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Traditional or Game-based High-Intensity Interval Exercise in Pediatric Asthma?- A Randomized Controlled Trial for Acute Response

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Research Article

Keywords: Childhood asthma, high-intensity interval exercise, game-based exercise, exergame

Posted Date: November 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11430833/v1

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Additional Declarations: No competing interests reported.

Abstract

Purpose

Game-based high-intensity interval exercise (GHIIE) has been used in asthma rehabilitation. However, personalised exercise approaches remain unexplored. We aimed to develop a GHIIE system for asthmatic children and to investigate its immediate impact on heart rate (HR), heart rate variability (HRV), systolic and diastolic blood pressure (SBP and DBP), oxygen saturation (SpO2), dyspnea, and fatigue, and to compare it with traditional HIIE (THIIE).

Methods

We enrolled forty children with asthma and randomized them to the GHIIE (n = 22;9 girls,age = 10.79 ± 1.40 years) or the THIIE (n = 18;5 girls, age = 11.44 ± 2.43 years) groups. Demographic and clinical characteristics were recorded. Target workloads were calculated based on symptom-limited exercise testing. The HRV, HR, SBP, DBP, SpO2, dyspnea, and fatigue were assessed before and after exercise, and recovery at 1, 5, and 10 minutes. A visual analogue scale was used to assess exercise feedback.

Results

The GHIIE demonstrated better HRV, HR, and fatigue responses after exercise than the THIIE ($p < 0.05$). The SBP, DBP, SpO2, and dyspnea were comparable between groups ($p > 0.05$). Exercise feedback was more favourable in the GHIIE group ($p < 0.05$).

Conclusion

The GHIIE represents an enjoyable alternative for asthmatic children. Additionally, the GHIIE elicited more favourable immediate responses in HR, HRV, and fatigue. Future studies should investigate its long-term effects.

Introduction

High-intensity interval exercise (HIIE) is an alternative to continuous exercise, characterized by repeated bouts of high-intensity exercise combined with low/moderate-intensity exercise/rest periods [1, 2]. It can produce physiological and functional effects comparable to those of continuous moderate-intensity exercise within a shorter duration, while also offering greater feasibility and tolerance for individuals with limited exercise capacity, deconditioned populations, or those who face time constraints that hinder adherence to conventional exercise programs [3, 4]. Intervening rest periods reduce ventilatory demands and dyspnea, conserve energy for breathing, and optimize performance in subsequent exercise bouts [4].

The HIIE is increasingly used in asthma rehabilitation as well as other populations. Its structured recovery phases allow the respiratory system extra time for adaptation, reducing symptom provocation and enhancing

exercise tolerance [5, 6]. Studies report tolerance of HIIE by asthmatic children similar to their healthy peers [7, 8]. It pulmonary rehabilitation, HIIE has been associated with lower perceived dyspnea and fatigue, faster recovery, higher exercise adherence, and favourable cardiovascular and muscular adaptations [9, 10]. Long-term studies in asthmatic children report that HIIE improves cardiorespiratory fitness [11, 12], induces favorable changes in blood lipid and pressure profiles [13], helps maintain body-mass index [11], and enhances quality of life [11, 12], although effects on heart rate variability (HRV) remain inconclusive [14].

Game-based HIIE (GHIIE) has been increasingly used to enhance motivation and enjoyment in children with asthma [11, 14, 15]. While individualized exercise prescription based on cardiopulmonary exercise testing is commonly applied in traditional HIIE (THIIE), translating and maintaining this individualized intensity within game-based environments remains challenging [5]. Most GHIIE interventions rely on standardized or loosely guided exercise protocols without continuous physiological feedback, limiting the ability to ensure that participants reach and sustain target exercise intensity. Given that exercise intensity is a key determinant of physiological adaptation, the lack of real-time intensity regulation may reduce the effectiveness of these interventions. Therefore, we developed a GHIIE system that integrates individualized exercise prescription with real-time heart rate monitoring and visual feedback to facilitate the achievement and maintenance of target exercise intensity within a game-based environment. We hypothesized that this integrated approach would elicit more favourable acute physiological responses compared to THIIE.

Materials and Methods

Study Design and Ethical Approval

This randomized controlled trial was conducted at Hafsa Sultan Hospital, Department of Pediatric Allergy. Ethical approval was obtained from Manisa Celal University Health Sciences Ethics Committee (Approval Number = 2204, Approval Date = 31.01.2024). The trial was registered under ClinicalTrials.gov after the system was developed (Number=NCT06895642). All children and parents were informed and signed the consent form. The Helsinki Declaration was followed for all procedures.

Development of the System

The GHIIE system integrates a treadmill, two monitors—one for the game display and one for the user software (Fig. 1-a, Fig. 1-b), and a chest strap HR sensor (Polar H10, Finland, Fig. 1-c). The system provides a low-cost virtual walking/running environment, enabling individualized exercise protocols by adjusting treadmill speed and incline, and HRmax, based on cardiopulmonary exercise test results. The software programs these parameters to control treadmill settings and synchronize avatar movements within the virtual environment.

The system comprises hardware and software components to enable real-time data collection, motion control, and visual feedback. Based on the individualized exercise protocols, treadmill speed and incline are automatically adjusted, and synchronized avatar movements are displayed in the virtual environment. HR and HRV are continuously monitored via a chest-worn sensor and recorded in real time. The core software, developed on Unity3D, integrates session configuration, treadmill communication, HR/HRV acquisition, and

data recording, ensuring precise protocol implementation and an immersive user experience. Further technical details regarding the system architecture, hardware components, and software development are described in detail in the study by Koçak et al. [16].

Following the system development, a pilot study was conducted with 12 asthmatic children (age = 10 ± 2 years, male/female = 5/7) [17] to assess feasibility and confirm target HR achievement. Symptom-limited cardiopulmonary exercise testing was performed using the Bruce protocol, and exercise intensities were adjusted accordingly. Participant feedback regarding potential improvements was collected before the game sessions, resulting in system updates that included color-coded acceleration bars (red for fast, green for slow), replacement of separate time and distance indicators with a single completion bar, and the addition of more trees and relaxing music in the virtual environment. The HR and perceived exertion were recorded during the sessions, and all participants achieved their target HR with exertion levels consistent with the prescribed intensity.

Sample Size and Study Population

Sample size was calculated using G*PowerV3.1 and Cohen's coefficients [18]. The effect size was taken as medium (F = 0.25) with the primary outcome being HR change. A two-way ANOVA was planned with 95% power and a significance level of 0.05. The calculated sample was 36 participants; however, 40 participants were recruited to account for a 10% potential dropout rate.

We enrolled children aged 8–15 diagnosed with asthma based on detection of episodic bronchoconstriction and bronchodilator reversibility, clinically or with spirometric measurement [19]. Exclusion criteria were the presence of any chronic comorbid disease (including obesity), asthma exacerbation within the previous four weeks, severe persistent or exercise-induced asthma, and inability to complete the exercise test. The study flowchart is presented in Fig. 2.

Randomization and blinding

Participants were randomly assigned in a 1:1 ratio to either the GHIIE group or the THIIE group using simple randomization. The randomization sequence was generated in advance by an investigator who was not involved in participant recruitment, baseline assessment, cardiopulmonary exercise testing, or intervention delivery, using the online randomization tool Randomizer.org. Odd-numbered allocations were assigned to the GHIIE group and even-numbered allocations to the THIIE group. The allocation sequence was concealed using sequentially numbered, opaque, sealed envelopes. The investigator responsible for randomisation opened the appropriate envelope after completion of the baseline assessments and cardiopulmonary exercise testing and communicated the group allocation to the investigator responsible for delivering the assigned exercise intervention.

The physician responsible for the clinical assessment and the investigator performing the cardiopulmonary exercise testing were blinded to group allocation throughout the respective assessment procedures. The investigator responsible for delivering the exercise intervention and the participants could not be blinded to group allocation because of the nature of the intervention. The investigator delivering the intervention was

not involved in baseline or outcome assessments. This procedure ensured separation between randomization, blinded assessment, and intervention delivery and was implemented to minimise the potential for selection and assessment bias.

Data Collection

Participants with their parents completed a form that included sociodemographic and disease-related data, the Asthma Control Test [20], the International Physical Activity Questionnaire [21], and the Pediatric Quality of Life Inventory [22]. A symptom-limited cardiopulmonary-exercise test was then performed to determine maximum HR (HR_{max}). Following the test, participants rested until HR, dyspnea, and fatigue returned to baseline, after which detailed instructions about the exercise session were provided. Subsequently, resting HRV, HR, blood pressure (BP), respiratory rate (RR), oxygen saturation (SpO_2), dyspnea, general fatigue, and leg fatigue were recorded.

Exercise intensity was individually prescribed based on HR_{max} obtained from the cardiopulmonary exercise test. Sessions were conducted in a well-ventilated, allergen-free environment. Each session included a 5-minute warm-up consisting of moderate-intensity jogging at 55–60% of HR_{max}, dynamic stretching, and acceleration running, followed by a cool-down period with deceleration running [23]. During the main exercise phase, loading periods were performed at 85–90% HR_{max} and recovery periods at 55–60% HR_{max}. For the GHIIE group, intensity monitoring was performed using a chest-worn HR sensor, and visual cues within the game guided participants to reach and maintain their target HR. The protocol consisted of 10 sets, each including 30 seconds of loading followed by 1 minute of recovery [24]. All exercise sessions were supervised by a physiotherapist, and emergency equipment was available to ensure participant safety.

Both groups wore the same heart-rate sensor for objective monitoring; however, real-time visual feedback was provided only to the intervention group. The intervention differed from the comparison condition solely in terms of gamified content. Regarding the method of delivering feedback, both groups received verbal guidance from the therapist; the gamified group additionally received visual feedback.

Participants in the GHIIE group exercised on a treadmill positioned in front of a screen, following a lead character running along a virtual forest path under a blue sky, accompanied by birdsong. Speed adjustments were signaled by on-screen countdowns, and exercise progress was displayed via a single completion bar. Avatar speed changed simultaneously with treadmill adjustments, reinforcing visual feedback. Participants in the THIIE group exercised without visual input, receiving verbal cues from a physiotherapist for speed changes.

All exercise evaluations are summarized in Fig. 2. HR and BP were measured using an upper-arm BP monitor (BraunBUA5000), SpO_2 by a pulse oximeter (BraunYK-81CEU), and HRV by a chest strap sensor (PolarH10). Dyspnea, general fatigue, and leg fatigue were assessed using a Visual Analogue Scale (VAS)[25]. After each session, participants rated statements such as "I enjoyed the exercise," "I would like to do this exercise again," and "The exercise was very fun" on a 0–10 VAS scale [26].

The primary outcome was HR, while secondary outcomes included HRV, BP, $SpO_{2,}$ dyspnea, leg and general fatigue, and exercise-related enjoyment scores.

Statistical Analysis

The data were blinded for analysis and processed using SPSS-V22.0. Descriptive data were expressed as mean±standard deviation for normally-distributed continuous variables, median (25/75 interquartile range) for non-normal variables, and percentage (%) for categorical variables. Pairwise comparisons used the Mann-Whitney U or Student's t-test for continuous variables, and the Chi-square test for categorical variables. Repeated measures were analysed by two-way ANOVA with Bonferroni correction for measurements before exercise (BE), after exercise (AE), and at 1 (R1), 5 (R5), and 10 minutes of recovery (R10).

Results

Mean age of children in the GHIIE group was 10.72 ± 2.02 versus 11.43 ± 2.43 in the THIIE group (p = 0.07). Body mass index was not significantly different between the two groups (p = 0.19). Similarly, physical activity level, regular exercise habit, IPAQ score, or Pediatric Quality of Life Inventory Scores were not found to differ between the two groups (Table 1).

Table 1
Participants' Sociodemographic and Disease-related Data

Variables	Groups		*p*	*OR or mean difference (95% CI)*
	GHIIE (n = 22)	**THIIE (n = 18)**		
Age, *years****	10.7 ± 2.0	11.4 ± 2.4	0.07*	1.6 (0.1/2.1)
Gender, ******	9 (40.9)	5 (27.8)	0.51**	2.4 (0.6/9.8)
Girl	13 (59.1)	13 (72.2)		
Boy				
Body mass index, *kg/m^{2}****	19.2 ± 3.3	19.0 ± 3.2	0.89*	1.7 (0.9/2.4)
Presence of asthma in the family******	8 (36.4)	7 (38.9)	0.56**	1.5 (0.5/3.2)
Presence of regular exercise habit******	11 (50.0)	10 (55.6)	0.49**	0.5 (0.2/1.3)
IPAQ score, *MET.min/week****	1923.1 ± 825.0	2227.9 ± 850.4	0.20*	795.7(689.8/1031.7)
Physical Activity Level ******	2 (9.0)	3 (16.7)	0.07**	-
Active	8 (36.4)	8 (44.4)		
Minimally Active	12 (54.6)	7 (38.9)		
Inactive				
Pediatric Quality of Life Inventory Scores**	87.4 ± 8.7	84.8 ± 11.1	0.42*	4.2(-3.4/8.7)
Diagnosis year, *year****	3.5 (2.0/6.75)	4.5 (2.0/8.5)	0.69*	
FEV1, %***	102.0 ± 6.5	105.1 ± 6.8	0.21*	2.8(-1.4/6.7)
FVC, %***	99.0 ± 9.1	102.5 ± 10.0	0.07*	3.1(-1.6/4.9)
FEV1/FVC**	88.2 ± 5.5	90.4 ± 6.9	0.46*	1.3(-3.4/5.9)
PEF, %***	87.3 ± 7.3	89.4 ± 8.6	0.19*	2.3(1.5/3.9)
Number of hospitalizations in the last year******	0 (0/1)	0 (0/1)	0.72*	-
ACT score**	24.7 ± 0.8	24.7 ± 0.8	0.95*	0.3(-0.4/1.0)
Asthma control level******	5 (22.7)	4 (22.2)	0.64**	1.0 (0.3/3.1)
Partial asthma control	17 (77.3)	14 (77.8)		
Complete asthma control				

Variables	Groups		p	OR or mean difference (95% CI)
	GHIIE (n = 22)	THIIE (n = 18)		
GHIIE: Game-Based High-Intensity Interval Exercise, THIIE: Traditional High-Intensity Interval Exercise, %FEV1: percentage of air volume exhaled in the 1st second of forced expiration, %FVC: percentage of forced vital capacity, FEV1/FVC: ratio of air volume exhaled in the 1st second of forced expiration to forced vital capacity, %PEF: percentage of peak expiratory flow.				
*Student T				
**chi-square tests				
*** expressed as mean±standard deviation				
****expressed as n(%)				
Categorical variables are presented as odds ratios with 95% CI, while continuous variables are presented with 95% confidence intervals of the mean difference.				

Pre- and post-cardiopulmonary exercise test results were comparable in hemodynamic responses, dyspnea, fatigue, HR_{max}, test duration, and maximum speed and incline ($p > 0.05$ for all) (Table 2).

Table 2
Participants' Test Results

Variables	Groups		Statistics	
	GHIIE (n = 22)	THIIE (n = 18)	*p*	*F*
Pre-Test Assessments				
Heart rate, *beats/minute*	88.5 ± 11.7	85.9 ± 11.4	0.50*	0.01
Systolic blood pressure, *mmHg*	99.9 ± 7.0	101.1 ± 6.7	0.72*	5.89
Diastolic blood pressure, *mmHg*	62.5 ± 5.0	62.6 ± 4.0	0.97*	0.96
Respiratory rate, *breaths/minute*	30.0 ± 2.0	28.9 ± 3.0	0.06*	0.73
Oxygen saturation, *%*	98.9 ± 0.4	98.7 ± 0.8	0.24*	5.72
Dyspnea, *0–10*	0	0	1.00*	
Fatigue, *0–10*	0.0 ± 0.1	0.2 ± 0.0	0.65*	4.01
Post-Test Assessments				
Heart rate, *beats/minute*	184.2 ± 6.7	182.7 ± 8.3	0.54*	0.62
Systolic blood pressure, *mmHg*	141.1 ± 5.2	139.0 ± 6.4	0.28*	1.78
Diastolic blood pressure, *mmHg*	87.3 ± 8.4	86.9 ± 7.3	0.23*	1.07
Respiratory rate, *breaths/minute*	45.1 ± 4.0	45.2 ± 3.8	0.35*	0.49
Oxygen saturation, *%*	95.0 ± 1.9	95.6 ± 2.5	0.83*	2.81
Dyspnea, *0–10*	6.3 ± 1.7	5.3 ± 1.4	0.61*	0.09
Fatigue, *0–10*	7.9 ± 1.1	7.3 ± 1.3	0.26*	7.32
Maximum speed, *meters/second*	6.4 ± 0.9	6.7 ± 0.9	0.30*	0.71
Maximum slope, %	15.5 ± 1.4	16.0 ± 1.4	0.30*	0.71
Test duration, *minutes*	9.4 ± 1.8	9.8 ± 2.2	0.62*	0.77
Maximum heart rate, *beats/minute*	191.1 ± 4.4	190.3 ± 4.3	0.63*	4.64
Percentage of reaching calculated maximum heart rate, *%*	95.7 ± 2.3	95.6 ± 2.5	0.98*	8.21
Reason for terminating the test, *n (%)*	14 (63.6)	10 (55.6)	0.14**	
Leg fatigue	0 (0)	3 (17)		
General fatigue	8 (36.4)	5 (27.8)		

GHIIE: Game-Based High-Intensity Interval Exercise, THIIE: Traditional High-Intensity Interval Exercise, %: slope and percentage. *Student T and **chi-square tests were used for comparisons.

Variables	Groups		Statistics	
	GHIIE (n = 22)	THIIE (n = 18)	*p*	*F*
Pre-Test Assessments				
Dyspnea				
GHIIE: Game-Based High-Intensity Interval Exercise, THIIE: Traditional High-Intensity Interval Exercise, %: slope and percentage. *Student T and **chi-square tests were used for comparisons.				

All participants were within the target load range throughout the exercise. This range was 7–9/10 based on VAS and 85–90% HR_{max} (± 5) for the loading period and 5–6/10 based on VAS and 55–60% HR_{max} (± 5) for the recovery periods. Additionally, none of the participants reported any adverse symptoms during exercise.

Repeated measurements at BE, AE, R1, R5, and R10, along with within-group analysis, are presented in Table 3. Significant changes were observed in all variables except dyspnea (Table 3, $p < 0.05$). Specifically, differences in HR and HRV at AE, R1, and R5 compared to BE were observed in both groups (Table 4), while SBP, DBP, and SpO_2 differed at AE compared to BE ($p < 0.05$). Dyspnea remained similar between groups across all time points ($p > 0.05$). Leg fatigue was higher in GHIIE at AE and R1, whereas it remained elevated in THIIE at AE, R1, and R5. General fatigue was higher in GHIIE only at R1, while in THIIE it was higher than baseline at all time points (Table 4). Between-group comparisons revealed that the GHIIE group exhibited lower HR in AE, reduced leg fatigue at ES and R1, and lower general fatigue at ES, R1, R5, and R10, while HRV was higher at AE ($p < 0.05$). Other parameters were similar between the groups ($p > 0.05$). Table 4 also presents changes relative to baseline (ΔAE-BE, ΔR1-BE, ΔR5-BE, and ΔR10-BE) for HR, HRV, leg fatigue, and general fatigue. While HRV changes were comparable at all time points, other variables showed significant differences at certain intervals ($p < 0.05$, Table 4). According to the analysis of the interaction effect, the largest effect sizes were observed for leg fatigue and general fatigue ($\eta^2p = 0.712$), indicating a very strong interaction between exercise protocol and time. Large effects were also observed for heart rate variability ($\eta^2p = 0.402$) and heart rate ($\eta^2p = 0.398$), whereas peripheral oxygen saturation showed only a small effect size ($\eta^2p = 0.031$).

Table 3
Within-group Exercise-related Changes in GHIIE and THIIE Groups

Variables	GHIIE					THIIE				
	$\bar{X}$±ss					$\bar{X}$±ss				
	BE	AE	R1	R5	R10	BE	AE	R1	R5	R10
Heart rate	87.6 ± 2.4	151.9 ± 1.6	128.7 ± 2.9	97.1 ± 2.7	88.1 ± 2.3	86.6 ± 2.6	157.9 ± 1.8	124.8 ± 3.3	97.1 ± 3.0	89.7 ± 2.5
	F_a=175.92; p_a<0.001					**F_b=188.27; p_b<0.001**				
	Group Effect: *F* = 0.06; *p* = 0.81, Time Effect: *F* = 529.96; *p* > 0.001, Group*Time Effect: *F* = 0.08; *p* = 0.79, Effect Size§=0.40									
Heart rate variability	665.5 ± 105.2	400.2 ± 25.4	483.4 ± 64.8	605.0 ± 83.0	659.4 ± 94.5	676.5 ± 105.2	372.0 ± 23.9	491.1 ± 72.4	580.8 ± 68.6	656.9 ± 99.6
	F_a=47.57; p_a<0.001					**F_b=47.71; p_b<0.001**				
	Group Effect: F = 0.15; p = 0.70, Time Effect: F = 94.29; p < 0.001, Group*Time Effect: F = 1.00; p = 0.42, Effect Size§=0.40									
Systolic blood pressure	100.2 ± 2.0	112.1 ± 1.9	108.0 ± 2.4	103.9 ± 2.0	100.2 ± 1.7	100.4 ± 2.2	118.6 ± 2.1	110.1 ± 2.6	101.3 ± 2.3	99.6 ± 1.9
	F_a=16.22; p_a<0.001					**F_b=34.97; p_b<0.001**				
	Group Effect: *F* = 0.21; *p* = 0.65, Time Effect: *F* = 48.98; **p > 0.001**, Group*Time Effect: *F* = 4.00; **p = 0.01**, Effect Size§=0.31									
Diastolic blood pressure	62.5 ± 1.4	69.5 ± 0.9	65.7 ± 1.3	61.4 ± 1.5	64.0 ± 1.1	61.9 ± 1.5	70.2 ± 0.9	64.5 ± 1.5	64.8 ± 1.3	63.6 ± 1.2
	F_a=7.26; p_a<0.001					**F_b=14.31; p_b<0.001**				
	Group Effect: *F* = 1.00; *p* = 0.32, Time Effect: *F* = 19.47; **p > 0.001**, Group*Time Effect: *F* = 2.81; **p = 0.01**, Effect Size§=0.24									
Peripheral oxygen saturation	98.9 ± 0.8	97.8 ± 0.2	98.0 ± 0.2	98.6 ± 0.3	98.9 ± 0.1	98.8 ± 0.1	97.3 ± 0.2	97.2 ± 0.2	97.3 ± 0.3	98.7 ± 0.1
	F_a=7.26; p_a<0.001					**F_b=14.31; p_b<0.001**				

GHIIE: Game-Based High-Intensity Interval Exercise, THIIE: Traditional High-Intensity Interval Exercise, $\bar{X}$: mean, sd: standard deviation. Two-way analysis of variance for repeated measures was conducted for all of the analyses. It was indicated that the within-group comparisons with F_a and p_a values for the GHIIE group and with F_b and p_b values for the THIIE group

	Group Effect: *F* = 1.90; *p* = 0.18, Time Effect: *F* = 36.37; **p > 0.001**, Group*Time Effect: *F* = 1.90; p = 0.13, Effect Size§=0.03									
Dyspnea	0.1 ± 0.3	0.1 ± 0.1	0.4 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.4	0.3 ± 0.1	0.4 ± 0.2	0.2 ± 0.1	0.1 ± 0.1
	F_a=1.76; p_a=0.2					F_b=1.96; p_b=0.1				
	Group Effect: *F* = 0.13; *p* = 0.72, Time Effect: *F* = 2.71; **p = 0.05**, Group*Time Effect: *F* = 1.04; p = 0.40, Effect Size§=0.31									
Leg fatigue	0.0 ± 0.0	0.6 ± 0.2	1.1 ± 0.3	0.3 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	2.1 ± 0.2	1.8 ± 0.3	0.8 ± 0.2	0.2 ± 0.1
	F_a=22.97; p_a=0.001					**F_b=4.13; p_b<0.001**				
	Group Effect: *F* = 11.44; **p = 0.001**, Time Effect: *F* = 21.61; **p < 0.001**, Group*Time Effect: *F* = 11.36; **p < 0.001**, Effect Size§=0.71									
General fatigue	0.1 ± 0.0	0.5 ± 0.2	0.8 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	1.3 ± 0.2	0.7 ± 0.1	0.2 ± 0.1
	F_a=3.58; p_a=0.02					**F_b=27.04; p_b<0.001**				
	Group Effect: *F* = 11.4; **p = 0.001**, Time Effect: *F* = 21.6; **p < 0.001**, Group*Time Effect: *F* = 11.4; **p < 0.001**, Effect Size§=0.7									

GHIIE: Game-Based High-Intensity Interval Exercise, THIIE: Traditional High-Intensity Interval Exercise, $\bar{X}$: mean, sd: standard deviation. Two-way analysis of variance for repeated measures was conducted for all of the analyses. It was indicated that the within-group comparisons with F_a and p_a values for the GHIIE group and with F_b and p_b values for the THIIE group

Table 4
Comparison of Changes in Exercise-Related Variables between GHIIE and THIIE Groups

		Groups		**Statistics†**	
				F	***p***
		GHIIE ($\bar{X}$±ss)	**THIIE ($\bar{X}$±ss)**		
Heart Rate	**ΔAE-BE**	63.6 ± 2.4	71.3 ± 3.0	**4.09**	**0.04**
		p_a<0.001	**p_a<0.001**		
	ΔR1-BE	41.1 ± 3.3	38.2 ± 2.4	0.46	0.50
		p_a<0.001	**p_a<0.001**		
	ΔR5-BE	9.5 ± 2.0	10.0 ± 2.4	0.12	0.74
		p_a<0.001	**p_a<0.001**		
	ΔR10-BE	3.7 ± 0.8	5.8 ± 1.4	3.14	0.08
		p_a=0.9	p_a=0.1		
Heart Rate Variability	**ΔAE-BE**	-285.3 ± 97.0	-304.5 ± 99.5	1.44	0.24
		p_a<0.001	**p_a<0.001**		
	ΔR1-BE	-182.1 ± 22.7	-185.4 ± 22.7	0.01	0.92
		p_a<0.001	**p_a<0.001**		
	ΔR5-BE	-80.5 ± 10.0	-95.7 ± 8.6	1.40	0.24
		p_a=0.001	**p_a<0.001**		
	ΔR10-BE	-16.1 ± 6.7	-19.6 ± 6.2	0.44	0.51
		p_a=0.9	p_a=0.9		
Leg Fatigue	**ΔAE-BE**	0.5 ± 0.2	2.11 ± 0.26	**30.60**	**< 0.001**
		p_a=0.05	p_a**<0.001**		
	ΔR1-BE	1.0 ± 0.2	1.8 ± 0.3	**4.00**	**0.04**
		p_a=0.001	p_a**<0.001**		
	ΔR5-BE	0.3 ± 0.2	0.7 ± 0.2	3.25	0.08
		p_a=0.4	p_a**<0.001**		
	ΔR10-BE	0.1 ± 0.0	0.1 ± 0.1	0.74	0.40

		Groups		Statistics†	
		GHIIE ($\bar{X}$±ss)	THIIE ($\bar{X}$±ss)	*F*	*p*
		p_a=0.9	p_a=0.3		
General Fatigue	**ΔAE-BE**	0.4 ± 0.1	1.8 ± 0.8	**36.64**	**< 0.001**
		p_a=0.2	p_a**<0.001**		
	ΔR1-BE	0.7 ± 0.2	1.3 ± 0.2	3.42	0.07
		p_a=0.001	p_a**<0.001**		
	ΔR5-BE	0.2 ± 0.1	0.7 ± 0.2	**7.70**	**0.01**
		p_a=0.9	p_a**<0.001**		
	ΔR10-BE	0.1 ± 0.0	0.2 ± 0.1	**9.55**	**0.00**
		p_a=0.9	**p_a=0.038**		

Comparison of differences between groups for repeated measures one-way analysis of variance. The p_a value refers to the comparison of the value before exercise with the corresponding time interval according to Student T test analysis.

Exercise-related feedback, including enjoyment, willingness to repeat, and perceived fun, was scored above 8/10 in both groups. However, the GHIIE group reported significantly higher scores for enjoyment (9.83 ± 0.14 for GHIIE, 8.89 ± 0.26 for THIIE), willingness to repeat (9.81 ± 0.19 for GHIIE, 8.02 ± 0.98 for THIIE), and perceived fun (9.94 ± 0.05 for GHIIE, 8.86 ± 0.42 for THIIE) compared to THIIE ($p < 0.001$).

Discussion

In our study, we developed the GHIIE system in asthmatic children and compared the immediate responses after a single HIIE session with THIIE. Our findings indicate that GHIIE elicited more favorable responses in HR, HRV, leg, and general fatigue. The SBP, DBP, SpO_2, and dyspnea showed similar responses in both groups. Furthermore, GHIIE was perceived as more enjoyable, and children expressed a higher willingness to repeat the exercise.

Although the research reports that HIIE offers advantages for patients with lung diseases who are unable to consistently exercise at sufficient intensity due to symptoms [27], it reduces dyspnea by decreasing breathing workload [26], and promotes physiological adaptations through alternating loading and recovery periods [28]. However, achieving and maintaining target exercise intensity remains challenging [5]. While game-based HIIE approaches have been used in asthmatic children, none have personalized or maintained target intensity [11, 14, 15]. Our system allows cardiopulmonary exercise testing in asthmatic children and generates

individualized loading-rest periods based on target exercise intensity, offering an innovative approach for personalized intensity determination and visual feedback to achieve and maintain target HR.

HR is a key indicator of exercise response in asthmatic children, who typically exhibit higher resting HR and slower post-exercise recovery [29]. There is limited evidence from a heterogeneous adult population regarding the immediate effects of HIIE on HR and HRV recovery [30, 31]. A systematic review and meta-analysis examining the impact of HIIE on HRV based on the relationship between HR and HRV responses of the autonomic system suggests that HIIE delays the HR response [30, 32]. However, studies lack evidence in asthmatic children following HIIE. Our study examining the HR response following THIIE and GHIIE in asthmatic children showed that HRs decreased by approximately 30 beats/min AE. However, this decrease was significantly greater in the GHIIE, and both groups reached BE levels in R10. The faster recovery in the GHIIE may be due to the positive effects of game-based exercises on the parasympathetic system and vagal activity [33]. Besides, the higher enjoyment perception reported in the GHIIE may positively impact HR recovery through increased motivation. Future studies could record real-time changes in HR by continuously monitoring recovery to interpret the results.

HRV is a simple and non-invasive indicator of autonomic function [34], defined simply as the time variability between consecutive RR intervals [35]. This reflects the interaction between sympathetic-parasympathetic systems [36]. A meta-analysis on HRV in asthmatic children demonstrated a decrease in HRV and sympathetic modulation and recommended its increased use as a clinical monitoring tool [37]. Furthermore, environmental conditions, disease severity, obesity, physical activity level, and exercise have been implicated as factors that may influence HRV in asthmatic children [14, 29, 38–40]. Because exercise is one of the most common triggers of acute asthma attacks, it is important to evaluate autonomic activity during exercise [40]. Autonomic dysfunction in asthma was suggested to be associated with a pathological exercise response [41]. Exercise is accompanied by increased sympathetic activity and a decrease in parasympathetic activity [42]. This explains the decrease in HR and HRV caused by exercise. While HRV decreases as an exercise response in healthy individuals, the decrease is reported to be more pronounced in asthmatic children [38]. Only one study has examined the effect of HIIE on HRV in asthmatic children. In this study, researchers examined the effects of a 6-month HIIE program in asthmatic children and reported that HIIE did not affect HRV values or exercise response [14]. However, no study has examined immediate HRV responses after HIIE in asthmatic children. In both groups, we found that HRV was found to be lower in AE, R1, and R5 compared to BE. However, it returned to BE values in R10. This similar response may reflect the HIIE effect applied in the same exercise protocol on HRV values.

Upon analysing responses to exercise, BP, SpO_2, dyspnoea, and fatigue, in conjunction with HR, demonstrate a cohesive response of the cardiorespiratory and musculoskeletal systems. These responses may change depending on exercise type, intensity, and modality [9, 43–46]. The limited studies examining the acute effects of HIIE in asthma have highlighted lower values for dyspnea and fatigue and faster recovery responses [9, 44]. However, no evidence was found for acute responses in BP and SpO_2. In our study, BP and SpO_2 increased AE and returned to normal during recovery in both groups. Dyspnea remained minimal and maintained nearly similar values to BE. Although performed in different ways, HIIE is advantageous for dyspnea and produces similar responses. When comparing the groups, fatigue showed the greatest

difference. The GHIIE achieved lower fatigue and demonstrated a better recovery. These results observed in groups with similar variables that could affect fatigue, such as physical activity and asthma control levels, may indicate that GHIIE may be a distraction strategy for fatigue.

One of the most important impacts of game-based exercise is increased positive exercise perception [46]. Research indicates that positive exercise experience may serve as a method to enhance exercise participation and adherence [47–50]. Additionally, adolescent studies have emphasized the superiority of HIIE over continuous exercise for perceptual responses [47]. Studies on HIIE in asthmatic children, likely because they focused on long-term effectiveness and examined the effects of HIIE on physical parameters and disease-related outcome measures, have reported positive impacts on tolerance and motivation, although they do not directly address parameters such as enjoyment, fun, and pleasure [13–15]. However, no studies comparing GHIIE with THIIE have been found. Our results indicate that exercise enjoyment and fun of the HIIE are high and higher in the GHIIE in asthmatic children. Besides, children in the GHIIE were more willing to do the exercise again. Our results highlight that, even though administered as a single session, GHIIE provides a positive exercise experience in asthmatic children. Future long-term studies may corroborate these outcomes, and it is questionable whether it may be a viable strategy to improve exercise participation and adherence in asthmatic children.

The major limitation of our study was that the HR_{max} method was used instead of maximal oxygen consumption to plan exercise intensity due to the inability to integrate the gas analyzer into the system. However, the intensity determined by HR was confirmed by perceived exertion at the desired HR percentage in two stages. Another limitation was the sole use of RR interval to assess HRV. While this value reflects the autonomic system's response to HRV, it does not solely reflect the involvement of the sympathetic/parasympathetic systems. Future studies could examine parameters reflecting the activation of parasympathetic and sympathetic systems. Another limitation of this study is the exclusion of children with exercise-induced bronchoconstriction (EIB). Although this criterion was applied to minimize the potential influence of exercise-induced bronchoconstriction on exercise responses and to ensure safety during high-intensity exercise, it may limit the generalizability of our findings. Therefore, the present results may not be directly applicable to all children with asthma, particularly those with coexisting EIB. Future studies should evaluate high-intensity exercise interventions specifically in children with asthma and EIB.

Conclusion

In our study, we developed the HIIE system for the rehabilitation of asthmatic children and compared its immediate effects on hemodynamic and autonomic responses with THIIE. Results indicate that the GHIIE system is enjoyable and offers advantages over THIIE for HR, HRV, leg fatigue, and general fatigue. Future studies are needed to investigate the long-term effects and benefits in increasing participation, exercise motivation, and adherence to the system. Furthermore, the system's customizable structure allows for its applicability and usability across different populations.

Abbreviations

in alphabetical order

AE
After exercise
BE
Before exercise
DBP
Diastolic blood pressure
GHIIE
Game-Based High-İntensity Interval Exercise
HR
Heart rate
HR_{max}
Maximum heart rate
HRV
Heart rate variability
RR
Respiratory rate
R1
1-minute recovery
R5
5-minute recovery
R10
10-minute recovery
SBP
Systolic blood pressure
SpO_2
Peripheral oxygen saturation
THIIE
Traditional High-intensity Interval Exercise

Declarations

Declarations of interest

None

Clinical Trial

The trial was registered under ClinicalTrials.gov after the system was developed (Number=NCT06895642).

Conflict of Interest:

The authors declare that there is no conflict of interest related to the research.

Funding:

Funding for the project equipment was provided by the University's Scientific Research Projects Coordination Office (Project number 2024-TDR-SABE-0002)

Author Contribution

M.K.1. contributed to conceptualization, data curation, formal analysis, investigation, methodology, and writing the original draft. Ö.Y. contributed to conceptualization, data curation, investigation, methodology, supervision, and writing – review and editing. H.Y. contributed to formal analysis, investigation, supervision, and writing – review and editing. M.K.2. contributed to conceptualization, methodology, project administration, software, and writing the original draft. İ.N. contributed to conceptualization, data curation, methodology, project administration, and writing – review and editing. All authors reviewed and approved the final version of the manuscript.

Acknowledgement

This publication is based on Melissa KÖPRÜLÜOĞLU KOÇ's doctoral thesis. The authors acknowledge TÜBİTAK for providing financial support throughout the doctoral process.

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Figures

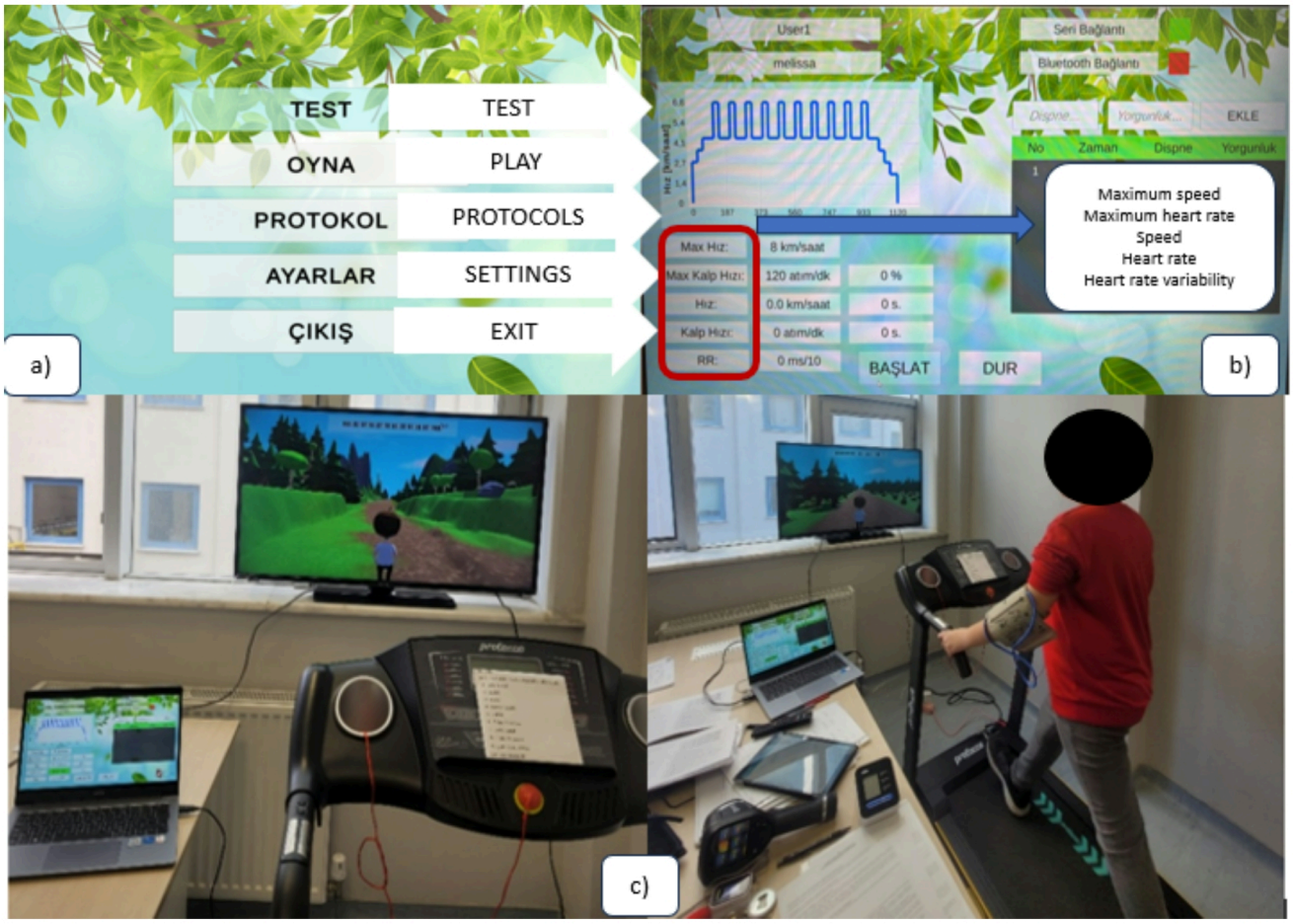


Figure 1

Game and System Images

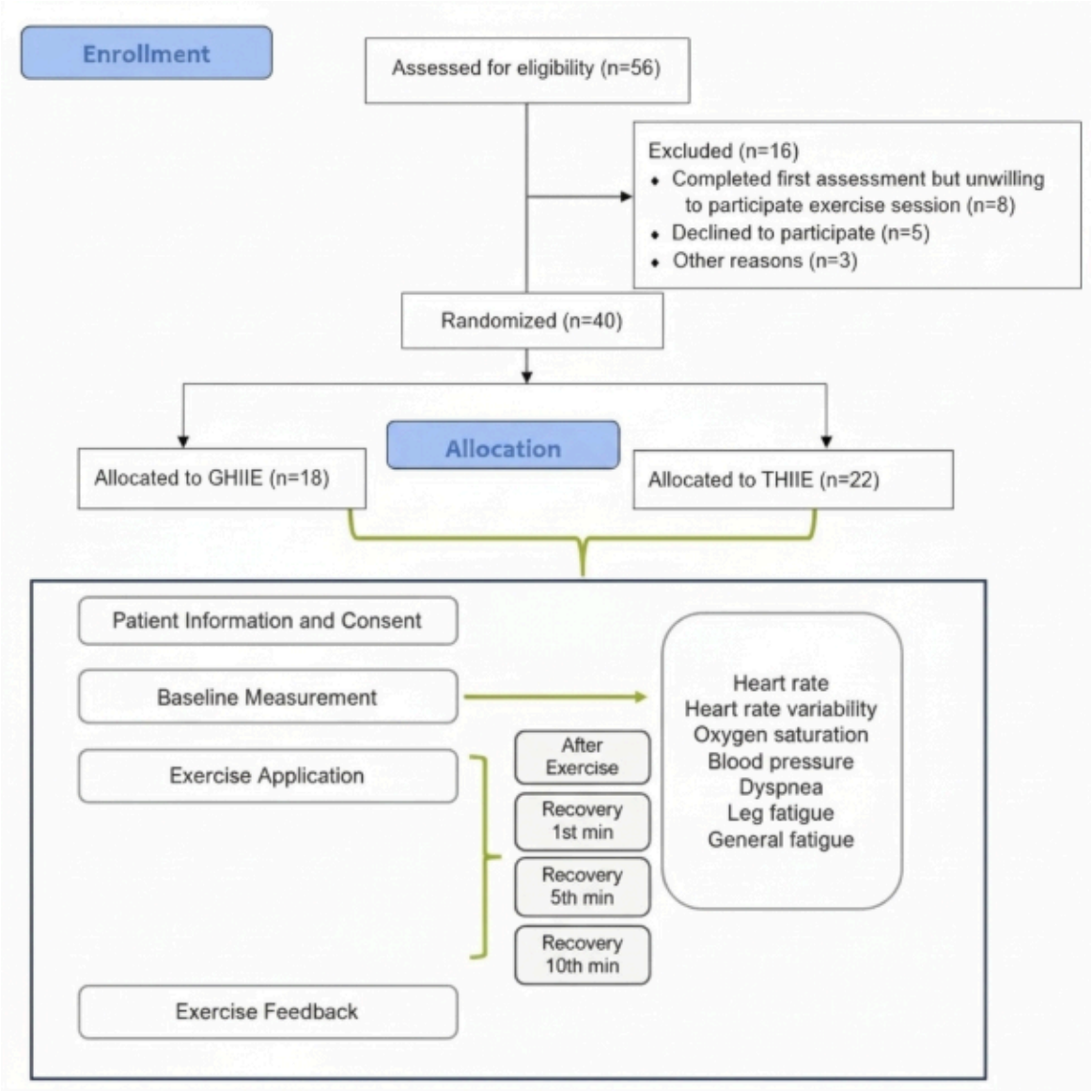


Figure 2

Flowchart and Settings of the Study