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Standing Up for Learning: A Pilot Investigation on the Neurocognitive Benefits of Stand-Biased School Desks

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Abstract: Standing desks have proven to be effective and viable solutions to combat sedentary behavior among children during the school day in studies around the world. However, little is known regarding the potential of such interventions on cognitive outcomes in children over time. The purpose of this pilot study was to determine the neurocognitive benefits, *i.e.*, improvements in executive functioning and working memory, of stand-biased desks and explore any associated changes in frontal brain function. 34 freshman high school students were recruited for neurocognitive testing at two time points during the school year: (1) in the fall semester and (2) in the spring semester (after 27.57 (1.63) weeks of continued exposure). Executive function and working memory was evaluated using a computerized neurocognitive test battery, and brain activation patterns of the prefrontal cortex were obtained using functional near infrared spectroscopy. Continued utilization of the stand-biased desks was associated with significant improvements in executive function and working memory capabilities. Changes in corresponding brain activation patterns were also observed. These findings provide the first preliminary evidence on the neurocognitive benefits of standing desks, which to date have focused largely on energy expenditure. Findings obtained here can drive future research with larger samples and multiple schools, with comparison groups that may in turn implicate the importance of stand-biased desks, as simple environmental changes in classrooms, on enhancing children's cognitive functioning that drive their cognitive development and impact educational outcomes.

Keywords: sedentary behavior; physical activity; exercise; executive function; working memory; brain activity; fNIRS; PFC

1. Introduction

Childhood obesity rates have quadrupled over the past three decades, particularly among adolescents aged 12–19 years [1]. Obesity is associated with immediate and long-term health effects such as cardiovascular disease, type II diabetes, osteoarthritis, sleep apnea, and some types of cancers [1]. In addition, adolescents who are obese are at greater risk of social and psychological problems, as well as impaired cognitive functioning [2]. Due to the significant amount of time spent at school, there have been several in-school interventions aimed to alter unhealthy eating habits, sedentary behavior, and physical inactivity that have been linked to the childhood obesity epidemic [3]. However, school administration struggle with the need to incorporate healthy behaviors with their primary focus of educating students. In recent years, dynamic classrooms, that allow movement during class time with an intent to minimize sedentary behavior, have gained interest as a way to facilitate

physical activity in the classroom without distracting from the primary focus of teaching [4]. These classrooms are equipped with desks that facilitate standing and movement, such as the stand-biased desks discussed in Dornhecker *et al.* [4]. These are elevated desks that allow for the students to have the option to stand or sit on a stool, thereby offering the potential to expend more energy during instructional activities and academic assignments. There is consensus on the effectiveness of stand-biased desks to help increase energy expenditure of children during the school day (~17% improvement in calorie expenditure when compared to traditional desks), which have also shown to cause no discomfort to students [5–7].

The continued exposure to stand-biased school desks has also been linked to improved student attention and focus, as measured qualitatively through teacher perceptions, in elementary school children [8]. This study targeted sixth grade students and reported that the use of standing desks resulted in an increase in energy expenditure and did not seem to impact to academic performance measured using teacher ratings [8]. More recently in a large elementary school study, Dornhecker *et al.* [4] reported that the use of stand-biased desks in classrooms did not disrupt students' level of engagement, allowing schools to address childhood obesity through improved energy expenditure without negatively impacting academic performance. It should be noted that these studies focused primarily on teacher/rater's observations of student engagement/performance. However, *why* these outcomes were observed is not known. Because student engagement and academic achievement are macro-outcomes that are influenced by several individual-, classroom-, and school-level factors, research to delineate the direct effects of exposure to standing desks and cognition can become very complex. Moreover, the extent to which standing desks in classrooms impact basic cognitive outcomes, such as executive functioning and working memory, among school-aged children is largely unexplored. Examining how continued standing relates to changes (improvement, no change, or decrement) in executive functioning and working memory is the first step that may provide the basis to investigate the link between exposure to standing desks and classroom engagement and ultimately academic achievement.

Cognition is attributed, at least in part to neurogenesis facilitated by increased regional cerebral blood flow during exercise [9] and has been shown to improve cognitive function, specifically executive function and working memory, through brain activation changes [10–12]. Executive function generally refers to the group of cognitive processes that guide human behavior [13], and working memory refers to a system for temporary storage and manipulation of information in the brain [14]. For example, the ability to mentally conceptualize a problem, store information temporarily in the visual-spatial sketchpad, develop a plan, evaluate and adapt complex goal-directed behavior have been identified as the products of working memory and executive function [15]. Imaging studies have linked the frontal brain region, particularly the prefrontal cortex (PFC), to both working memory and executive functioning [16–18]. In addition, numerous studies have associated enhanced neurocognitive functioning (indicative of improved working memory and executive functioning and PFC activity) to physical activity interventions [19–22]. As is observed with traditional school-based physical activity interventions, stand-biased desk interventions in schools have shown to result in 17%–30% increase in calorie expenditure [6]. Thus, by increasing caloric expenditure through standing throughout the school day, it is likely that stand-biased desks influence cognitive performance, particularly executive function and working memory, in children. However, there is no published data on how standing desks that help combat sedentary behavior impact neurocognitive processing.

The purpose of this pilot study was to explore neurocognitive benefits, *i.e.*, enhancement of executive functioning and working memory, of stand-biased desks among freshman high school students. It was hypothesized that continued exposure to stand-biased desks would be associated with improvements in executive functioning and working memory. Additionally, the study explored whether these cognitive improvements were associated with changes in frontal brain function.

2. Experimental Section

2.1. Experimental Design and Procedure

The present study is a part of a larger intervention study that tested the impact of stand-biased desks on sedentary behavior on a high school student population over two years. In brief, the two-year larger study involved converting a Texas high school from traditional seated classrooms to stand-biased classrooms after six months into the academic year. The present study was conducted in a freshman cohort during the second year of the two-year study and employed a repeated measure experimental design to explore neurocognitive benefits of continued exposure to the stand-biased desks. Both studies were approved through the Institutional Review Board.

Participants were recruited for neurocognitive testing at two time points during the school year: (1) at the beginning of the fall semester and (2) end of the spring semester. Fall/Spring testing was spread across 27.57 (1.63) weeks across all participants. All testing was performed during lunch hours in the school computer lab at a stand-biased desk on computers with standardized keyboards and mice. At the start of both testing times, participants were familiarized with the test protocol and were instrumented with biosensors, described later. A computerized neurocognitive test battery was employed that targeted basic working memory and executive function assessments using the Psychology Experiment Building Language (PEBL; [23]). Participants were familiarized with the tasks before the testing and were instructed to perform the test battery as quickly and accurately as they could.

2.2. Participants

A total of 34 incoming freshman high school students (10 males, 24 females) participated in this study. Descriptive statistics for the study sample are shown in Table 1. There was an attrition rate of 21% resulting in the final study sample of 27. Because the classrooms were already equipped with the stand-biased desks, only new incoming freshman students were recruited for this study to ensure that the participant pool had no prior exposure to the intervention. Parental consent for student participation in the study was in accordance with Institutional Review Board procedures. Letters explaining the study and its purpose were sent home to parents within a general start-of-the-year packet sent with students in September. Parental consent was obtained following a presentation about the study during parent orientation meetings at the start of the school year. Additionally, all participating students were asked to give their individual verbal consent to participate in the data collection portion of the study and were reimbursed with \$25 gift cards post each testing for participating in the study.

Table 1. Participant demographics.

Demographics	Neurocognitive Assessment Group (<i>n</i> = 27)	fNIRS Subgroup (<i>n</i> = 14)
Age (years)	14.30 (0.61)	14.14 (0.36)
Height (m)	1.61 (0.08)	1.64 (0.05)
Weight (kg)	60.64 (12.42)	61.39 (14.52)
BMI (kg/m ²)	23.27 (4.44)	22.74 (4.85)
Sex	M 9, F 18	M 7, F 7
Race (%)		
White	41%	7%
Black	4%	7%
Hispanic	52%	57%
Asian	4%	7%

Data are mean (SD).

2.3. Neurocognitive Assessments

The neurocognitive test battery consisted of five tasks: Wisconsin Card Sorting Task (WCST); Flanker Task (FT); Memory Span Task (MST); Trail-Making Task (TMT), and Stroop Color Word Task (SCWT). The Wisconsin Card Sort Task assesses abstract reasoning abilities, and the ability to modify cognitive strategies according to environmental influences [24]. In the WCST, participants were presented with a card and were asked to sort it into a pile based on an unknown rule. They were instructed to sort based on number of shapes (1, 2, 3, 4), color of shapes (red, green, blue, yellow), or the shape itself (triangle, star, plus, circles). Feedback was provided on the screen with “correct” when the card was sorted correctly or “incorrect” when the card was sorted incorrectly and 140 cards were presented. The cards being sorted remained present until a “correct” response was achieved. Median reaction time for correct and incorrect responses and percentage correct responses were recorded [25]. The Flanker task requires speeded decision-making and discrimination of directionality of a given stimulus with accuracy, and the ability to inhibit responding inaccurately when presented conflicting visual information [26]. In FT, participants were asked to determine the direction of an arrow presented at the center of a screen by pressing the corresponding response button. The arrow was flanked by four arrows pointing either in the same direction (congruent task) or by four arrows pointing in the opposite direction (incongruent task). Participants were instructed to respond as quickly and accurately as possible to the 152 flankers presented to them; median reaction time for the congruent and incongruent tasks, and percent correct responses were obtained [25]. The Memory Span Task is an assessment of working memory responsible for active maintenance of information in the face of ongoing processing and/or distraction [27]. In the MST, participants were presented with a sequence of named images (tree, apple, bird, plane, fish, deer, pear, squirrel, bus). They were required to click on the images in the order in which they were presented. If the sequence was answered correctly, the next list displayed had an additional image. The block consisted of 15 trials and the total number of correct responses were obtained [25]. Both the Trail Making Task and Stroop Color Word Task measure set-shifting/cognitive flexibility [28,29]. In the TMT, participants were asked to connect dots alphabetically or numerically. Four sets were completed; each set included a series of Numbers (1–26), a series of Letters (A–Z), and alternating Number+Letter (1-A-2-B-3-C), for a total of 12 trials. Total time spent on each trial and numbers of errors were recorded [30]. Finally, in the SCWT, participants were asked to respond based on either the color or name of the stimulus presented on the screen (red, green, blue, or yellow). They completed six blocks of 15 stimuli each for a total of 70 responses. Median reaction time for each block was measured [25].

2.4. Prefrontal Cortex (PFC) Activity

PFC activity was measured using functional near infrared spectroscopy (fNIRS) on a small cohort of the participant pool ($N = 14$) when participants were performing the test battery. fNIRS sensors (NIRO 200 NX, Hamamatsu Photonics, Japan) containing one emitter and one detector each were placed bilaterally on the participant’s forehead, between Fpz and Fp3 for the left hemisphere and between Fpz and Fp4 for the right hemisphere according to the International EEG 10–20 system. The sensors were covered with a black headband to eliminate external lights. Based on the manufacturer’s guidelines, the fNIRS system was zero-set at the beginning of the experiment and all future data were presented relative to the zero-set values. Changes in oxygenated hemoglobin (HbO₂) and total hemoglobin (HbT) were recorded continuously from initial values. To obtain baseline cerebral oxygenation levels, participants performed a functional baseline task, where they were instructed to direct their attention to a red cross on the wall in front of them. The baseline HbO₂ and HbT values were subtracted from their respective task-related value, and these normalized values (nHbO₂ and nHbT) were averaged for each neurocognitive test. Given evidence that HbO₂ is a more robust and reliable measure of brain activation than HbT [31,32], it was used as the main measure of functional brain activity.

2.5. Statistical Analyses

All dependent measures were visibly checked for parametric assumptions and follow up Shapiro-Wilk tests determined that all dependent measures were normally distributed. Paired Student T-tests on the two time points (Fall/Spring) were performed for all the neurocognitive metrics. Separate two-way repeated measures analyses of variance (ANOVAs) were used to determine the effects of time points (Fall *vs.* Spring) and hemisphere (left and right) on nHbO₂ and nHbT values across the five cognitive tasks. Statistical significance was determined when $p < 0.05$. Significant interaction effects were examined using pairwise comparisons with Bonferroni corrections as required. All statistical analyses were conducted using SPSS 21 (IBM SPSS Statistics). Summary data are presented as mean (SD).

3. Results and Discussion

3.1. Neurocognitive Assessments

In general, continued utilization of the stand-biased desks (*i.e.*, Spring testing) was either associated with improved task performance or no change from the Fall testing (Figure 1). Specifically, the Paired Student T-test analyses found significant improvements in the neurocognitive metrics in the Wisconsin Card Sort, *i.e.*, median reaction time for correct (~10%; $p < 0.0001$) and incorrect responses (~14%; $p = 0.014$) and percentage correct responses (~13%; $p = 0.016$). No significant changes were observed in the reaction times for congruent ($p = 0.112$) or incongruent ($p = 0.079$) responses, or percent correct congruent ($p = 0.18$) and incongruent responses ($p = 0.749$) over time in the Flanker test. Similarly, performance on the Memory Span test was comparable between Fall/Spring semesters ($p = 0.09$). While percent correct responses did not change from the Fall to Spring on any of the Trail Making tests (all $p > 0.205$), a significant decrease in the total time to perform the TMT Letters (~7%; $p = 0.012$) and TMT Number+Letter (~14%; $p > 0.0001$) was observed. Finally, reaction times on the Stroop Color Word decreased significantly in the Spring semester (~13%; $p = 0.001$), with no changes observed with percent correct responses ($p = 0.239$).

3.2. PFC Activity

No significant main effects of time points (all $p > 0.212$) or hemisphere (all $p > 0.194$) were found on nHbO₂ levels across all five tasks. However, significant time point x hemisphere interactions were found during WCST ($F_{(1,12)} = 5.2$; $p = 0.042$), MST ($F_{(1,12)} = 4.62$; $p = 0.05$), and TMT ($F_{(1,12)} = 5.84$; $p = 0.033$). Post hoc comparisons revealed that greater activation in the right hemisphere was observed when performing WCST in Fall when compared to the Spring semester (Figure 2). Interestingly, the post hoc comparisons for MST and TMT revealed that greater activation in the left hemisphere was found in the Spring when compared to the Fall semester (Figure 2). A similar trend was noted during SCWT, however this effect was marginally significant ($F_{(1,12)} = 4.39$; $p = 0.058$).

nHbT values were found to remain stable across both time points (*i.e.*, Fall and Spring) across all the tests in the neurocognitive test battery (all $p > 0.114$; Figure 3). However, nHbT levels were significantly higher in the left hemisphere during the Stroop Color Word test ($F_{(1,12)} = 19.22$; $p = 0.001$), while no differences were seen across hemispheres, or their interaction with time points, across any other tests (all $p > 0.117$).

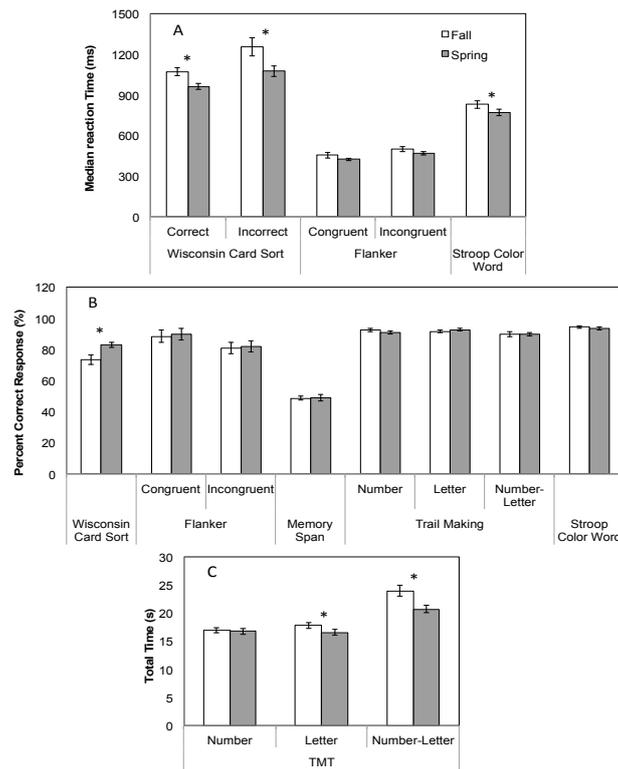


Figure 1. Performance metrics ((A) median reaction time; (B) percent correct responses; (C) total time) across Fall/Spring test points on the neurocognitive test battery. The symbol * indicates a significant ($p < 0.05$) difference between the Fall and Spring semester within each test. Error bars represent standard error.

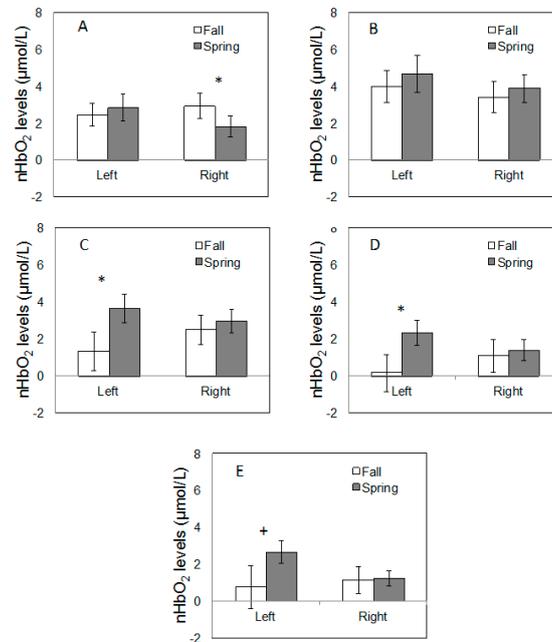


Figure 2. Right and left prefrontal cortex activation (nHbO₂ values) during the neurocognitive tests ((A) Wisconsin Card Sort; (B) Flanker; (C) Memory Span; (D) Trail Making; (E) Stroop Color Word). The symbols * and + indicate significant ($p < 0.05$) and marginally significant ($0.1 > p > 0.05$) interactions between test points (Fall vs. Spring) and hemisphere (left vs. right). Error bars represent standard error.

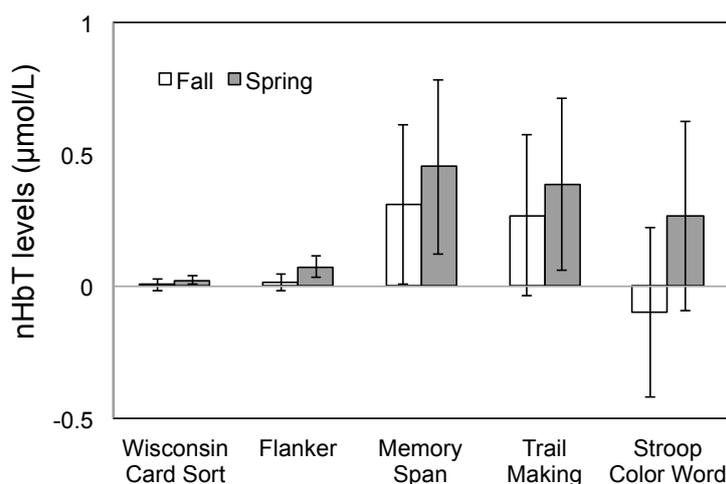


Figure 3. Total hemoglobin levels (nHbT) during the neurocognitive tests pooled across hemisphere. Error bars represent standard error.

4. Discussion

The present study explored the neurocognitive benefits of stand-biased school desks among freshman high school students over the course of two semesters. In general, continued utilization of the stand-biased desks was largely associated with improved executive function and working memory capabilities. Concomitant with these outcomes, brain imaging using fNIRS revealed significant left frontal lobe activation during three of the five tasks. These findings provide the first preliminary evidence on the neurocognitive benefits of standing desks, which to date have focused largely on energy expenditure. Moreover these findings implicate the importance of stand-biased desks, as simple environmental changes in classrooms, on enhancing children's cognitive functioning that drive their cognitive development and impact educational outcomes.

School-based vigorous exercise and/or physical activity interventions have been linked to enhanced cognitive functioning in children [3,22] and research, both animal and human studies, has demonstrated exercise-facilitated improved cognition to enhanced brain functioning [11,12,33]. The present study reported ~7%–14% improvement in cognitive performance across several executive function and working memory tasks; this improvement range was consistent with that reported in a 13-week low to vigorous exercise program [10]. Moreover, Davis *et al.* [10] reported program-related improvements in PFC activation using functional magnetic resonance imaging, which are consistent with fNIRS findings obtained in the present study. Of the studies that examine physical activity improvements with standing desks, Koepp *et al.* [8] and Dornhecker *et al.* [4] reported that stand-biased desks facilitate student learning, as perceived by the teachers, and more importantly the desks do not create a distraction in the classroom. The present study extends this literature by providing evidence on improved executive function, working memory, and brain activation changes due to the standing desks.

Due to the exploratory nature of the study, some limitations are recognized. First, there was no comparison group to evaluate the benefits of the standing desk intervention against a control. Thus, the cognitive improvements observed could be attributed to factors other than the continued exposure to the standing desk environment, such as cognitive improvements with age, or school-related educational activities over time. Studies have demonstrated that executive function and working memory capabilities, such as those tested in this study, have shown to mature around age 12 [34]. Additionally, given that the time between testing was ~27.5 weeks, it is unlikely that these factors could influence the findings observed. Testing a physical intervention, *i.e.*, change to classroom furniture, is challenging due to intervention contamination issues, particularly in a high school

setting, since students move between classrooms. Future work may address this limitation by testing multiple schools with control/intervention assignments. Second, only a small cohort of the high school student population (*i.e.*, incoming freshman students) was studied and only in one high school. It is likely that the statistical analyses may be affected by the small sample size. Because several comparisons were tested, a repeated measures design was employed to test the impact of standing desk exposures over time. Even so, future research is warranted that include larger samples and multiple schools to generalize these findings to the broader school-based population. Third, data was collected on a neurocognitive test battery evaluating specific executive function and working memory tasks to minimize any influence of classroom set-up of standing desks on lesson delivery and student learning. In order to comprehensively understand the educational benefits of standing desks, academic performance on standardized tests may serve as a more direct and usable metric for school administration and health professionals for policy/program considerations. Moreover, a greater focus on how such dynamic classrooms impact lesson delivery due to desk arrangements and teacher motivation are also warranted.

5. Conclusions

In comparison to most school-based physical activity programs, standing desk interventions are non-intrusive—*i.e.*, does not require any additional training, instructional time, nor accommodations and therefore does not tax school resources. As such, results from the present study make an important first contribution to the existing knowledge base regarding the relationships between physical activity, basic cognition, and brain function in adolescents. Future work on larger samples, in multiple schools, with comparison groups, over a longer time period is warranted to confirm these preliminary findings. While preliminary, continued investigation of this research may have strong implications for policy makers, public health professionals, and school administrators to consider simple and sustainable environmental (*i.e.*, furniture) changes in classrooms that can effectively increase energy expenditure and physical activity as well as ensure (and enhance) cognitive development and educational outcomes.

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Author Contributions: All authors conceived and designed the experiments; Ashley E. Shortz performed the experiments; Ranjana K. Mehta analyzed the data; all authors contributed to manuscript development and review.

Conflicts of Interest: Ranjana K. Mehta and Ashley E. Shortz declare no conflict of interest. Mark E. Benden declares a financial conflict of interest since his U.S. patented designs have been licensed by Texas A&M University to PositiveMotion, Stand2Learn and NextDesk, and those designs have been present on several models of desks purchased for use in his studies.

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