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Game-based and individualized movement training improves physiological and motor outcomes in young adults with autism spectrum disorder: an experimental study from Türkiye

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Abstract

Background This study aims to examine the effects of game-based and individualized movement training (GBIMT) program on physiological (body weight, body fat percentage, BMI) and motor outcomes (balance, reaction time, motor speed) in young adults diagnosed with autism spectrum disorder (ASD).

Methods An experimental design with pre-test–post-test control groups was used in the study. A total of 20 participants (10 in the experimental group, 10 in the control group) with a mean age of 22.2 ± 4.8 years were monitored for eight weeks. The experimental group participated in GBIMT sessions for 60 min per day, two days per week, while the control group continued their usual educational routines. Body composition (InBody 270 Body Composition Analyzer, model Plus 270, South Korea), balance (TechnoGym, Cesena, Italy), reaction time (BlazePod Ltd., Israel), and motor speed (Computerized Tapping Test, Neurosoft Inc., USA) parameters were used as measurements.

Results Repeated measures ANOVA results indicated a significant reduction in body weight in terms of the experimental group ($p = 0.014$, $\eta^2 = 0.289$). Large effect sizes were observed for body fat percentage and BMI; however, the group $\times$ time interactions were not found to be statistically significant. A significant improvement was observed in the motor speed parameter within the experimental group ($p = 0.032$, $\eta^2 = 0.231$). Reaction time decreased by 9.8%, although the group $\times$ time interaction stayed within the significance limit ($p = 0.063$). A trend toward improvement was observed in balance parameters; however, no statistically significant difference was found.

Conclusion The findings indicate that GBIMT produced significant improvements in body composition and motor speed after implementing for eight weeks, and also showed a strong tendency to affect reaction time. As a controlled experimental study conducted in Türkiye, this research offers a unique contribution to the literature by demonstrating

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the effects of game-based and individualized movement programs on both physiological and motor outcomes in individuals with ASD.

Trial registration GameBased and Individualized Movement Training Improves Physiological and Motor Outcomes in Young Adults with Autism Spectrum Disorder An Experimental Study From Türkiye, ClinicalTrials.gov NCT07170891, Date 20,062,025.

Keywords Autism spectrum disorder, Balance, Exercise, Game-based and individualized, Motor skills, Performance, Physical activity, Reaction time

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by difficulties in social communication, restricted interests, repetitive behavior patterns, as well as significant differences in motor functions (American Psychiatric Association, 2013). Recent research has shown that individuals with ASD fall behind particularly in fundamental skills such as balance, postural control, reaction time, and sequential motor speed compared to their peers. It is increasingly accepted that these motor limitations not only affect physical capacity but also directly impact cognitive attention processes, social participation, and independent living skills [1, 2].

The neurophysiological mechanisms underlying these disparities in motor skills are also remarkable. Cerebellar dysfunction, impairments in proprioceptive integration, and delays in multisensory integration have been reported as key determinants of reduced motor performance in individuals with ASD [3]. These mechanisms are particularly associated with balance and reaction time parameters [4–6]. For instance, while cerebellar dysfunction adversely affects postural stability, sensory integrative dysfunction can cause delayed motor responses to environmental stimuli [7–11]. Therefore, assessing motor impairments in ASD is critical not only in terms of physical performance but also in terms of neurological functionality [11, 12].

Exercise-based interventions are increasingly being researched in individuals with ASD to support not only physical fitness but also cognitive and social functioning. Recent systematic reviews have demonstrated that physical activity programs have positive effects on motor skills, social participation, and health-related physical fitness [13, 14]. Furthermore, experimental findings suggest that regular exercise programs may be associated with improvements in certain components of executive functions –particularly inhibition and cognitive flexibility [15]. Nevertheless, the impact of these programs depends not only on structured applications but also on game-based and individualized approaches. While gamified exercises facilitate sustained participation by enhancing motivation [16], progressive structuring based on the principle of increasing load becomes prominent as a fundamental factor supporting the sustainability of

motor gains [17]. Although a growing body of literature has examined game-based or gamified exercise interventions in individuals with ASD, most existing studies focus on either motor or psychosocial outcomes, are predominantly conducted in children, and rarely integrate individualized progression principles within a single structured protocol. Moreover, controlled experimental studies simultaneously examining both physiological and motor outcomes in young adults with ASD, particularly in the Turkish context, remain scarce.

From a physiological perspective, studies conducted in recent years indicate that exercise-based programs can have positive effects on body composition. For instance, Mao et al. [18] reported that a training program combining ball sports prevented BMI increases in children, thereby reducing obesity risk. In terms of motor outcomes, exercise programs have been shown to provide significant improvements in balance, coordination, and reaction time [13]. An experimental study conducted in Türkiye identified significant reaction time improvements in children participating in a 12-week circuit training program [19]. Nevertheless, findings related to parameters based on multisensory integration, such as reaction time, are not always consistent. Hence, a systematic review by Suárez-Manzano et al. [20] revealed that while some studies reported significant gains, others showed limited effects. This situation clearly demonstrates the need for more controlled and comprehensive research in the future.

In the context of Türkiye, experimental research in this field is quite limited. Özcan et al. [21] reported that motor intervention programs conducted with children with ASD contributed not only to motor skills but also to academic and social skills. However, existing studies have mostly focused on motor and social outcomes, and there are very few experimental studies that comprehensively address physiological indicators such as body weight, fat percentage, or BMI alongside motor parameters such as balance, reaction time, and tapping within the same protocol. This lack demonstrates that controlled studies conducted in Türkiye can not only contribute to the literature but also directly contribute to the development of rehabilitation programs and special education practices [21]. A game-based movement training

program is characterized by the integration of physical exercises into game-like contexts that include clear rules, achievable goals, immediate feedback, and motivational elements such as challenge and variability. Unlike traditional exercise-based interventions, GBIMT emphasizes engagement through play while preserving core training principles such as task specificity, progressive overload, and individualization. In the present study, game-based movement training refers to a structured physical training program in which motor tasks are embedded within rule-based, goal-oriented, and feedback-driven game scenarios, combined with individualized progression and exercise prescription principles. The GBIMT framework builds upon principles derived from gamified exercise and exercise-based intervention literature while extending these approaches through individualized load progression and multisensory task design. In the present study, games were not used merely as motivational tools but as structured vehicles to deliver balance, coordination, reaction time, and motor speed training.

The purpose of this study is to examine the effects of an eight-week GBIMT program on physiological (body weight, fat percentage, BMI) and motor outcomes (balance, reaction time, tapping) in young adults diagnosed with ASD. The intervention is structured around activities that integrate multi-sensory inputs and the principle of progressive overload. The originality of this study lies in (i) integrating a game-based approach with individualized interventions, (ii) being one of the rare controlled experimental studies conducted in the context of Türkiye, and (iii) evaluating both motor and physiological parameters within the same framework. In these respects, this research offers an original contribution to understanding the multidimensional effects of exercise-based interventions in ASD and filling the existing gap in the literature.

Although there are findings in the literature suggesting that game-based, multi-sensory supported, and individualized exercise programs may be effective in addressing these deficiencies, controlled studies examining specific parameters such as balance, reaction time, and motor speed alongside physiological outcomes are limited. In this context, the present study seeks to answer the following fundamental question:

Does the GBIMT program significantly improve physiological (body weight, fat percentage, BMI) and motor outcomes (balance, reaction time, motor speed) after eight weeks in young adults diagnosed with ASD?

The following hypotheses were formulated to seek answers to this research question:

H1 (Physiological)

Participants in the experimental group will display statistically significant improvements in body composition

(body weight, fat percentage, BMI) compared to the control group at the end of the eight-week program.

This hypothesis is based on findings that exercise-based programs positively affect metabolic and physiological outcomes in individuals with ASD. Mao et al. [18] reported that a ball sports training program prevented BMI increases in adolescents, reducing obesity risk and improving physical fitness. Similarly, comprehensive review of Rivera et al. [14] emphasizes that game based and individualized exercises can have beneficial effects on body composition and general health indicators. Additionally, Wang and Chen [13] reported that physical activity interventions can mediate positive changes not only in motor skills but also in health-related physiological outcomes. Therefore, in the current study, GBIMT is expected to provide significant improvements in body weight, fat percentage, and BMI in the experimental group compared to the control group.

H2 (Balance)

Participants in the experimental group will show significant improvements in balance parameters (bilateral and single-leg stability indices) compared to the control group after eight weeks.

This hypothesis is based on finding showing that exercise-based interventions can improve postural control/balance in children with ASD. Indeed, Li et al. [15] reported significant improvements in balance and behavioural inhibition in children following an exercise program. Systematic reviews combining interventions targeting balance in ASD also suggest that various exercise approaches aimed at improving postural balance yield promising results. Evidence exists that the Biodex-based “bilateral” and “single-leg” stability indices to be used in the present study are commonly used objective measures in ASD samples [15, 22, 23].

H3 (Reaction Time)

Participants in the experimental group will display statistically significant reductions in reaction time compared to the control group after the eight-week program.

This hypothesis is based on findings that exercise-based interventions can enhance response control and processing speed in ASD. In a study conducted in Türkiye, reaction times improved significantly in children with ASD after 12 weeks of circuit training [19]. Additionally, exercise and gamified activities have shown short-term positive effects on executive function components such as inhibition [15, 24]. Nevertheless, there are also some reviews that report inconsistent findings regarding reaction time outcomes; this situation suggests the impacts of duration of the measurement, program dosage, and individual differences [20]. Therefore, it is expected that the structure of GBIMT, which combines multi-sensory

stimuli and gradual loading, will produce significant reductions in reaction time compared to the control group [15, 19, 20, 24].

H4 (Motor Speed)

Participants in the experimental group will demonstrate statistically significant increases in motor speed (finger tapping test) compared to the control group at the end of the eight-week program.

This hypothesis is based on findings suggesting that exercise and game-based applications may be associated with improvements in reaction time/motor speed indicators. In an experimental study conducted in Turkey, reaction time was significantly reduced after 12 weeks of circuit training [19]. Gamified exercise protocols have also been reported to positively impact response speed and motor performance [25]. Furthermore, finger tapping measures are sensitive to motor speed and timing differences related to autistic traits; timing and synchronization issues in tapping-based tasks have been reported in ASD groups [26, 27]. Therefore, it is expected that GBIMT, which combines multi-sensory inputs and progressive loading, will produce meaningful gains in motor speed as assessed by finger tapping [14, 19, 25–27].

Methods

Participants

Twenty young adults diagnosed with ASD voluntarily participated in this study. All participants had received a formal ASD diagnosis based on the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) criteria, confirmed by licensed child psychiatrists or clinical psychologists through official medical records. According to available clinical documentation and institutional assessments, participants were classified as requiring Level 1 or Level 2 support (requiring support or requiring substantial support). Individuals requiring Level 3 support (very substantial support) were not included in the study due to safety considerations and the need to follow structured verbal and visual instructions during the movement training program.

Eligibility criteria included the ability to understand and follow simple verbal and visual instructions, independent ambulation without assistive devices, and the absence of any diagnosed neurological, musculoskeletal, or cardiovascular conditions that could contraindicate participation in moderate-intensity physical activity. Participants with uncontrolled epilepsy, severe behavioral challenges that could compromise group safety, or recent orthopedic injuries were excluded. At the time of recruitment, none of the participants were engaged in structured or systematic sport or exercise programs specifically designed for individuals with ASD. Although some participants participated in occasional recreational

physical activities as part of their daily routines, none had prior experience with regular, supervised movement training programs comparable to the GBIMT intervention.

The participants had a mean age of 22.2 ± 4.8 years, an average height of 171.52 ± 6.70 cm, body weight of 70.56 ± 8.93 kg, body fat percentage of $22.51 \pm 2.79\%$, and a body mass index (BMI) of 22.21 ± 2.21 kg/m². All participants were enrolled in a licensed special education and rehabilitation center operating under the supervision of the Turkish Ministry of National Education. The institution provides educational and therapeutic services for individuals with neurodevelopmental disorders, including ASD, such as individualized education programs, occupational therapy, and motor skill support. Although the institution serves individuals with various developmental profiles, only individuals enrolled in ASD-specific educational programs were recruited for the present study.

Prior to data collection, detailed information regarding the study objectives, procedures, potential risks, and expected benefits was provided to the parents or legal guardians of all participants. Written informed consent was obtained from the parents or legal guardians in accordance with ethical guidelines. In addition, verbal assent was obtained from the participants themselves, taking into account their cognitive and communicative abilities. Participants and their families were informed that participation was voluntary and that they could withdraw from the study at any time without any negative consequences. All procedures were conducted in accordance with the principles of the Declaration of Helsinki and the CONSORT guidelines. Ethical approval for the study was obtained from the Health Sciences Ethics Committee of Çankırı Karatekin University (Decision No: 2024/11). The confidentiality of participants' personal information was maintained, and the data obtained were used solely for scientific purposes [28].

Research model

This study was designed using the true experimental design with a pre-test and post-test control group, which is one of the experimental research designs. In this model, the groups were formed using random assignment, and the experimental and control groups were ensured to have similar characteristics at the start [29]. The pre-test measurements are critically important for determining the initial conditions of the groups before the intervention and for interpreting the post-test results in reference to these initial states [30]. In the study, the experimental group ($n = 10$), which participated in an 8-week movement training program, and the control group ($n = 10$), which did not take part in the program, were selected through a random assignment method

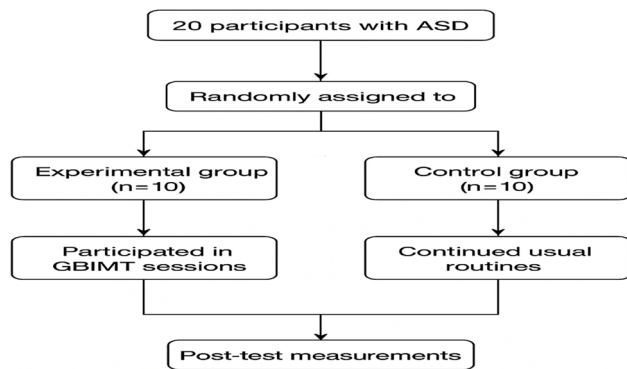


Fig. 1 CONSORT flowchart including detailed information on the intervention received

(Fig. 1). The eight-week duration of the intervention was selected based on previous exercise-based and play-based intervention studies in individuals with ASD, which commonly report meaningful motor and physiological adaptations following programs lasting between 6 and 12 weeks. This duration was considered sufficient to induce measurable training effects while maintaining participant adherence and minimizing fatigue or drop-out. The sample size was calculated using the G*Power statistical software, and 10 participants per group were deemed sufficient considering a significance level of 0.05, statistical power of 0.80, and a medium effect size ($d = 0.5$). Thus, the study was conducted with a total of 20 participants [31].

Design, implementation, and details of the Game-Based and Individualized Movement Training (GBIMT) program

The GBIMT program was designed as a structured, progressive, and individualized physical training intervention, in which motor tasks were systematically embedded within rule-based, goal-oriented, and feedback-driven game scenarios. The program was developed by integrating principles from gamified exercise and exercise-based intervention literature with individualized exercise prescription and motor learning frameworks, specifically adapted for young adults with ASD.

Program design and structure

The GBIMT program was implemented over eight weeks, with two sessions per week, resulting in a total of 24 training sessions. Each session lasted approximately 50–60 min and consisted of a standardized structure including a warm-up phase (10 min), a main game-based training phase (30–40 min), and a cool-down phase (10 min). The primary focus of the program was to improve balance, coordination, reaction time, and motor speed through progressively challenging game-based movement tasks.

Table 1 Exercise and education design

Week	Component	Game-Based Activity	Motor Focus	Intensity	Progression
1–2	Balance	Stay-on-the-island balance game	Static balance	50–60%	Duration ↑
3–4	Coordination	Ball scoring game	Eye–hand coordination	60–65%	Reps ↑
5–6	Reaction	Light/color response game	Reaction time	65–70%	Speed ↑
7–8	Motor Speed	Timed tapping challenge	Fine motor speed	75–80%	Complexity ↑

Rather than delivering isolated repetitive exercises, physical movements were incorporated as the motor content of structured games. Thus, exercises such as balance maintenance, stepping, reaching, throwing, and rapid response movements were framed within game scenarios featuring clear rules, achievable goals, performance feedback, and variability to enhance engagement and motivation. In this context, exercise was not considered a game in itself; instead, it functioned as the physical component embedded within the game-based structure.

Game-based activities

The GBIMT program included a variety of structured motor games targeting specific motor and physiological outcomes. These games were selected and designed to be simple, predictable, and adaptable to individual abilities while maintaining motivational elements. Examples of game-based activities included: Balance challenge games, such as single-leg or tandem stance tasks framed as “stay-on-the-island” or “do not touch the ground” games, requiring participants to maintain balance for increasing durations. Coordination games, including ball-based throw-and-catch challenges with scoring rules, target-based throwing games, and bilateral movement tasks emphasizing eye–hand coordination. Reaction-based games, such as color- or signal-response games in which participants were required to respond rapidly to visual or auditory cues by performing specific movements. Motor speed games, including timed tapping tasks, rapid stepping games, and obstacle-based movement challenges, emphasize quick initiation and execution of movement. All games incorporated explicit instructions, defined success criteria, and immediate verbal or visual feedback provided by the instructors to reinforce task performance (Table 1).

Consideration of individual differences and adaptations

Individual differences in motor competence, attention span, sensory sensitivity, and motivation were systematically addressed throughout the program. Prior to the intervention, baseline motor assessments and observational evaluations were conducted to determine each participant's functional level and tolerance for physical activity. Based on these assessments, the difficulty, duration, and complexity of each game were individually adjusted. Adaptations included modifying task duration (e.g., shorter balance-holding times), simplifying movement sequences, adjusting the size or weight of equipment, reducing sensory load (e.g., minimizing auditory stimuli for sensory-sensitive participants), and providing additional visual cues when necessary. These adaptations ensured that all participants could safely engage in the program while maintaining an appropriate level of challenge.

Individualized progression and ongoing adjustments

Individual performance assessments were conducted continuously during the intervention to guide progression and program modifications. Adjustments were made based on observed task mastery, fatigue levels, behavioral responses, and safety considerations. Progression strategies included increasing task duration, adding movement complexity, increasing response speed demands, or introducing dual-task elements once participants demonstrated adequate control and confidence.

Conversely, when participants experienced difficulty, task demands were temporarily reduced by simplifying rules, decreasing intensity, or providing additional instructional support. This flexible and individualized progression approach ensured adherence to core training principles such as task specificity, progressive overload, and individualization, while preserving the motivating nature of the game-based format.

Implementation setting and personnel

All training sessions were conducted in the indoor gymnasium of the special education and rehabilitation center where the participants were enrolled. The training environment was structured to be safe, controlled, and minimally distracting, and was equipped with balance boards, soft mats, cones, balls, resistance bands, and visual cue materials appropriate for individuals with ASD.

The GBIMT program was delivered by trained exercise professionals with academic backgrounds in physical education, exercise science, or related fields, all of whom had prior experience working with individuals with ASD. Sessions were supervised by a senior researcher with doctoral-level expertise in adapted physical activity and autism interventions. An instructor-to-participant ratio of 1:1 or 1:2 was maintained to ensure safety,

individualized feedback, and appropriate behavioral support throughout the intervention. For balance- and coordination-based game activities, intensity (% maximum capacity) did not refer to cardiovascular load or heart rate-based measures. Instead, intensity was operationalized as task difficulty and perceived effort, determined by factors such as task duration, movement complexity, postural demand, and accuracy requirements. Progression was achieved by increasing these task-related demands rather than by targeting physiological intensity zones (Table 1).

Body composition measurement

As part of the study, participants' heights were first measured and recorded. After the height measurement, participants underwent body composition measurement. Body weight (kg) and body composition analyses were performed using the InBody 270 Body Composition Analyzer (model Plus 270, South Korea) device [32, 33]. Body composition measurements were taken one day before the performance tests, in the morning (8:30–12:00) and after evening fasting. Participants were instructed not to consume any liquids or food and to use the restroom before the measurement. Additionally, all metal accessories and jewelry that could affect the accuracy of the measurements were removed. Measurements were taken with individuals wearing light clothing and in accordance with the device's standard measurement procedures. Data were recorded digitally via the device's software system and stored for use in the analyses. The measurement protocol was implemented in accordance with standards in the literature, and reliability and validity. Although the InBody 270 provides estimates of additional body composition parameters such as skeletal muscle mass and intracellular and extracellular water, the present study focused on body weight, body fat percentage, and BMI. These variables were selected due to their widespread use in the ASD and exercise intervention literature, ease of interpretation, and relevance for monitoring general morphological changes in response to short-term training interventions.

Balance test

In order to evaluate balance performance in autism, a balance measurement device manufactured by the Italian brand TechnoGym (TechnoGym, Cesena, Italy) was used. This device can measure postural sway with high accuracy by means of its integrated sensors and convert it into numerical data. Thus, participants' static balance abilities were objectively assessed [34].

Within the test protocol, participants were instructed to stand on the device and keep their eyes open. Balance was assessed in three positions:

- 1) **Bilateral Standing Balance:** With both feet parallel and approximately shoulder-width apart, participants were asked to maintain balance for 30 s with their eyes open.
- 2) **Single-Leg Balance – Right Leg:** The participants were asked to stand on their right foot and lift their left foot slightly off the ground, maintaining balance with their eyes open for 30 s. This measurement allows for the assessment of unilateral balance and postural stability.
- 3) **Single-Leg Balance – Left Leg:** The same procedure as the right foot test was repeated on the left foot.

At each test stage, participants' success in maintaining balance was recorded numerically using parameters such as the amount of postural sway detected by the device and the stability index. During the test, participants were verbally informed in advance and provided with support for safety purposes when necessary. The application of balance tests is an extremely critical method for monitoring postural control in specific conditions such as neurodevelopmental disorders [35]. Furthermore, such measurements of balance are considered an important tool for evaluating the effectiveness of rehabilitation programs and tracking progress [36]. All tests were conducted in a controlled environment under similar environmental conditions, with noise and distractions minimized. Measurements were taken during specific hours of the day (8:30 a.m. to 12:00 p.m) to reduce the impact of time-related biological variables. Balance performance was quantified using the overall stability index, with lower values indicating better postural stability.

Reaction test

Individuals with ASD may exhibit varying degrees of impairment in cognitive processing speed, attention control, and motor response time. In this context, a reaction time test was administered in the study to assess participants' psychomotor speed and response times. Reaction time refers to the duration of an individual's motor response to a stimulus and provides important information about central nervous system functionality, attention level, and neuromotor integrity [37]. For this purpose, the BlazePod Reaction Training System (BlazePod Ltd., Israel), a portable, visual stimulus-based reaction measurement device, was used in the tests. The device is controlled via a Bluetooth-enabled application and records the participant's reactions to the lighted pods at the millisecond (ms) level. During the test, participants were

asked to touch the lighted pods that lit up randomly at different intervals with their hands as quickly as possible. Each participant was given three attempts, and the average reaction time was calculated and used in the analysis. The measurements were conducted in a quiet environment with minimal distractions and with one-on-one supervision. The BlazePod Reaction Training System (BlazePod Ltd., Israel) has been shown to be a valid and reliable tool for assessing reaction time in both athletic and non-athletic populations. Previous studies have reported high test–retest reliability and concurrent validity of BlazePod-based reaction time measures when compared with established reaction time assessment methods [38].

Finger tapping test

Individuals with ASD may experience difficulties in motor speed and fine motor control. In the present study, to assess these areas, the Finger Tapping Test was used. The test is a widely used, reliable, and valid method for measuring motor speed and the performance of repetitive movements [39]. During the test, the participants were asked to tap a disk or button as quickly and consecutively as possible with their index finger. The taps were counted for a specified period (usually 10 s), and the total number of taps was recorded as motor speed performance. In this study, the test application was performed using the CTT-1 (Computerized Tapping Test, Neurosoft Inc., USA) device. The device records tapping speed with millisecond precision and enables data analysis in a digital environment. Tests were conducted in a quiet environment with minimal distractions; each participant was given three attempts for each hand, and average values were used in the analyses. The Finger Tapping Test is an effective tool for identifying developmental differences in motor speed and hand coordination in individuals with autism and for monitoring motor skill development [40].

Statistical analysis

All statistical analyses were performed using SPSS software (version 25.0; IBM Corp., Armonk, NY, USA). Data normality was assessed using the Shapiro–Wilk test. In addition, distributional characteristics were examined through skewness and kurtosis values, as well as histograms, box-and-whisker plots, and Q–Q plots, to ensure conformity with normal distribution assumptions. As the data met the criteria for normality, results are presented as mean ± standard deviation (SD). Percentage changes between measurements ($\Delta\%$) were calculated using the formula presented in Fig. 2.

According to this formula, a positive $\Delta\%$ value indicates a reduction in the post-test value relative to baseline, such as decreases observed in reaction time or body weight. To examine differences between trials, a two-way

$$\% \Delta = \frac{\text{Pre Test} - \text{Post Test}}{\text{Pre Test}} \times 100$$

Fig. 2 Formula for percentage change

repeated-measures analysis of variance (ANOVA) was conducted, with Bonferroni correction applied for post hoc comparisons where appropriate. Effect sizes for between-group comparisons were calculated using partial eta squared (η^2). The magnitude of η^2 was interpreted as follows: values around 0.01 indicate a small effect, values around 0.06 indicate a moderate effect, and values of 0.14 or higher indicate a large effect [41]. All statistical analyses were conducted using a 95% confidence level, and statistical significance was set at $p < 0.05$.

Results

This section presents the results of the data analysis. The findings are displayed in tables. Findings comparing the effects of GBIMT on physiological traits between groups over time are presented in Table 2.

Table 2 summarizes the between-group comparison of changes in key physiological traits over the intervention period, including body weight, body fat percentage, and body mass index (BMI), using a repeated measures two-way ANOVA framework complemented by descriptive statistics and percentage changes.

Time effects

A statistically significant time effect was observed for all physiological parameters examined, indicating meaningful improvements across the intervention period irrespective of group allocation. Body weight demonstrated a robust reduction over time ($F(1-18) = 46.238$, $p = 0.001$), accompanied by a very large effect size ($\eta^2 = 0.720$). Similarly, body fat percentage showed a pronounced time-related decrease ($F(1-18) = 114.656$, $p = 0.001$), with an extremely large effect size ($\eta^2 = 0.864$), suggesting substantial changes in body composition throughout the study duration. Body mass index also decreased significantly over time ($F(1-18) = 48.750$, $p = 0.001$), again with a very large effect size ($\eta^2 = 0.730$). Collectively, these findings indicate that the intervention period was highly effective in eliciting favourable anthropometric and body composition adaptations, potentially reflecting the combined influence of structured physical activity, metabolic adaptations, and behavioural changes.

Group $\times$ time interactions

Regarding group $\times$ time interactions, a statistically significant interaction was observed only for body weight ($F(1-18) = 7.321$, $p = 0.014$, $\eta^2 = 0.289$), representing a large interaction effect. This finding indicates that the magnitude of body weight reduction differed between groups, favouring the experimental group. Consistent with this result, the experimental group exhibited a greater percentage decrease in body weight ($\Delta\% = 5.36$) compared with the control group ($\Delta\% = 2.64$), suggesting an added benefit of the experimental intervention beyond general time-related effects. In contrast, no statistically significant group $\times$ time interactions were detected for body fat percentage ($p = 0.084$) or BMI ($p = 0.477$). Nevertheless, the associated effect sizes for body fat percentage ($\eta^2 = 0.156$) suggest a moderate-to-large practical effect, indicating a trend toward greater fat reduction in the experimental group that did not reach statistical significance. For BMI, the interaction effect size was small ($\eta^2 = 0.028$), suggesting largely parallel improvements between groups.

Practical and clinical implications

From a clinical and practical perspective, the consistently larger $\Delta\%$ reductions observed in the experimental group across all physiological parameters indicate a pattern of superior adaptation, even when statistical significance was not achieved. The combination of large time effects and selective group-specific advantages suggests that while both groups benefited from the intervention period, the experimental protocol may confer additional efficacy for body weight reduction, with potential but less definitive advantages for body fat reduction. Overall, these findings support the effectiveness of the intervention in improving body composition-related outcomes and highlight body weight as the parameter most sensitive to group-specific influences.

Findings comparing the effects of GBIMT performance parameters between groups over time are presented in Table 3.

Table 3 presents a comprehensive comparison of changes in balance, reaction time, and disk performance between the experimental group (EG) and control group

Table 2 Comparison of changes in physiological traits over time between groups

Parameters	Group	Pre-test	Post-test	$\Delta\%$	Time Effect		Group $\times$ Time Interaction	
		$\bar{X} \pm SD$	$\bar{X} \pm SD$		F	p (η^2)	F	p (η^2)
Body Weight (kg)	EG	75.32 $\pm$ 5.55	71.28 $\pm$ 4.06	5.36	46.238	0.001 (0.720)	7.321	0.014* (0.289)
	CG	65.80 $\pm$ 9.34	64.06 $\pm$ 10.03	2.64				
Body Fat Percentage (%)	EG	22.50 $\pm$ 2.36	19.48 $\pm$ 2.08	13.42	114.656	0.001 (0.864)	3.335	0.084 (0.156)
	CG	22.52 $\pm$ 2.28	20.38 $\pm$ 2.10	9.50				
Body Mass Index (kg/m ²)	EG	23.20 $\pm$ 1.03	20.81 $\pm$ 0.85	10.30	48.750	0.001 (0.730)	0.527	0.477 (0.028)
	CG	21.23 $\pm$ 2.67	19.29 $\pm$ 1.78	9.14				

* $p < 0.05$; η^2 : small > 0.01 , medium ≥ 0.06 , large ≥ 0.14

Table 3 Comparison of differences in performance parameters over time between groups

Parameters	Group	Pre-test $\bar{X} \pm SD$	Post-test $\bar{X} \pm SD$	$\Delta\%$	Time Effect		Group x Time Interaction	
					F	p (ηp^2)	F	p (ηp^2)
Balance R (sec.)	EG	6.38 $\pm$ 0.72	5.96 $\pm$ 0.70	6.58	15.228	0.001 (0.458)	3.428	0.081 (0.160)
	CG	4.86 $\pm$ 0.35	4.71 $\pm$ 0.40	3.09				
Balance L (sec.)	EG	6.03 $\pm$ 0.80	5.76 $\pm$ 0.82	4.48	12.451	0.002(0.409)	1.190	0.290 (0.062)
	CG	6.02 $\pm$ 0.76	5.88 $\pm$ 0.80	2.33				
Reaction (ms)	EG	655.59 $\pm$ 13.15	591.42 $\pm$ 15.32	9.79	5.186	0.035(0.224)	3.912	0.063 (0.179)
	CG	656.95 $\pm$ 10.46	652.43 $\pm$ 12.42	1.69				
Disk (repetitions/sec)	EG	22.80 $\pm$ 1.67	21.03 $\pm$ 1.53	7.76	20.107	0.001 (0.528)	5.405	0.032* (0.231)
	CG	22.77 $\pm$ 1.01	22.21 $\pm$ 0.53	2.46				

* $p < 0.05$; η^2 : small ≥ 0.01 , medium ≥ 0.06 , large ≥ 0.14

(CG) over the intervention period, incorporating pre-post descriptive statistics, percentage change ($\Delta\%$), and repeated measures two-way ANOVA outcomes.

Time effects

Across all performance parameters, statistically significant time effects were observed, indicating that participants improved over time irrespective of group allocation. Specifically, balance performance demonstrated marked improvements on both the right and left sides, with large effect sizes (Balance R: $F(1-18) = 15.228$, $p = 0.001$, $\eta p^2 = 0.458$; Balance L: $F(1-18) = 12.451$, $p = 0.002$, $\eta p^2 = 0.409$). These findings suggest that the intervention period, whether through structured training or exposure to repeated testing, was sufficient to induce meaningful neuromuscular and postural adaptations. Reaction time also improved significantly over time ($F(1-18) = 5.186$, $p = 0.035$), with a large effect size ($\eta p^2 = 0.224$), indicating enhanced sensorimotor processing and response efficiency. The most pronounced time-related improvement was observed in disk performance ($F(1-18) = 20.107$, $p = 0.001$), accompanied by a very large effect size ($\eta p^2 = 0.528$), underscoring substantial gains in rapid alternating movement capacity and coordination across the study duration.

Group $\times$ time interactions

With respect to group $\times$ time interactions, a statistically significant interaction was identified only for disk performance ($F(1-18) = 5.405$, $p = 0.032$, $\eta p^2 = 0.231$). This large interaction effect indicates that the magnitude of improvement differed between groups, favoring the experimental group. Notably, the experimental group exhibited a greater percentage improvement ($\Delta\% = 7.76$) compared with the control group ($\Delta\% = 2.46$), suggesting that the applied intervention exerted an additional, group-specific benefit on disk performance beyond general time-related effects. In contrast, no statistically significant group $\times$ time interactions were detected for balance or reaction time parameters ($p > 0.05$), despite moderate-to-large effect sizes in some cases (e.g., Balance

R $\eta p^2 = 0.160$; Reaction $\eta p^2 = 0.179$). These findings may indicate that both groups benefited similarly from time-dependent factors such as familiarization, learning effects, or nonspecific training adaptations, thereby attenuating between-group differences.

Practical and clinical relevance

From a practical standpoint, the consistently higher $\Delta\%$ values observed in the experimental group across all parameters suggest a trend toward superior performance gains, even where statistical significance was not achieved. This pattern, combined with moderate-to-large effect sizes, implies that the intervention may possess practical relevance that is not fully captured by p-values alone, particularly in the context of a relatively small sample size. Overall, the results support the efficacy of the intervention in enhancing motor performance over time, with specific added value for disk performance, while improvements in balance and reaction time appear to reflect more generalized training or exposure effects.

Discussion

This study investigated the effects of a GBIMT program on physiological and motor outcomes in young adults diagnosed with ASD. Although the magnitude of the observed effects may appear relatively large, similar improvements have been reported in structured physical activity and play-based intervention studies involving individuals with ASD, particularly when interventions are individualized and delivered in low-distraction environments. Previous studies examining play-based or game-oriented interventions in individuals with ASD have primarily focused on psychosocial outcomes such as social interaction, motivation, or behavioural engagement, with limited emphasis on physiological or motor performance indicators. In contrast, the present study extends this line of research by simultaneously examining both physiological and motor outcomes within a structured game-based movement training framework. Moreover, exercise-based and movement training studies have consistently reported improvements in balance,

coordination, and motor performance; however, these interventions are often delivered through repetitive and non-playful formats, which may limit long-term engagement. The present findings suggest that embedding movement training within structured game scenarios may bridge this gap by combining the motivational advantages of play-based approaches with the physiological effectiveness of exercise-based interventions. Before interpreting the motor performance findings, it is important to clarify the direction of change observed in the motor speed (disk tapping) outcome. Although the numerical values decreased from pre- to post-test, this result reflects an improvement in motor speed, as the variable was operationalized as time per repetition rather than repetitions per second. Accordingly, lower values indicate faster movement execution and enhanced motor speed performance. This clarification resolves the apparent discrepancy between the tabulated values and the interpretation of improved motor speed. The findings indicated that not all hypotheses were equally supported. While H1 (physiological outcomes) and H4 (motor speed) were largely confirmed, H2 (balance) was not supported, and H3 (reaction time) was partially supported. These results indicate that GBIMT is particularly effective on body composition and fine motor speed; however, more complex sensorimotor outputs such as balance and reaction time require longer-term interventions with larger sample sizes.

Physiological outcomes

The findings of this study indicate that an eight-week game-based and individualized movement training program can produce limited but noteworthy effects on physiological indicators. A statistically significant reduction in body weight was observed in the experimental group. Although large effect sizes were noted for body fat percentage and Body Mass Index (BMI), they did not reach statistical significance. This situation suggests that short-term interventions may be insufficient in creating rapid and consistent changes, particularly in metabolic parameters.

Previous studies have shown that exercise-based programs present similar trends. Mao et al. [18] reported that a program which combine ball games prevented BMI increase in adolescents and reduce the risk of obesity. Similarly, the integrative review of Rivera et al. [14] emphasizes that game-based and individualized exercises have beneficial effects on body composition. In the context of Türkiye, Arslan et al. [19] have revealed that regular exercise programs improve not only motor outcomes but also physiological indicators. In this context, the current findings, consistent with the general trends in the literature, indicate that exercise programs contribute to physiological development in individuals with ASD.

However, the positive but statistically non-significant changes in fat percentage and BMI indicate a need for longer-term studies with larger samples. In conclusion, GBIMT appears to be a promising approach in terms of physiological outcomes, but the generalizability of the findings should be reinforced by further studies.

Balance outcomes

This study found that an eight-week GBIMT program created a positive trend in balance outcomes; however, this did not reach statistical significance. This indicates that H2 is not supported. Nevertheless, the trend toward improvement observed in the experimental group suggests that the intervention may have partially supported postural control by activating the proprioceptive and vestibular systems. The absence of statistically significant improvements in balance performance may also be related to the relatively short duration of the intervention. Postural control is a complex motor function that relies heavily on central nervous system adaptations, including cerebellar plasticity, sensorimotor integration, and gradual neural reorganization. Such processes may require longer-term and more repetitive exposure to balance-specific stimuli to induce measurable changes. In individuals with ASD, atypical sensory processing and delayed neural adaptation may further prolong the time course needed for balance-related improvements. Therefore, an eight-week intervention period may be sufficient to elicit changes in more rapidly adaptable motor domains, such as reaction time or movement speed, but insufficient to induce robust adaptations in postural control mechanisms.

Studies in the literature partially confirm these findings. Li et al. [15] reported that exercise-based programs produced significant improvements in balance and behavioural inhibition in children with ASD. Similarly, a systematic review of Date et al. [23] found that balance interventions improve postural control, but the findings are sensitive to program duration and application intensity. Abdel Ghafar et al. [22] also found that differences in sensory integration processes limit balance performance in children with ASD and that multi-sensory interventions therefore play a critical role. Furthermore, a meta-analysis by Fournier et al. [42] shows that individuals with ASD go through persistent difficulties in balance and motor coordination tasks compared to their peers.

These studies show that the current study's findings present a picture consistent with the literature. By means of the GBIMT's structure of multi-sensory stimuli, an improvement trend emerged in balance outcomes; however, the eight-week period was insufficient to produce a statistically significant difference. For this reason, future studies should focus on longer-term and more intensive

protocols, which are important to support the development of balance skills.

Reaction time outcomes

The experimental group showed an approximately 10% reduction in reaction time. Although Cohen's d value was quite high, statistical significance remained borderline ($p=0.063$). This result indicates that H3 is only partially supported. Although the improvement in reaction time did not reach conventional statistical significance ($p=0.063$), the associated effect size was extremely large (Cohen's $d=4.49$), indicating a substantial practical impact of the intervention. This discrepancy between statistical significance and effect magnitude may be attributable to the relatively small sample size. With a modest increase in participant numbers, the observed effect would likely have reached statistical significance. The magnitude of this effect suggests that the game-based movement training had a meaningful influence on reaction time performance, warranting further investigation in studies with larger samples.

The literature partly confirms the findings of the present study. Yu et al. [43] demonstrated that exercise-based programs can increase sensorimotor response speed by strengthening executive functions. Similarly, Ji et al. [44] noted that digital exergaming applications improve not only balance and attention processes but also reaction times. From this perspective, the findings of the current study are consistent with the literature. However, Pan [45] reported that short-term interventions only produced trend-level changes in reaction time. This suggests that reaction speed is closely related not only to motor skills but also to attention, motivation, and multisensory integration. Therefore, GBIMT may show a clinically meaningful trend of improvement in reaction time, but due to time and sample limitations, it cannot produce a statistically significant difference.

Motor speed outcomes

A significant increase was recorded in the finger tapping test performance in the experimental group. This finding supports H4 and shows that GBIMT is effective in on fine motor speed. Travers et al. [46] found that individuals with ASD performed worse on motor speed tasks compared to their peers, but this gap can be closed with structured interventions. Pan [16] reported that game-based exercises improved motor speed and hand-eye coordination, while Rivera et al. [14] noted that individualized programs support fine motor control.

Recent studies also support these findings. Messing [26] demonstrated that finger tapping performance is closely related to attention and executive functions in individuals with ASD. Similarly, Cannon et al. [27] found that reduced sensitivity in motor and rhythmic timing

explains slowness in fine motor skills. These studies show that the current study's findings are consistent with both classical and recent literature. The gamified structure and individualized approach of GBIMT supported the development of fine motor speed, and this contribution was clearly demonstrated through the finger tapping test.

Context of Türkiye and practical contributions

In Türkiye, controlled experimental studies addressing both physiological and motor outcomes of game-based motor interventions in individuals with ASD within the same protocol are quite limited. Although Özcan [21] demonstrated the contribution of motor interventions to social and academic outcomes, there are almost no studies examining multidimensional physiological and motor outcomes together.

This study fills an important gap in the literature in Türkiye. The GBIMT program not only contributes to academic knowledge but also presents an applicable model for rehabilitation centers, special education institutions, and family-based support programs. Its individualized and multi-sensory structure has the potential to become one of the increasingly needed holistic approaches in Türkiye.

Contributions, limitations, and future directions

This study offers a unique contribution to the literature as one of the few controlled experimental studies conducted with young adults with ASD in the Turkish context. The findings show that game-based interventions are particularly effective in areas such as body composition and motor speed, whereas longer-term protocols may be necessary for complex outcomes such as balance and reaction time.

There are some limitations to this study. The small sample size made it difficult to reach statistical significance despite large effect sizes in some parameters. The short eight-week intervention period may have produced limited effects, particularly on balance development. The wide age range of participants introduced heterogeneity, and conducting measurements at a single center and only in the short-term limited generalizability. Furthermore, the limitations of the measurement devices used (InBody, BlazePod, TechnoGym) in non-laboratory conditions should be considered. One limitation of the present study is the relatively wide age range of the participants, despite their classification as young adults. Although all participants fell within the commonly accepted young adult age category, differences between younger (e.g., late adolescence) and older young adults may have influenced baseline motor and physiological characteristics. Future studies may benefit from narrower age stratification to further clarify age-related responses to game-based movement training.

Future research should:

- Use larger and more heterogeneous samples,
- Conduct long-term follow-up studies,
- Examine reaction time by separating it into simple, preferred, and complex tasks.
- Integrate digital exergaming elements to increase participation motivation.
- Assess dominant foot differences and goal-oriented exercise protocols for balance.

Conclusion

This study is one of the rare controlled experimental studies in Türkiye that examines the effects of a GBIMT program on physiological and motor outcomes in young adults diagnosed with ASD. The findings revealed a significant decrease in body weight and an apparent improvement in motor speed; no significance was observed in balance parameters; and a trend toward a reduction in reaction time was observed, despite a very high effect size (Cohen's $d = 4.49$), which remained statistically borderline ($p = 0.063$). These results suggest that GBIMT is particularly effective on body composition and fine motor speed, while longer-term and larger-sample programs are needed for more complex sensorimotor outputs such as balance and reaction time.

The original value of this study lies in its integrated approach to addressing both physiological (body weight, fat percentage, BMI) and motor outcomes (balance, reaction time, motor speed) within the same protocol and in offering a model applicable in the Turkish context. With this aspect, the findings are consistent with those of Özcan et al. [21], highlighting that motor interventions are linked not only to performance but also to academic and social outcomes. The results obtained indicate that game-based and multi-sensory supported movement programs could be an important alternative for rehabilitation centers, special education institutions, and family-based applications. However, the limitations of the study should be taken into consideration. The small sample size and the limited statistical power related to this, the short intervention period of eight weeks, the wide age range of participants, and the fact that measurements were taken at a single center have limited the generalizability of the findings. Furthermore, the validity of the devices used out of the laboratory should also be taken into account when interpreting the results.

Future studies should be conducted with larger and more heterogeneous samples, and include long-term follow-up studies; reaction time should be differentiated into simple, preferred, and complex tasks; motivation should be increased with digital exergaming elements; and protocols targeting dominant foot differences for balance should be developed. In conclusion, the GBIMT

program features as a promising approach for both physiological and motor development in young adults with ASD.

Abbreviations

GBIMT	Game-Based and Individualized Movement Training
ASD	Autism Spectrum Disorder
BMI	Body Mass Index

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Authors' contributions

Conceptualization: Ahmet Serhat Aydın, Mehmet Söyler, Raif Zileli, Medera Halmatov, Alper Cenk Gürkan, İbrahim Orkun Akcan, Coşkun Yılmaz; Methodology: Raif Zileli, Mehmet Söyler; Data curation/collection: Ahmet Serhat Aydın, Alper Cenk Gürkan, İbrahim Orkun Akcan, Coşkun Yılmaz; Supervision: Raif Zileli, Mehmet Söyler, Coşkun Yılmaz; Writing original draft: Mehmet Söyler, Medera Halmatov, Raif Zileli, Coşkun Yılmaz; Writing edition: all authors.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participants

The study protocol was reviewed and approved by the Health Science Ethics Committee of Çankırı Karatekin University (Decision No: 2024/11) prior to data collection. The research was conducted in accordance with institutional guidelines, national legislation, the CONSORT guidelines, and the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to participation.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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