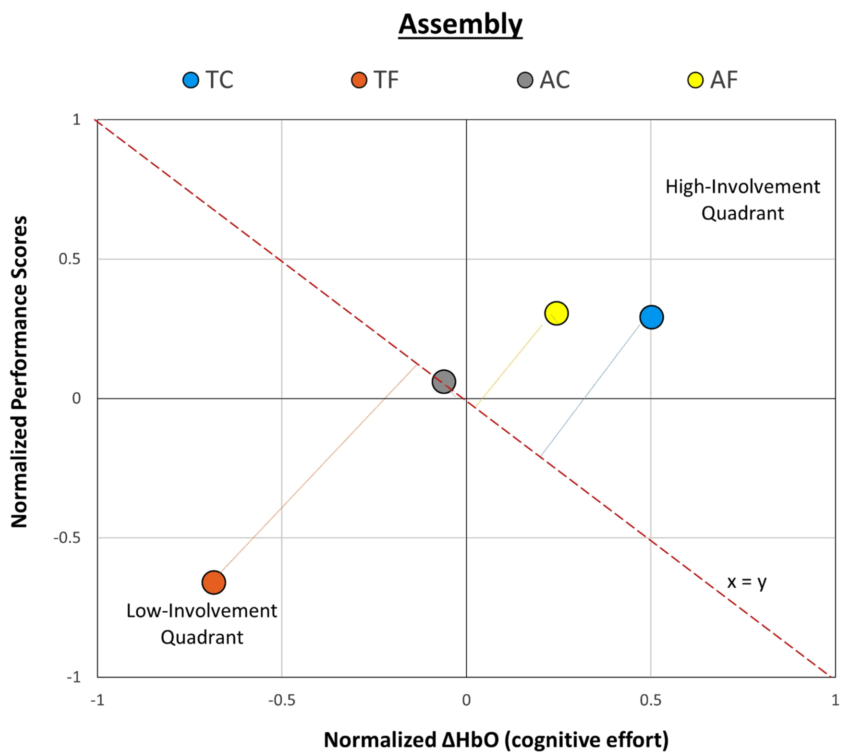


(B)

Figure 9. Relative neural efficiency (RNE) during the PPT task. The lower right quadrant represents low-RNE while the top left quadrant represents high-RNE. $y = x$ is where RNE = 0 in which cognitive effort matches performance. RNE is calculated as distance from RNE = 0. Typical-Control (TC), Typical-Fidget (TF), ADHD-Control (AC), ADHD-Fidget (AF) (A) Non-assembly RNE where RNE_{AC} is significantly different from RNE_{AF}, RNE_{TF}, RNE_{TC}. *($p < 0.05$). (B) Assembly RNE with no significant differences ($p > 0.05$).



(A)



(B)

Figure 10. Relative neural involvement (RNI) during the PPT assembly task. RNI is calculated as the distance from the dotted line I = 0. Typical-Control (TC), Typical-Fidget (TF), ADHD-Control (AC), ADHD-Fidget (AF). (A) Non-assembly tasks. (B) Assembly task.

4. Discussion

In our research, we examined the behavioral performance and brain activation when individuals with and without ADHD performed a fine motor task after an acute fidget/no fidget time interval. The behavioral performance measures alone indicated that no statistical differences existed among the groups in the assembly task and confirmed the superiority of the Typical Control and Fidget (TD) groups over the ADHD Control (AC) on the non-assembly tasks; however, ADHD Fidget (AF) performed similarly to the TD groups. In addition, ΔHbO measures alone indicated that no significant differences existed among groups or conditions in assembly or non-assembly tasks. In our previous study on healthy adults, we found fidget spinners only decreased oxygenation in Left DLPFC for assembly task [32] while no differences existed in performance or oxygenation in PFC similar to this study. To better understand the interplay between brain activation and performance, we introduced two measures, relative neural efficiency (RNE) and relative neural involvement (RNI) that have been used in assessments of Cognitive Load theory. The combined measures yielded comprehensive information about the cognitive effort associated with performance as individuals perform the PPT task, and also revealed differences among groups and conditions that did not appear when examining the measures individually.

RNE is an approach to determine the efficiency of an individual's cognitive workload while performing different cognitively challenging tasks. Values within the high efficiency quadrant indicate superior behavioral performance with a relatively lower amount of cognitive effort. This increased efficiency represents an increase in a learners' skill acquisition by using fewer cognitive resources after adequate training [40]. A recent study used functional near infrared spectroscopy (fNIRs) to determine RNE during multiple virtual laparoscopic tasks used for surgery; here, the authors found different practice schedules (random or blocked) produced different overall RNE [42]. The cognitive effort was objectively measured for each task using ΔHbO of the PFC, and this measure was compared to behavioral performance to determine relative neural efficiency. Using this same approach to measure cognitive workload during different Purdue Pegboard Tests, our research suggests that short-term use of fidget spinners prior to performing simple fine motor skills may improve RNE in individuals with ADHD. The assembly task requires greater amounts of cognitive effort to complete due to the increase in complexity and motor planning requirements relative to the non-assembly tasks. In the assembly task, the fidget spinner appeared to not have an impact on overall RNE across groups.

Motivation is an important factor in task performance. If a task is uninteresting or too difficult, an individual may perform the task well but remain cognitively unengaged, which can impact overall learning. RNI provides a measure of motivation and mental effort involvement as they relate to behavioral performance, and when applied to a novice/beginner within a learning environment, can help to identify which instructional setting promotes higher amounts of motivation. In our study on the non-assembly tasks, participants without ADHD matched their mental effort with performance. This is perhaps not surprising, given the low cognitive load that performance of non-assembly tasks places on participants without ADHD. On the other hand, significant differences existed between conditions in the ADHD groups. There may be a benefit of the fidget interval in the ADHD groups, where RNI in the AF group was not only significantly higher than AC, but also within the high-involvement quadrant. The fidget spinner may have helped to modulate their attentional demands and improve executive function in the less interesting, lower cognitive demanding tasks, thereby increasing performance. This is in line with two recent studies that found a positive association between an increased fidgeting level and cognitive working memory task performance in a hyperactive ADHD group but not in the TD group [16] [17]. More research is needed to determine the strength of this effect. In the more difficult assembly task, TC and AF do not differ in RNI and both fall in the high-involvement quadrant compared to the TF group, for which the fidget interval appears to have a deleterious effect on motivation. Future studies should explore the potential positive and negative effects that fidgeting has on different populations along with a variety of tasks and learning environments. In addition to different types of motor and attention tasks, it is also important to distinguish the effects that may arise from using the fidget spinners prior to the task, versus using them during the task, as well as task duration all of which may contribute to positive or negative findings. In our previous study, we found that fidget spinners may result in lower oxygenation in the Left DLPFC [32]. Left DLPFC is associated with goal hierarchy to analyze information in constructing a plan [42] [43]. Further studies on specific regions of interest that combine behavioral and brain activation measures may provide a more nuanced picture of specific motor planning mechanisms impacted by the fidget spinners. Age is also another important factor that should not be neglected when it comes to fidget spinners. Aside from potential differences due to a different developmental state, there is the potential choking hazard and health hazards [25] [44] [45]. Clinicians should consider the dangers that the ingestion of fidget spinners poses to pediatric patients, ingestion of these toys in children should not be ignored as these incidents are on the rise [46].

This study was not without limitations. There were a limited number of participants per group; thus, perhaps Type II error was present along with increased variability. By increasing the sample size and replicating this work, the issues surrounding reduced statistical power and increased variability would potentially address these statistical issues. Also, this study was limited to the prefrontal cortex and different regions within the prefrontal cortex or other motor areas were not studied. In addition, we did not differentiate among the different ADHD subtypes; by narrowing our participant pool to a specific sub-type, different RNE and RNI patterns may have emerged. Finally, any differences that resulted from fidget spinner intervals represent short-term adaptations. More research is needed to determine how the effect of the fidget spinner changes over time once the novelty of the fidget task is gone.

5. Conclusion

In conclusion, our study provides a unique insight into the use of an acute bout of fidget spinners in neurotypical and ADHD performers using fNIRS for activation of the prefrontal cortex. We assessed differences through neural and behavioral measures while we analyzed the performance of assembly and non-assembly fine motor tasks. We demonstrated that including integrated measures of behavioral performance and brain activation such as relative neural efficiency and relative neural involvement, can broaden our understanding of skill acquisition and shed some light on conflicting findings when it comes to the effect of fidget spinners on motor performance, executive functioning, and cognitive effort. Specifically, our results suggested that using fidget spinners improved neural efficiency for simple motor tasks in an ADHD sample. However, this effect was not present for a more complex motor task or non-ADHD group in PFC. Further studies are required to identify impacted and associated mechanisms in different regions of interest within the PFC. Additionally, results from neural involvement indicate that using fidget spinners improved ADHD subjects' involvement and motivation for the simple motor tasks while using fidget spinners in a more complex motor task had a detrimental effect on non-ADHD group's involvement and attention modulation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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