Exercise Intervention for Academic Achievement Among Children: A Randomized Controlled Trial

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abstract

OBJECTIVES: Physical inactivity is an important health concern worldwide. In this study, we examined the effects of an exercise intervention on children's academic achievement, cognitive function, physical fitness, and other health-related outcomes.

METHODS: We conducted a population-based cluster randomized controlled trial among 2301 fourth-grade students from 10 of 11 public primary schools in 1 district of Ulaanbaatar between February and December 2018. Schools were allocated to an intervention or control group with 5 schools each by using urban and mixed residential area stratified block randomization. The intervention group received a 3-minute high-intensity interval exercise program that included jumps, squats, and various steps implemented twice weekly over 10 weeks for 10 to 25 minutes per session. The control group received the usual physical education class. The primary outcome was academic achievement assessed by scores on the national examination. A linear mixed-effects model was applied. The difference between preintervention and post intervention was compared by least-squares means, estimated on the basis of the interaction of group, measurement time point, and school location. Only 1 statistician, responsible for the analysis, was blinded.

RESULTS: Of 2301 students, 2101 (1069 intervention; 1032 control) were included in the analysis. Intervention group members in an urban area showed an 8.36-point improvement (95% confidence interval: 6.06 to 10.66) in academic scores when compared with the control group, whereas those in a mixed residential area showed a 9.55-point improvement (95% confidence interval: 6.58 to 12.51). No intervention-associated injuries were observed.

CONCLUSIONS: The exercise program significantly improved children's academic achievement.

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WHAT'S KNOWN ON THIS SUBJECT: The evidence on the effect of a physical activity intervention on academic achievement remains weak, especially in lower income countries. A meta-analysis revealed its effect on mathematics and reading, and another only revealed its effect evaluated by a progress-monitoring tool.

WHAT THIS STUDY ADDS: This study revealed the effectiveness of a physical activity intervention on children's academic achievement by a high-quality population-based cluster randomized controlled trial. This study adds robust evidence to the literature and contributes to the promotion of physical activity among children.

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Physical activity interventions reduce obesity among school-aged children and adolescents.[1] In addition, the effects of physical activity on broader aspects, such as children's academic achievement and cognitive function, are increasingly being reported.[2–4] Because school education has focused more on basic literacy and numeracy skills and disregarded physical education, the effects of physical activity on academic achievement are gaining attention.[5,6] The effect of physical activity on children's academic achievement and cognitive function has been investigated in several studies from high- and upper middle-income countries.[7–10] Although authors of systematic reviews have reported that physical activity positively affects children's academic achievement and cognitive function, meta-analyses have indicated that strong evidence is still lacking.[11–16]

The World Health Organization (WHO) provides recommendations on children's physical activity for acquiring physical and psychological health benefits.[17] Establishing appropriate physical activity habits in childhood and maintaining these into adulthood can reduce the risk of morbidity and mortality from noncommunicable diseases.[17] Despite physical activity importance, an estimated 81% of adolescents are physically inactive globally.[18] The WHO has set a 15% relative reduction of insufficient physical activity as a global noncommunicable disease target for 2030.[19] Globally, ~90% of children live in low- to middle-income countries (LMICs),[20] and the prevalence of physical inactivity among adolescents in LMICs is 79% to 85%.[18] Physical inactivity is especially serious in urban areas.[21] Physical inactivity among children in LMICs is associated with structural factors, such as lack of indoor and outdoor play space, load safety, security, and air pollution, in rapidly urbanizing, overcrowded cities.

Schools are among the most appropriate settings to provide physical activity intervention for children in LMICs, where children have fewer opportunities for structured after-school sports activities and are less exposed to health information promoting physical activities outside school.[5] Furthermore, at school, interventions can be delivered equitably to a large portion of the school-aged population, including the socially disadvantaged. High-intensity interval training (HIIT) is a potentially effective method for physical activity intervention among children in LMICs regarding its health benefits and feasibility in LMICs. HIIT impacts physical fitness, obesity, and cognitive function among children.[22–25] However, large-scale trials have not been conducted. HIIT has high feasibility because it requires only a small space and short periods.

Therefore, we hypothesized that a short HIIT-based physical activity intervention delivered at school would improve children's academic achievement and other health outcomes. We examined its effects through a population-based cluster randomized controlled trial (RCT).

METHODS

Study Design and Participants

This population-based cluster RCT was conducted in the Sukhbaatar District, Ulaanbaatar, Mongolia, from February to December 2018. The study schedule is presented in Fig 1. The study design and methods are detailed in the protocol.[26] The World Bank classifies Mongolia as a lower middle-income country, with strong structural factors contributing to children's physical inactivity.[27] Half of the country's population resides in Ulaanbaatar, where urbanization is rapid, leaving little space for outdoor play.

We selected 10 of the 11 Sukhbaatar public elementary schools as a cluster for this study. One other school was used for a pilot study that was used to assess feasibility.

We enrolled all children who met the following inclusion criteria: (1) were in fourth grade at one of the included schools, (2) had written consent from parents or guardians, and (3) were able to speak, read, and understand Mongolian. The exclusion criteria were (1) having comorbidities or contraindications prohibiting exercise program participation and (2) attending special-curriculum classes. Recruitment started February 1, 2018. The school's teachers and guardians or parents assessed eligibility before the schools were randomly assigned. The ethical committees at the National Center for Child Health and Development (Japan) and the Mongolian National Institute of Physical Education (MNIPE) approved this study.

Consent to participate was obtained from all 10 school directors. Because the participants were minors, they were enrolled after written consent had been obtained from their guardian or parents. Informed assent was not obtained, but guardians and parents were encouraged to explain the study to their children.

Randomization and Masking

Stratified block randomization was used to randomly allocate the 10 cluster schools into the intervention and control groups. To ensure balance of socioeconomic status and lifestyle between the groups, we considered in the stratification school location (urban and mixed residential area) and population size, with a block size of 2. School location is officially determined by

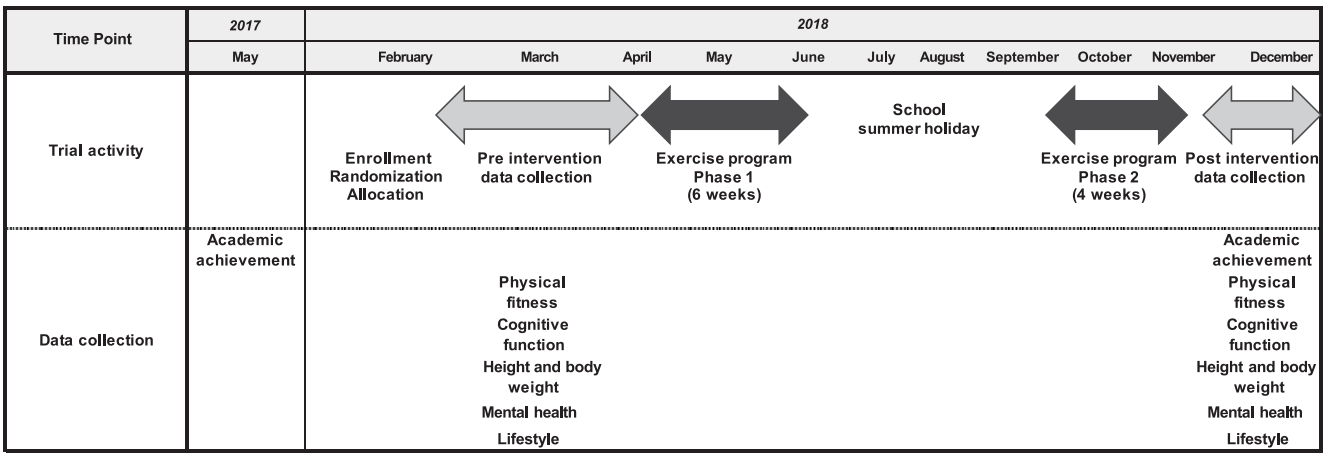

FIGURE 1
The schedule of enrollment, randomization, allocation, intervention, and data collection.

the local government and by subdistrict level.[28] Six schools were in the urban area; thus, 3 were randomly assigned to the intervention group, and the remaining 3 were assigned to the control group. Similarly, 4 schools in the mixed residential area were randomly assigned to these groups (Fig 2). The random allocation sequence was performed with computer-generated random numbers by using R version 3.3.2. The participants, schoolteachers, and data collectors were not blinded to the intervention assignment. One researcher (M.M.) performed masked statistical analyses with raw data sets using a dummy variable.

Intervention Program

The intervention implementation comprised 2 phases (Fig 1). In the preparation phase, which lasted 6 weeks from April to June 2018, the participants performed ∼20-minute exercise programs aimed at practicing the movements and synchronizing them with music. In the second phase, which lasted 4 weeks from October to November 2018, the participants performed ∼10-minute exercise programs consisting of a 3-minute main session and stretching. For the rest of the class, participants underwent the normal physical education class.

For the intervention program, we adopted an HIIT-based exercise program combined with music. The program comprised 4 exercise parts separated by rest intervals. The exercise parts had various types of movements intended to improve not only aerobic fitness but also basic motor skills. We used music originally arranged and optimized to support dynamic and fluid movement of children. The music tempo was gradually increased to let exercise intensity increase incrementally. We also added well-timed cues providing movement instruction in Mongolian (Supplemental Information).

Several groups of MNIPE teachers and research assistants (RAs) instructed and administered this intervention program.

Control group participants received the usual physical education class consisting of a 10-minute warm-up and stretching; 30-minute activities, such as small-sided team sport games, for example, basketball, jump rope, and throw and catch activities; and a 5-minute cooldown.[29,30] Main activities were scheduled and followed the official physical education curriculum from March to November 2019. Control group participants received the intervention program from RAs after the study period.

Outcomes

The primary outcome was academic achievement, assessed by the participants' total mathematics and Mongolian language scores on the national examination. The participants' scores ranged from 0 to 100 points, meaning the total score for both ranged from 0 to 200 points.

The secondary outcomes were the individual mathematics and Mongolian scores, cognitive function, the proportion of children with obesity and overweight, physical fitness (20-m shuttle run, side-to-side jumps), lifestyle (sleep, exercise, hours playing outside), and mental health.

Cognitive function was assessed by using the Flanker test (assessing inhibitory control of executive function) with an originally designed application accessed through a tablet. Stimuli appeared on the screen for 2 seconds, with 2- to 5-second interstimulus intervals. The Flanker effect and the number of

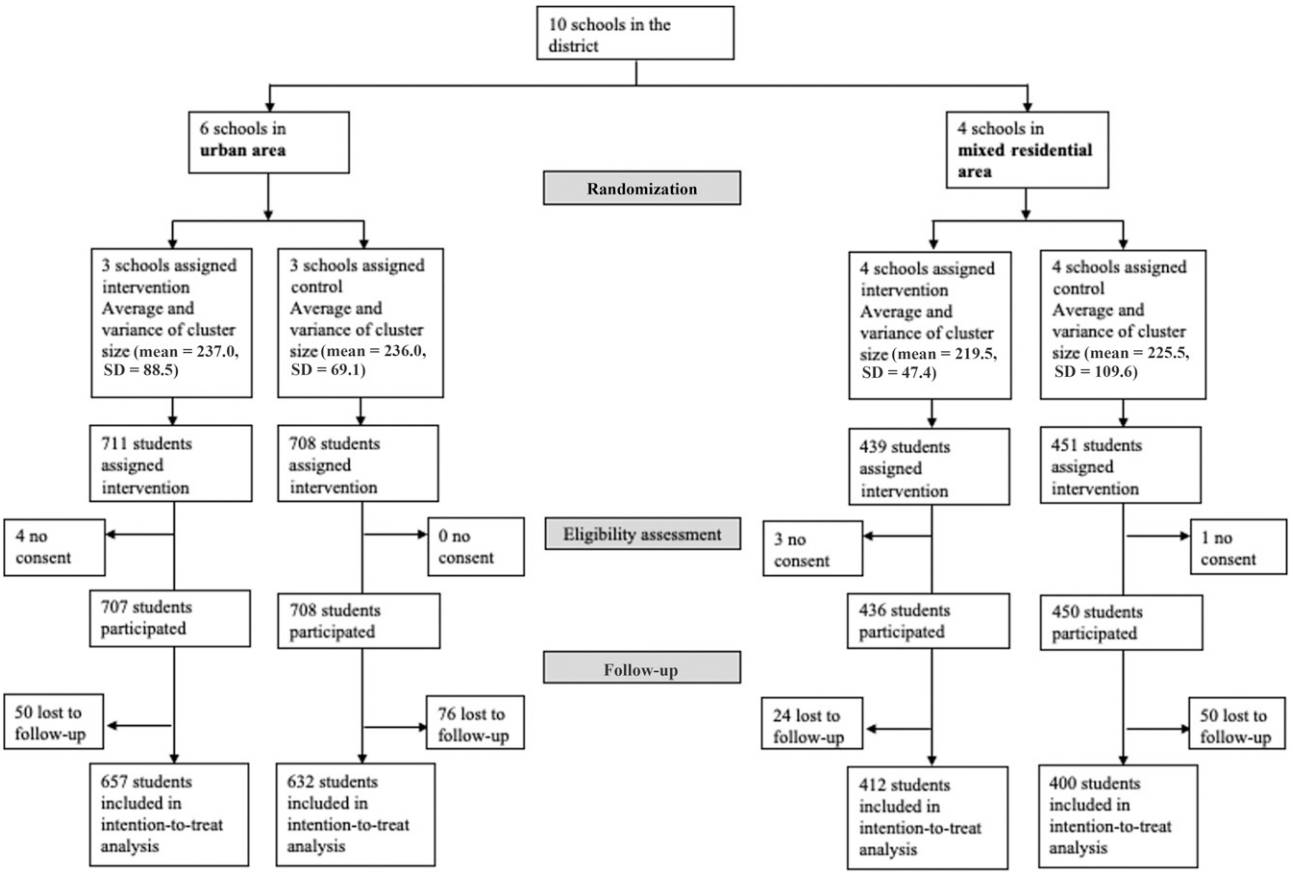

FIGURE 2
Flow of the participants.

correct responses for 50 tasks, congruent and incongruent, were evaluated. The Flanker effect was calculated by subtracting the response time for incongruent tasks from that for congruent tasks.

BMI was calculated to evaluate the proportion of children with obesity (≥95th percentile) and overweight (≥85th percentile) on the basis of the WHO and Centers for Disease Control and Prevention criteria.[31] Physical fitness was evaluated through a 20-m shuttle run and side-to-side jumps.[32,33] Mental health was evaluated by using the Mongolian parental version of the Strengths and Difficulties Questionnaire (SDQ).[34,35] The total difficulties score and subscale scores (emotional symptoms, conduct problems, hyperactivity and/or inattention, peer relationship problems, and prosocial behavior) were calculated.

Sample Size and Statistical Power

Statistical power was determined before the trial and exceeded 0.8 when we assumed that the standardized difference of the primary outcome was 0.2[12]; the dropout rate was 5%, and correlation within the same individual was 0.6.

Statistical Analysis

Individual data were analyzed considering the participant's group allocation, regardless of his or her intervention adherence (intention to treat). The intervention effect was examined by using a linear mixed-effects model. The Bonferroni method was applied to adjust for multiplicity for the primary outcome, with a 2-sided significance level of .025; 95% confidence intervals (CIs) were also calculated. In the secondary analysis, the same analytical method was performed for continuous variables. A generalized linear mixed-effects model assuming multinomial distribution and a cumulative logit link was used for categorical data. A generalized linear mixed-effects model assuming binomial distribution and a logit link was used for binary data (eg, physical activity frequency, hours playing outside). A generalized linear mixed-effects model assuming Poisson distribution with log link was used for count data (eg, SDQ scores, sleeping hours). The covariate set for these models was planned to be the same as the primary analysis

but failed to converge. Thus, the models were altered so that the outcome was postintervention data; the fixed effects were preintervention data, group, site, and the group-site interaction; and the random effect was school.

Four subgroup analyses were conducted to examine the intervention effect in detail. Three subgroup analyses were performed to examine the intervention effect on the primary outcome by participants' sex, preintervention physical fitness, and preintervention academic achievement. Another subgroup analysis was conducted to consider the Flanker effect and included participants with a correct rate >80% at both preintervention and post intervention.

In the secondary and subgroup analyses, adjustment for multiplicity of statistical testing was not adopted because of exploratory evaluation. Nominal *P* values <.05 indicated statistical significance. No imputation of missing data due to participant dropout or incomplete data collection was performed. For each relevant variable, participants with no missing values in both pre- and postintervention data were included. All statistical analyses were performed by using SAS software 9.4 (SAS Institute, Inc, Cary, NC).

RESULTS

The participant flow is shown in Fig 2. Of the 2309 fourth-grade children, none met the exclusion criteria. Overall, 2301 agreed to participate (intervention: 1143; control: 1158) (Table 1). However, 200 were lost to follow-up because of school transfers (intervention: 74; control: 126). Ultimately, 2101 were included in the primary and secondary outcome analyses (intervention: 1069; control: 1032). The number of participants per school was 152 to 313 in the intervention group and 130 to 280 in the control group.

School and participant basic characteristics by group are described in Tables 1 and 2. There were 969 boys (46.1%) and 909 girls (43.3%) (missing = 223; 10.6%). The mean age was 9.7 years in both the intervention and control groups.

Primary Outcome

At preintervention, the median total examination scores (first and third quantile scores) among participants with complete pre- and postintervention data were as follows: the urban area intervention group scored 176 points (165, 187.75), the urban area control group scored 175 points (164, 183), the mixed residential area intervention group scored 165 points (147, 180), and the mixed residential area control group scored 173 points (153, 177). At post intervention, the median scores were 178 (160, 187) for the urban area intervention group, 170 (150, 182) for the urban area control group, 167 (152, 182) for the mixed residential area intervention group, and 164 (137, 182) for the mixed residential area control group (Supplemental Table 4). Regarding total mathematics and Mongolian score changes (from preintervention to post intervention), the mean differences between the intervention and control groups were as follows: the urban area intervention group showed an 8.36-point greater improvement than the corresponding control group (95% CI: 6.06 to 10.66), whereas the mixed residential area intervention group showed a 9.55-point greater improvement (95% CI: 6.58 to 12.51) (Table 3). The intracluster correlation coefficient was 0.100 between participants in the same cluster and 0.628 between measurement time points for the same individual, both similar to the value assumed from the statistical power calculation.

Secondary Outcomes

Individual Scores

The mean intergroup difference regarding mathematics score change was as follows: urban area intervention group members showed a 6.17-point greater improvement than the corresponding controls (95% CI: 4.74 to 7.60), whereas mixed residential area intervention group members showed a 2.71-point greater improvement (95% CI: 6.58 to 12.51). For Mongolian, urban area intervention group members showed a 2.25-point greater improvement than the corresponding controls (95% CI: 0.99 to 3.51), whereas mixed residential area intervention group members showed a 7.41-point greater improvement (95% CI: 5.80 to 9.00).

Body Weight

The odds ratios (ORs) among mixed residential area participants classified as having obesity or overweight were significantly higher among the intervention group than the control group (OR: 2.97; 95% CI: 1.34 to 6.60); no significant difference was observed for urban area participants (OR: 1.84; 95% CI: 0.84 to 4.02). For the mean intergroup difference in BMI change, urban area intervention group members scored 0.33 higher than the corresponding controls (95% CI: 0.18 to 0.48), whereas mixed residential area intervention group members scored 0.33 higher (95% CI: 0.19 to 0.48).

Physical Fitness

For the intergroup difference regarding change in 20-m shuttle runs, urban area intervention group members made 1.42 more runs than the corresponding controls (95% CI:

TABLE 1 Children Registered and Participated at Each School

Area	No. Participated Children/No. Registered Children at Each School (%)	
	Intervention Group	Control Group
Urban area (3 schools per group)	336/337 (99.7)	307/307 (100.0)
	167/169 (98.8)	232/232 (100.0)
	204/205 (99.5)	169/169 (100.0)
Mixed residential area (2 schools per group)	250/253 (98.8)	302/303 (99.7)
	186/186 (100.0)	148/148 (100.0)
Total	1143/1150 (99.4)	1158/1159 (99.9)

0.35 to 2.48), whereas mixed residential area intervention group members made 4.12 more runs (95% CI: 3.00 to 5.25). Regarding side-to-side jumps, urban area intervention group members made 3.56 more jumps than the corresponding controls (95% CI: 3.12 to 4.01), whereas mixed residential area intervention group members made 4.65 more jumps (95% CI: 4.08 to 5.21).

Regarding lifestyle, mental health, and cognitive function, no significant intergroup differences were observed. Summary statistics for each are summarized in Supplemental Table 4.

Regarding the primary outcome, subgroup analyses revealed a significant difference in all subgroups (Supplemental Table 5). A trend arose of the difference being greater among boys, among those in the lower half for preintervention physical fitness, and among those in the lower half for preintervention academic achievement. This trend was the same for both the urban and mixed residential areas. Regarding the Flanker effect, subgroup analysis did not reveal any significant difference (Supplemental Table 5).

There were no reports of serious injuries during the study period, including during the intervention and data collection.

TABLE 2 Background of Participants

	Intervention Group	Control Group
Age, mean (SD), y	9.7 (0.4)	9.7 (0.4)
Sex, *n* (%)		
Male	481 (51.1)	488 (52.1)
Female	460 (48.9)	449 (47.9)
Missing	128	95
House type, *n* (%)		
Ger or simple house	287 (30.5)	507 (54.4)
Apartment	611 (64.9)	372 (39.9)
Others	43 (4.6)	53 (5.7)
Missing	128	100
Household income, *n* (%)		
≤700 000 Mongolian Tugrik[a]	245 (26.2)	413 (44.7)
≥700 001 Mongolian Tugrik	691 (73.8)	511 (55.3)
Missing	133	108
Maternal education, *n* (%)		
No education to lower secondary	32 (3.6)	71 (8.4)
Upper secondary or vocational training	234 (26.1)	328 (38.8)
College and more	631 (70.3)	446 (52.8)
Missing	172	187
Paternal education, *n* (%)		
Less than lower secondary	37 (4.4)	94 (11.6)
Upper secondary or vocational training	314 (37.0)	372 (46.0)
College and more	498 (58.7)	342 (42.3)
Missing	220	224
Siblings, *n* (%)		
With siblings	806 (85.5)	817 (87.4)
Without siblings	137 (14.5)	118 (12.6)
Missing	126	97

[a] 1 Mongolian Tugrik was ∼0.0004 US dollars in 2017–2018.

DISCUSSION

This study's main finding reveals that an HIIT-based exercise program improves academic achievement among Mongolian primary school students. Similar improvements were observed across all intervention subgroups by sex, physical fitness, and academic achievement. Risk of childhood obesity and BMI tended to increase. No significant differences were observed regarding mental health, cognitive function, or lifestyle.

The effects of HIIT-based exercise on academic achievement may be greater for children with lower preintervention academic achievement, implying that exercise can reduce inequity among children; however, further studies are required because our results for children with higher academic achievements may have been influenced by the national examination score's ceiling effect.

The authors of one meta-analysis reported that physical activities have statistically positive effects on

TABLE 3 Outcomes

	Urban Area				Mixed Residential Area			
	Estimate	SE	CI	*P*	Estimate	SE	CI	*P*
Primary outcome								
Total examination score, points	8.36	1.17	6.06 to 10.66	<.001	9.55	1.51	6.58 to 12.51	<.001
Secondary outcome								
Mathematics, points	6.17	0.73	4.74 to 7.60	<.001	2.71	0.93	0.88 to 4.53	<.001
Mongolian language, points	2.25	0.64	0.99 to 3.51	<.001	7.42	0.82	5.80 to 9.03	<.001
BMI	0.33	0.07	0.18 to 0.48	<.001	0.33	0.07	0.19 to 0.48	<.001
Obesity or overweight, odds ratio	1.84	—	0.84 to 4.02	.12	2.97	—	1.34 to 6.60	<.001
20-m shuttle run, times	1.42	0.54	0.35 to 2.48	.01	4.12	0.58	3.00 to 5.25	<.001
Side-to-side jump, times	3.56	0.23	3.12 to 4.01	<.001	4.65	0.29	4.08 to 5.21	<.001
Flanker effect, s	−0.01	0.01	−0.03 to 0.01	.18	−0.02	0.01	−0.04 to 0.00	.10
SDQ								
Total difficulties score, rate	0.99	0.03	0.93 to 1.05	.71	1.02	0.03	0.96 to 1.09	.51
Emotion subscale score, rate	0.94	0.03	0.88 to 1.01	.08	1.03	0.04	0.94 to 1.11	.54
Conduct subscale score, rate	1.00	0.06	0.88 to 1.14	.96	1.01	0.08	0.87 to 1.17	.92
Hyperactivity subscale score, rate	0.96	0.03	0.90 to 1.03	.24	1.04	0.04	0.97 to 1.13	.28
Peer subscale score, rate	1.04	0.04	0.97 to 1.11	.25	0.97	0.04	0.89 to 1.06	.47
Prosocial subscale score, rate	1.01	0.03	0.95 to 1.06	.79	1.01	0.03	0.94 to 1.08	.83
Sleeping hours, rate	1.04	0.02	0.997 to 1.09	.07	1.05	0.03	0.99 to 1.11	.10
Frequency of physical activity, odds ratio	1.03	—	0.70 to 1.51	.88	1.29	—	0.81 to 2.06	.27
Playing outside hours, odds ratio	1.14	—	0.65 to 2.00	.64	0.75	—	0.38 to 1.45	.38

—, not applicable.

only some constructs of academic achievement, mathematics, and reading.[13] In another, the authors reported that classroom-based physical activity positively impacts academic achievement when a progress-monitoring tool is used as an outcome measure but not when a national standardized examination is used.[13] Although the findings of several well-designed RCTs remain controversial,[8,9] the present results add robust evidence regarding the positive effects of physical activity on academic achievement.

We found that the effect size differed by academic subject between residential areas. Urban area participants greatly improved their mathematics scores (6.17 points in urban area; 2.71 points in mixed residential area), and mixed residential area participants greatly improved their Mongolian language scores (2.25 points in urban area; 7.42 points in mixed residential area). As per a previous meta-analysis, the effect on each academic subject may vary.[13] Further studies considering participants' basic characteristics are required to analyze exercise effect differences on academic subjects.

The childhood obesity increase in this study contradicts findings from previous literature.[1] Our results are partially explained by the analytical model's poor fit while adjusting for the preintervention covariates. In a sensitivity analysis, we built a model that did not adjust for preintervention covariates and obtained results for urban (OR: 1.22 [95% CI: 0.87 to 1.72]) and mixed residential areas (OR: 1.57 [95% CI: 1.12 to 2.20]). This difference implies that the results are not robust, especially for mixed residential areas.

An overview review revealed that routine physical activity has positive effects on children's cognitive function and mental health. However, in this study, the intervention did not result in a significant change. In this study, we mainly compared the effects of the HIIT program and the usual physical education class activities, and the Flanker test, conducted in a large group, may not have been a valid measure.

Within the school context, a trend has appeared that traditional academic subjects are prioritized in curricula, with physical education being killed to accommodate; however, the importance of physical education is beginning to gain attention.[5,6] Our findings suggest that learning can be enhanced by exercise, which has the potential to promote further educational policy change.

Previous systematic reviews have highlighted a need for well-designed studies.[12,16] The current study meets many recommendations, including appropriate randomization methods, intervention program standardization, adequate sample size, and application of valid and reliable measures of academic achievement. Additionally, this study is a population-based study in socioeconomically diverse areas; thus, the extrapolability of the results is high.

There are several limitations. First, there are 2 types of potential bias: (1) measurement bias due to inability to blind the study and (2) bias due to missing outcome data. Regarding the former, measurement of the outcomes was conducted by persons who knew the goal of the assignment. National examination test scoring was conducted by teachers at each school, and RAs performed data collection regarding physical fitness and cognitive function. Regarding the second bias, the proportion of missing outcome data was 7.0% in the intervention group and 12.1% in the control group. The main reason for missing outcome data was transfers to schools outside the study area.

Regarding the study design, the study period included time windows during which there may have been an external factor influence. There was a 9-month time gap between preintervention and the start of the trial postintervention academic achievement data collection. However, this would not have induced artificial effects in the intervention group because the randomization was performed just before the intervention began.

Finally, we did not consider participants' physical activity levels or the program's exercise intensity. Further studies that assess physical activity using accelerometers and maximum oxygen consumption per unit time are required to determine the dose-response relationship between physical activity amount and the magnitude of the effect on academic performance. This will contribute to uncovering what aspect of physical activity influences children's academic achievement.

CONCLUSIONS

This is the first cluster RCT to examine the effects of an HIIT-based exercise program delivered at schools in a population-based setting in a developing country. It reveals the beneficial effects of the exercise program for children's academic achievement and physical fitness. This evidence contributes to policy development and social implementation.

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ABBREVIATIONS

CI: confidence interval
HIIT: high-intensity interval training
LMIC: low- to middle-income country
MNIPE: Mongolian National Institute of Physical Education
OR: odds ratio
RA: research assistant
RCT: randomized controlled trial
SDQ: Strengths and Difficulties Questionnaire
WHO: World Health Organization

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and

Dr Suwabe conducted data collection, established logistics, and reviewed and revised the manuscript; Dr Soya conceptualized and designed the study and reviewed and revised the manuscript; Mr Mikami conceptualized and designed the study, conducted the initial analysis, and reviewed and revised the manuscript; and all authors read and approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

The deidentified data and the data dictionary for this trial will be available on reasonable request, with the relevant institutional research ethics board approval of the proposal and a signed data access agreement.

This trial has been registered with UMIN Clinical Trials Registry (https://www.umin.ac.jp/ctr/) (identifier UMIN000031062).

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