Cybercycling Effects on Classroom Behavior in Children With Behavioral Health Disorders: An RCT

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abstract

BACKGROUND AND OBJECTIVES: Exercise is linked with improved cognition and behavior in children in clinical and experimental settings. This translational study examined if an aerobic cybercycling intervention integrated into physical education (PE) resulted in improvements in behavioral self-regulation and classroom functioning among children with mental health disabilities attending a therapeutic day school.

METHODS: Using a 14-week crossover design, students (N = 103) were randomly assigned by classroom (k = 14) to receive the 7-week aerobic cybercycling PE curriculum during fall 2014 or spring 2015. During the intervention, children used the bikes 2 times per week during 30- to 40-minute PE classes. During the control period, children participated in standard nonaerobic PE. Mixed effects logistic regression was used to assess relationships between intervention exposures and clinical thresholds of behavioral outcomes, accounting for both individual and classroom random effects.

RESULTS: Children experienced 32% to 51% lower odds of poor self-regulation and learning-inhibiting disciplinary time out of class when participating in the intervention; this result is both clinically and statistically significant. Effects were appreciably more pronounced on days that children participated in the aerobic exercise, but carryover effects were also observed.

CONCLUSIONS: Aerobic cybercycling PE shows promise for improving self-regulation and classroom functioning among children with complex behavioral health disorders. This school-based exercise intervention may significantly improve child behavioral health without increasing parental burden or health care costs, or disrupting academic schedules.

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Ms Bowling helped design and manage implementation of the study, carried out the analyses, and drafted the initial manuscript; Drs Davison and Slavet conceptualized the study, oversaw its design and implementation, coordinated and supervised data collection, and critically revised the manuscript; Dr Haneuse provided analytical guidance, critically reviewed analysis results, and reviewed the manuscript; Dr Miller assisted with database development and management, developed the initial analytical plan, and critically revised the manuscript; Dr Beardslee provided critical feedback on study design, study measures, and implications of study findings and reviewed the manuscript; and all authors approved the final manuscript as submitted.

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WHAT'S KNOWN ON THIS SUBJECT: Children with behavioral health disorders (BHD) demonstrate low participation in aerobic exercise. Research shows exercise improves mood and behavior in children and lowers chronic disease risks, but little research exists in educational settings serving children with complex BHD.

WHAT THIS STUDY ADDS: Using a randomized controlled crossover design, we investigated whether an aerobic cybercycling physical education curriculum could successfully engage and improve behavioral regulation and classroom functioning among children and adolescents with complex BHD.

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The Centers for Disease Control and Prevention reports 13% to 20% of children living in the United States experience behavioral health disorders (BHD) in a given year; such disorders are among the most costly conditions to treat in children.[1] Those experiencing BHD have other chronic health conditions (eg, asthma, diabetes) more often than children without BHD.[1,2]

Meanwhile, there is growing evidence that children with BHD are less likely to engage in aerobic exercise/physical activity than their typically developing peers.[3,4] This can occur for many reasons, including exclusion from sports due to behavioral problems, comorbid sensory issues, delayed motor skills, and anxiety.[4,5] Low engagement in aerobic activity is linked with lower fitness, which may then additionally discourage exercise participation.[3]

Low engagement in exercise is particularly troubling given these children's increased risk for chronic diseases and evidence that exercise may have cognitive, behavioral, and emotional benefits. Relatively short bouts of exercise have been shown to improve impulsivity and mood state among typically developing children and those with a single BHD, such as attention-deficit/hyperactivity disorder, autism, or depression.[6–8] Exercise intensity has also been linked to cognitive effects in children; 1 study found that vigorous intensity exercise resulted in better executive function outcomes than moderate/light intensity exercise.[9]

These findings emphasize the importance of finding aerobic exercise modalities that overcome the engagement challenges facing this population of children with BHD. However, this research has not been translated into special education settings or extended to examine effects in children with heterogeneous BHD. Thus, in this study, we examine if a cybercycling physical education (PE) intervention, which successfully engages children with BHD in aerobic exercise,[10] is linked to improvements in behavioral self-regulation and classroom functioning relative to standard nonaerobic PE.

METHODS

Setting and Participants

The study was conducted at a therapeutic day school affiliated with Harvard Medical School. The school enrolls ~110 children each year in kindergarten through 10th grade with diagnosed BHD, many of whom have learning disabilities, but does not serve children with intellectual disabilities.

Students are predominantly boys and have multiple diagnoses; in an average school year, ~40% of enrolled students are diagnosed with autism, 60% with attention-deficit/hyperactivity disorder, 40% with an anxiety disorder, and 30% with a mood disorder. There are 14 classrooms, each with a head teacher, an assistant teacher, and a classroom counselor. Students are engaged with a variety of in-school service providers including psychologists, occupational therapists, and speech pathologists.

Intervention Design

A 14-week crossover design was used. Children were randomly assigned by classroom to receive the 7-week intervention during the fall or spring, with a 10-week washout period between treatment arms. A simple random number generator was used to assign 7 classes to the fall treatment; the remainder served as the fall control group and received treatment in the spring. Detailed information on the intervention and its development is published elsewhere.[11]

The intervention, known as "Manville Moves," featured a progressive and aerobically challenging PE curriculum using virtual-reality exergaming stationary bicycles (cybercycles). The curriculum overview is shown in Supplemental Fig 3. Existing PE efforts at the school were not successful at engaging the majority of children in extended bouts of aerobic exercise. Therefore, the exercise modality was selected to optimally engage children with complex BHD who, again, often face exercise engagement challenges, such as sensory processing disorders, low fitness levels, socialization challenges, and motor delays; the curriculum was designed to gradually accustom participants to riding for extended durations and higher intensities.

During the intervention, children used the bikes 2 times per week during 30- to 40-minute PE classes, starting at 10 minutes riding duration and building to >20 minutes over the 7-week period. During the control period, children continued to participate in standard PE programming (2 times per week × 30–40 mins). Standard PE is focused on games to build socialization and team skills as well as motor skill acquisition through activities, such as basketball shooting; thus, there are only short bouts of aerobic exercise and many students struggle to remain engaged even with extensive staff attention.

The study protocol was reviewed and approved by the Harvard T.H. Chan School of Public Health Institutional Review Board. The intervention was codesigned by school personnel and the research team and implemented during the 2014–2015 academic year. The school elected to integrate the intervention into school programming; thus, an opt-out consent process was used. Demographic/baseline data were obtained by using an online caregiver survey after an active consent process.

Objectives

The study's first research aim was to determine if students had improved classroom functioning demonstrated through reduced disciplinary

time out of class (TOC), as well as improved self-regulation scores when participating in the intervention PE curriculum compared with standard nonaerobic PE. Thus, the first aim was to assess the combined acute and chronic effects of exercise, along with programmatic effects of the intervention, over the duration of the 7-week intervention compared with the 7-week control condition.

The second research aim was to specifically assess the acute effects of exercise by examining behavioral changes only on days that children participated in the aerobic cybercycling PE intervention compared with the control condition.

Exposure and Outcomes

Exercise exposure was measured using the data captured by the bicycles via student-specific login codes. Data compiled for each riding bout included timestamp, average heart rate, and minutes of riding. Student refusals to ride, as well as any occurrences of mechanical or electrical failure, were documented on paper. It was not feasible to collect objective exercise data for the control condition because children would not tolerate wearing heart rate monitors or accelerometers. However, the standard PE curriculum did not include programming targeting aerobic exercise while children were in the control condition. Additional information on fidelity of implementation and student engagement is described elsewhere.[10]

Behavioral self-regulation was operationalized by using the Conners' Abbreviated Teacher Rating Scale (CATRS-10), a validated screening instrument for behavioral problems related to inattention, impulsivity/hyperactivity, and emotional lability.[12,13] Classroom counselors completed the CATRS-10 at the end of each school day for each student. The instrument consists of 10 statements regarding the child's behavior rated on a 4-point Likert scale, with a total score ranging from 0 to 30.[13] A score of ≥15 has been the standard for screening children with symptomatology at a level of clinical concern.[14–16] Equivalent screening thresholds were used for the emotional lability subscale (4 questions, ≥6 out of a possible 12) and impulsivity subscale (6 questions, ≥9 out of a possible 18).

Because the classroom counselors accompanied students to PE, it was not possible to blind them to the participants' treatment group assignment. However, the counselors were not explicitly informed of the study objectives and received no incentives dependent on the participants' treatment group assignment. They were also prevented from viewing previous recordings of CATRS-10 to help prevent manipulations of variability based on previous measurements. The study coordinator for the school reviewed counselor reporting records on a weekly basis to ensure compliance. A research assistant was also assigned to check CATRS-10 scores for variability on a bi-weekly basis; no statistically significantly decrease in reporting variability was observed during the course of the study. In addition, no differences in reporting patterns were observed on days when floating counselors filled in for classroom counselors who were absent. Of note, the floating counselors did not attend PE sessions with the class and therefore were not aware of their treatment status.

Classroom functioning was operationalized based on TOC. When teachers determined a child must leave class due to unacceptable behavior, counselors recorded the event using the mobile survey platform to enter the student identification code and number of minutes for each TOC event as it occurred. This measure yielded minutes of TOC per day and number of TOC events per day for each student. Teachers followed a school-wide policy when determining whether a child receives TOC and, unlike counselors, were blinded to treatment status. Because recording TOC has been a longstanding procedure, and any TOC must be reported to parents, we feel that this measure is less vulnerable to subjective interpretation or bias if the treatment status was learned by teachers.

School clinicians established a priori thresholds for clinically relevant TOC per day that constituted either a disruption to a student's ability to learn classroom material (defined as ≥1 events per day regardless of cumulative time or ≥10 minutes per day regardless of total number of events), or prevented meaningful learning for that day (defined as ≥5 events per day or ≥90 minutes per day).

Sample Size and Analytical Plan

Because exposures and outcomes were measured each day, the relevant unit of analysis for the study is a child-day. A logistic-normal mixed effects regression model[17] was used to assess relationships between intervention exposures and clinical thresholds of behavioral outcomes accounting for both individual and classroom random effects. Outcome variables were dichotomous indicators of whether a child exceeded clinical or screening thresholds for either classroom functioning, measured by TOC, or self-regulation by using the CATRS-10.

The maximum possible sample size was 109 based on school enrollment, and a priori power calculations indicated that a sample of at least 75 students would provide power >90% to detect the small to moderate effect sizein executive functioning evident in the literature.[6,18,19] Given nearly universal participation, daily outcome measurements, crossover design, and minimal attrition, the sample size was more than adequate.

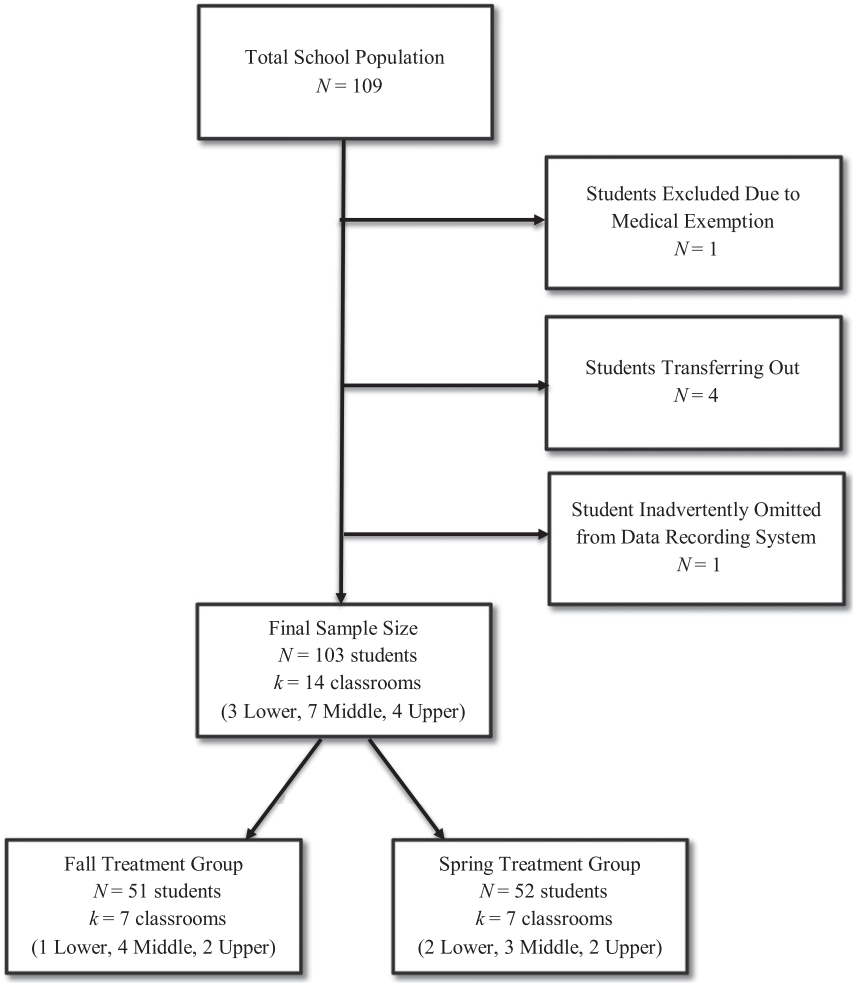

FIGURE 1
Enrollment, randomization, and attrition flow diagram (Consolidated Standards of Reporting Trials). Lower, elementary school classroom; Middle, middle school classroom; Upper, high school classroom.

The number of child-days varied by outcome and are described in the results section.

The primary models tested aim 1 (ie, the overall treatment effect of the intervention) for each outcome measure. Treatment status and treatment order were included in each model as independent variables to evaluate overall treatment effects while accounting for potential seasonality/contamination effects. The secondary models assessing aim 2 (ie, the acute exercise effects of the intervention) additionally included terms indicating whether a child participated in the cybercycling PE class intervention on that day. Finally, the models were also run introducing a dichotomous variable representing whether the students used the bikes in the virtual course mode or the video gaming mode to test for potential exergaming effects. All statistical analyses were conducted in Stata version 13.1 (Stata Corp, College Station, TX), by using a two-tailed significance level of $P = .05$.

RESULTS

Demographic Characteristics

Figure 1 shows the CONSORT enrollment, randomization, and attrition flow diagram. The final enrollment was $N = 103$ students; the fall intervention arm included $n = 51$ students in 7 randomly assigned classrooms, and the spring intervention arm included $n = 52$ students in the remaining 7 classrooms. Baseline demographic data are contained in Table 1. Participants were 83.5% boys, and ages ranged from 7 to 16 years with a mean of 11.8 years. No adverse events occurred during the intervention.

TABLE 1 Baseline Participant Characteristics

	Overall ($N = 103$)
Boys, *N* (%)	86 (83.5)
Age, y, mean (range)	11.8 (7–16)
Multiple diagnoses, *N* (%)[a]	46 (57.5)
Taking medication, *N* (%)[a]	39 (50.7)
Race/ethnicity, *N* (%)[a,b]	
Black	7 (8.8)
White	68 (85.0)
Other	4 (5.0)
Eligibility free/reduced-cost lunch, *N* (%)[a]	23 (29.9)
Met fitness standards at baseline, *N* (%)[c]	11 (17.8)

[a] Subset of students for whom a guardian returned a baseline survey ($n = 80$).
[b] One family declined to answer so categories do not add to 100%.
[c] Subset of students who participated in baseline fitness testing ($n = 62$).

Documentation of the Exposure and Outcome Variables

There were 913 cybercycling PE days; average cycling duration in class was 16.1 (±5.3) minutes, while average heart rate was 146.6 (±25.3) beats per minute. This indicates that students achieved sustained aerobic exercise[20] during cybercycling PE classes on average.

For the classroom functioning outcome of TOC, there were 6419 observations recorded over both intervention periods (fall, $n = 3318$, mean minutes per day, $\bar{x} = 17.44 \pm 50.11$; spring, $n = 3101$, $\bar{x} = 17.48 \pm 54.18$), of which there were 2122 instances of students having ≥1 removals from class in a day (fall, $n = 1205$; spring, $n = 917$). There were 5252 observations of CATRS-10 scores recorded (fall, $n = 2378$, mean score, $\bar{x} = 9.03 \pm 7.02$; spring, $n = 2874$, $\bar{x} = 8.50 \pm 6.52$); of those,

955 exceeded the clinical screening threshold for disruptive behavior (fall, n = 475; spring, n = 480). Treatment order was not found to be significant in any of the models. Individual and classroom random effects are controlled for in all analyses; children serve as their own controls and group level differences in outcome variables between fall and spring do not affect the validity of analyses. Compared with days in the control condition, percentages of children exceeding screening thresholds for overall CATRS-10 score and both impulsivity and emotional lability subscores declined on days in the intervention condition and were lowest on days when the children participated in cybercycling PE class (Fig 2). Post-hoc tests found no evidence of time-of-day effects for morning versus afternoon PE classes.

Models Testing Overall Intervention Effect (Aim 1)

Results (Table 2, Model 1) show clinically significant intervention effects. While in the 7-week intervention, students experienced significantly reduced odds of exceeding screening thresholds for total CATRS-10 score (odds ratio [OR], 0.68; 95% confidence interval [CI], 0.57–0.81), emotional lability subscore (OR, 0.64; 95% CI, 0.52–0.77), and impulsivity/hyperactivity subscore (OR, 0.49; 95% CI, 0.36–0.67), relative to when they participated in standard nonaerobic PE (ie, the control condition). Students also experienced significantly lower odds of having ≥5 TOC events (OR, 0.54; 95% CI, 0.32–0.91). The overall treatment effect was not significant for learning disruptive TOC outcomes (1+ events, 10+ minutes) or preclusive to learning TOC minutes (90+ minutes).

Models Testing Acute Exercise Effects (Aim 2)

The effects of acute exercise were significantly more pronounced than the overall intervention effects (Table 2, Model 2). On days that students participated in an intervention PE class, they experienced clinically and statistically significantly reduced odds of exceeding screening thresholds for total CATRS-10 score (OR, 0.29; 95% CI, 0.14–0.61), emotional lability subscore (OR, 0.24; 95% CI, 0.11–0.53), and impulsivity/hyperactivity subscore (OR, 0.28; 95% CI, 0.13–0.59), relative to the control condition. Acute effects of cybercycling PE class also resulted in significantly reduced odds of both learning-disruptive and preclusive TOC events (OR, 0.43; 95% CI, 0.26–0.72; OR, 0.10; 95% CI, 0.02–0.61) and minutes (OR, 0.50; 95% CI, 0.29–0.89; OR, 0.34; 95% CI, 0.14–0.84). Treatment order and video gaming mode were not significant in any of the models.

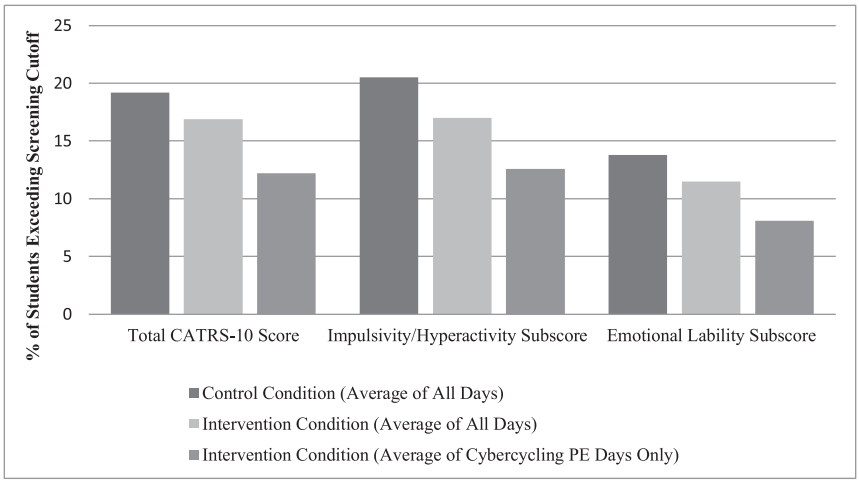

FIGURE 2
Percentage of participants exceeding CATRS-10 screening thresholds as a function of study condition.

TABLE 2 Overall Intervention and Cybercycling PE Effects on Behavioral Outcomes Compared With Control Condition

Outcome	Overall Intervention Effect, Adjusted OR (95% CI)[a]	Intervention Effect on Cybercycling PE Days, Adjusted OR (95% CI)[b]
	(Model 1)	(Model 2)
Exceeds Total CATRS-10 Screening Threshold	0.68 (0.57– 0.81)	0.29 (0.14–0.61)
Exceeds Impulsivity/Hyperactivity Threshold	0.49 (0.36–0.67)	0.28 (0.13–0.59)
Exceeds Emotional Lability Threshold	0.64 (0.52–0.77)	0.24 (0.11–0.53)
1+ TOC events/day	1.04 (0.92–1.18)	0.43 (0.26–0.72)
5+ TOC events/day	0.54 (0.32–0.91)	0.10 (0.02–0.61)
10+ TOC minutes/day	1.03 (0.89–1.18)	0.50 (0.29–0.89)
90+ TOC minutes/day	1.04 (0.84–1.31)	0.34 (0.14–0.84)

[a] Adjusted for treatment order and accounting for random effect of individual and random effect of classroom assignment. Odds relative to any day in the control condition.
[b] Adjusted for treatment order, elective biking days, and nonadherent PE class days in the treatment condition. Odds relative to nonbiking days in the control condition.

DISCUSSION

This study provides compelling evidence that children and adolescents with multiple, heterogeneous BHD in a school setting can successfully engage in and experience behavioral benefits from an aerobic, cybercycling PE curriculum. Across the intervention period, odds that children would display clinically disruptive behaviors, including impulsivity and emotional lability, were 32% to 51% lower than during the control condition. These effects strengthened on days when children participated

in an intervention cybercycling class; here, odds of disruptive levels of behavioral dysregulation declined between 71% and 76% relative to the control condition. Acute exercise led to significant declines in odds of receiving learning disruptive and preclusive amounts of disciplinary TOC. These results build on previous research showing positive effects of aerobic exercise on mood and impulsivity in children, and translate those findings into a program implemented in a real world setting with children with multiple BHD.

The primary research aim was to determine whether intervention participation resulted in improved behavioral outcomes for students; this was the case; however, effects were more pronounced on days when the children participated in the structured, aerobic cybercycling PE classes. So although there seemed to be chronic exercise and programmatic effects of this intervention on behavioral self-regulation and classroom functioning even on days when children did not bike, acute exercise is the primary driver of the intervention effect. This finding is consistent with previous studies and proposed mechanisms by which neuroendocrine and reticular-activating systems affect mood and functioning in areas of the brain related to executive function and impulse control.[21]

Although it was impossible to blind counselors to the intervention condition, we feel risk of bias in recording student behaviors due to knowledge of treatment status was low. Neither teachers nor counselors were aware of the primary study hypotheses. Also, the outcome of disciplinary TOC is determined by classroom teachers who were not aware of treatment condition. Post-hoc tests for bias included comparison of CATRS-10 by blinded (floating) and nonblinded counselors, which indicated no reporting differences, and examination of scores on days students electively rode. If counselors were aware of the hypothesis/biased in reporting, scores should have been lower for children on those days as they were for cybercycling PE days because counselors accompany them to ride; in fact, point estimates indicated worse scores than on nonriding days (not statistically significant).

In addition to aerobic exercise, the cybercycling PE classes may hold several other advantages over standard PE programming. They require fewer transitions, which are often challenging to children with BHD. Also, the cybercycling PE allowed students to avoid peer judgments of performance, because other students could not see their performance data unless they shared it. It was also less noisy and chaotic than standard PE classes.[10] However, it is important to note that a standard PE class may confer its own benefits, including motor skill acquisition, team sports practice, and socialization. Cybercycles are also relatively expensive; because the key is overcoming aerobic exercise engagement barriers, other modalities should be explored with similar populations.

Because the intervention was implemented as part of school programming, participation was nearly universal; therefore, selection biases that generally accompany active participant recruitment and consent protocols were avoided. The generalizability of the results is enhanced because participants had a wide variety of diagnoses, including complex comorbidities. Finally, this study demonstrates strong ecological validity because the intervention was conducted within the existing school schedule and staffing. This improves potential for scale-up/dissemination in more diverse settings catering to children with BHD.

Despite these strengths, the generalizability of the results is limited by the setting and population targeted. Therapeutic day schools serve children who have been unsuccessful in public school special education environments. Thus, findings from this study are limited to students with substantial BHD. Future research that tests the intervention in special education programs in public schools is needed to determine if a broader group of children may benefit from the program.

Despite overall cuts to PE class-time allocation,[22] efforts are taking place across the United States to allow movement in classrooms to facilitate improved learning and behavior.[23] However, although children with BHD may benefit the most from the effects of aerobic exercise, they are least likely to be easily engaged in such activities. This study shows that a cybercycling PE curriculum can successfully engage children with a variety of complex BHD in high-quality aerobic exercise and, as a result, they experience significant improvements in important behavioral measures. Critically, such a curriculum can successfully affect student behavior within existing school programming with short durations and low frequency.

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ABBREVIATIONS

BHD: behavioral health disorder
CATRS-10: Conners' Abbreviated Teacher Rating Scale
CI: confidence interval
OR: odds ratio
PE: physical education
TOC: disciplinary time out of class

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