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The impact of sensory-motor integration exercises using the game sense approach on working memory and fine motor skills in children with learning disorder

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HIGHLIGHTS
- First study combining sensory–motor exercises with Game Sense in LD children
- Targets working memory and fine motor deficits crucial for learning success
- Game Sense intervention improved memory, visual-motor control, and agility
- Interactive exercises boosted motivation and reduced fatigue during sessions
- Combined approach effectively enhances cognitive, motor, and academic skills

ABBREVIATIONS

BOTMP	Bruininks–Oseretsky Test of Motor Proficiency
GSA	Game Sense Approach
ISI	Inter-stimulus interval
MANOVA	Measures multivariate analysis of variance
SD	Standard Deviation
TGfU	Teaching Games for Understanding

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BACKGROUND: Early life is a critical period for the development of motor skills, supporting brain function and cognitive performance.
AIM: This study investigated the effects of sensory–motor integration exercises grounded in the Game Sense Approach (GSA) on working memory and fine motor skills in children with learning disorder.
METHODS: A quasi-experimental pre-test–post-test design with a control group was employed. Thirty-six female children diagnosed with learning disorders were randomly assigned to three groups: GSA-based intervention, goal-oriented exercise, and control. Working memory was assessed using the N-back task, while fine motor skills were measured with the Bruininks–Oseretsky Test of Motor Proficiency. The intervention groups participated in two sessions per week 60-minute sessions over eight weeks, while the control group maintained routine activities. A mixed-design ANOVA was used for statistical analysis.
RESULTS: Results showed that the GSA group exhibited significant improvements in working memory compared to the control group. In fine motor domains, the GSA group demonstrated greater gains in response speed, upper-limb agility, and visual–motor control compared to both goal-oriented and control groups.
INTERPRETATION: These findings suggest that sensory–motor integration exercises implemented within a GSA framework may offer an effective strategy for enhancing cognitive and motor functioning in children with learning disorder.

KEYWORDS: Fine Motor Skills | Game Sense | Learning Disorder | Sensory-Motor Integration | Working Memory

INTRODUCTION

Learning disorder (LD) is diagnosed when academic performance in reading, writing, or math is significantly below expectations for age and ability [1]. Learning disorders often involve difficulties in executive functions such as planning and self-regulation [2,3]. Among executive functions, working memory is especially vital. As proposed by Baddeley and Hitch, it serves as a central cognitive system responsible for the temporary storage and manipulation of information, supporting higher-order processes like reasoning and learning [4]. Empirical evidence consistently shows that children with learning disorders typically perform worse on working memory tasks than their peers [5]. In parallel, fine motor skills support cognitive processing and classroom tasks such as writing; delays can negatively affect learning [6]. Research underscores the importance of fine motor proficiency in academic success, as these skills facilitate classroom tasks such as writing, and tool use [7].

Physical activity has been shown to enhance cognitive processes, executive functions, overall brain health and motor skills [8,9]. The Game Sense Approach (GSA), an innovative pedagogical model adapted from the Teaching Games for Understanding (TGfU) framework, prioritizes decision-making, tactical awareness, and player engagement over technical instruction [10]. By encouraging reflection, collaboration, and strategic thinking through game-based learning, GSA fosters both motor skill development and cognitive engagement [11-13]. Numerous studies have highlighted the cognitive and physical benefits of game-based interventions in children [14]. Concurrently, sensory–motor integration plays a foundational role in learning and adaptive behavior. According to Ayres' Sensory Integration Theory, effective learning depends on the brain's ability to organize sensory input; children with learning disorders often show deficits in this process [15-17]. Previous studies have shown that physical and motor-based interventions can improve working memory, fine motor skills, and executive function in children with learning disorders [9,18].

The present study incorporates sensory–motor integration exercises grounded in Ayres' theoretical framework and delivered through the Game Sense Approach. Despite the growing literature on physical and cognitive interventions for learning disorders, little research has integrated these two modalities within a unified, play-based structure. The use of GSA enhances intrinsic motivation, engagement, and enjoyment, thereby fostering greater participation and cognitive investment.

Elementary school years represent a critical period for the development of both executive and motor functions. This stage is also marked by the maturation of sensory integration capacities, which are essential for cognitive and behavioral regulation [16,19]. However, children with learning disorders often exhibit developmental lags in these domains, making early intervention crucial [20]. Given the interdependence of cognitive and motor development and the crucial role of early, developmentally appropriate interventions for children with learning disorders, programs that simultaneously target both domains may have a greater impact on academic, cognitive, and motor outcomes. This rationale highlights the importance of exploring integrated, play-based approaches, such as the Game Sense model, in this population.

To our knowledge, this study is the first to directly compare a game-sense sensory–motor intervention with a traditional goal-oriented approach in children with learning disorders. By examining their effects on working memory and fine motor skills, it addresses a critical gap in the literature and proposes an innovative, developmentally appropriate strategy to support children with learning difficulties. This study aims to examine the effects of a sensory–motor integration program using the Game Sense Approach on working memory and fine motor skills in children with learning disorders.

METHODS

Study Design and Ethical Considerations

This study employed a quasi-experimental design with a pre-test–post-test control group and was applied in nature. The research was conducted in Mashhad, Iran, between 2024 and 2025. Ethical approval was obtained from the Ethics Committee of the Physical Education and Sports Sciences Research Institute under the code IR.SSRC.REC.1402.140. The objectives, procedures, and potential risks of the study were clearly explained to the parents or legal guardians of all participants. Written informed consent was obtained from the parents or legal guardians, and verbal assent was provided by the children prior to participation. Participants were informed that their involvement was voluntary and that they could withdraw from the study at any time without any consequences.

Participants

The statistical population of this study consisted of female children with learning disorders, with a mean age of 8.39 years and a standard deviation of ±0.49. Only female participants were recruited due to the accessibility of the sample, as the collaborating learning disorder centers and schools were limited to female students. The participants were identified through referrals made by the examiner to the Exceptional Education Department of Mashhad and subsequently to the Comprehensive Assessment and Health Centers in District 6 of Mashhad. Out of an initial group of 65 children, 45 were selected through convenience sampling from learning disorder centers in Mashhad. Due to limited access to the target population of children with learning disorders, the sample size was determined based on previous studies with similar populations, in which 10–15 participants per group were typically considered sufficient. Ultimately, due to participant attrition, a total of 36 children were included in the final sample and were randomly assigned to three groups: two intervention groups (a sensory–motor exercising group using the Game Sense Approach and a sensory–motor exercising group with a goal-oriented approach) and a control group, with 12 participants in each group.

Inclusion criteria included a confirmed diagnosis of learning disorder based on standardized assessments conducted by learning disorder centers, and no participation in structured sensory-motor or physical exercise programs within one month prior to the study. Exclusion criteria included having an IQ below 85 or above 110, and having visual or auditory impairments [21]. This study posed no risk or harm to the participants in terms of intervention or measurement methods, and participants were free to withdraw from the study at any point, with or without providing a reason.

Instruments

a) N-back Test

The N-back test is a widely used cognitive task for assessing working memory and executive functions. It is frequently employed in neuroimaging studies to activate specific brain regions in participants. Originally introduced by Kirchner (1958), the test has been extensively validated in subsequent research. Busch et al. (2008) reported its reliability to be 78%, and Taghizadeh et al. (2014) confirmed its validity for use in Iran [22,23].

In the N-back task, a series of visual stimuli are presented sequentially on a computer screen. Participants are required to determine whether the current stimulus matches the one presented n steps earlier. The task becomes increasingly challenging as the value of n increases. For example, in a 1-back task (n = 1), the current stimulus is compared with the immediately preceding stimulus, whereas in a 3-back task (n = 3), the comparison is made with the stimulus presented three steps earlier [24].

In the present study, the 1-back version of the task was used, with the following details:

- Task version: 1-back

- Number of trials: 30 trials per participant
- Stimulus presentation duration: 500 milliseconds per stimulus
- Inter-stimulus interval (ISI): 1500 milliseconds
- Response method: Participants responded using two separate keys: one key indicated a “match/correct” and the other indicated a “non-match/incorrect”
- Software: The 1 back version of the N back working memory task was programmed and administered using the SINAPsycho N Back Working Memory Test (Sina Cognitive & Behavioral Research Institute, Tehran, Iran), a stand-alone software application provided on CD (not web-based). The software allows individual and group result analysis, data export to SPSS, and summary reporting for each participant [25]
- Practice trials: Participants completed 5 practice trials before the main task to familiarize themselves with procedure and response requirements

Based on a pilot study and a review of the previous literature, the current study employed the 1-back version, which is suitable for the target population [12,18].

b) Bruininks–Oseretsky Test of Motor Proficiency (BOTMP):

To assess the motor proficiency of the participants, the Bruininks–Oseretsky Test of Motor Proficiency (BOTMP) was utilized. This standardized test is designed to evaluate motor performance in children aged 4.5 to 14.5 years. The BOTMP includes both a long form (46 items) and a short form (14 items), composed of eight subtests.

The test evaluates both gross and fine motor skills. Gross motor skills include running speed and agility, balance, bilateral coordination, and strength, whereas fine motor skills include response speed, visual–motor control, and upper-limb speed and dexterity. Upper-limb coordination does not fit neatly into either category. As the present study specifically focused on fine motor proficiency, only the three fine motor subtests were analyzed.

Each subtest includes a set of standardized tasks that the participant performs twice. The examiner records the score of each attempt and sums the two scores. The higher score of the two trials is then recorded as the final score for that subtest.

<u>Response Speed Subtest</u>: This subtest measures the participant’s ability to react quickly to a visual stimulus. The examiner attaches a strip of tape to the wall at a height above the ruler but below the participant’s shoulders. The participant sits with the dominant hand farthest from the examiner and places the palm near the ruler. Upon release of the ruler by the examiner, the participant must catch it with the thumb of the dominant hand as quickly as possible. The median score across trials is recorded as the final score.

<u>Visual–Motor Control Subtest</u>: This subtest evaluates precision and coordination in visually guided movements. The participant sits at a table near the examiner and performs tasks such as drawing a line along a specified path and copying geometric shapes. The participant must avoid rotating the clipboard excessively. Performance is scored according to deviations from the path or accuracy in copying shapes, following the BOTMP manual guidelines.

<u>Upper-Limb Speed and Dexterity Subtest</u>: This subtest measures the speed, coordination, and dexterity of the upper limbs. Participants sit at a table facing the examiner and perform tasks such as sorting cards by color and marking dots on a page. Tasks are performed as quickly and accurately as possible, and if the participant does not understand instructions, the examiner repeats the task. Scores are recorded according to the number of successfully completed actions within the time limit.

The BOTMP has demonstrated strong psychometric properties. Validity for motor skill assessment in children aged 5 to 13 years has been reported to reach up to 90%, and test–retest reliability is high (0.87 for the long form and 0.86 for the short form) [26]. In the present study, the short form of the BOTMP was administered.

Due to the design of the study, the assessments (including both the N-back and BOTMP tests) were not blinded; however, random group allocation reduced the likelihood of intentional bias.

Data Collection Procedure

At baseline (pre-test), participants completed the N-back test to assess working memory and the short form of the BOTMP to evaluate fine motor skills.

The exercise intervention was implemented at a sports facility in Mashhad, Iran. Two experimental groups (Game Sense sensory-motor exercise group and Goal-Oriented sensory–motor exercise group) participated in an 8-week intervention program consisting of 16 sessions (two 60-minute sessions per week). Each session included a 10-minute warm-up, 40 minutes of main exercises, and a 10-minute cool-down. The exercise utilized equipment such as balance boards, wobble beams, suspended swings, sandbags, pendulum balls, various-sized balls, marked rulers, trampolines, and scooters [15,18].

The intervention emphasized balance and coordination to enhance cognitive and motor skills, as these processes engage both brain hemispheres and support improved cognitive functioning in children with learning disorders. Exercises were adapted individually based on each child’s readiness, fatigue, attention, and engagement. The instructor adjusted repetitions, complexity, or duration to ensure safety and effectiveness. No physiological parameters (e.g., heart rate or VO_2) were measured, as the study focused on motor behavior and skill acquisition [15,27].

The sensory–motor integration program was implemented in two formats:

1. Game Sense-based Approach:

This method emphasized interactive, child-centered learning with the following characteristics:

- Sensory systems were stimulated by simulating real-life scenarios to offer children novel sensory–motor experiences.
- Children actively participated in the process, proposing solutions and variations based on their own experiences.
- The instructor adopted a learner-centered approach, facilitating an environment for exploration and problem-solving.
- Each child's performance was compared only to their own previous performance, respecting individual differences.
- Instructions were provided both during and outside of gameplay.
- The instructor's role shifted from directive to facilitative, prompting children to reflect through guided questioning to develop tactical awareness.
- Exercises were adapted to match each child's physical skill level.
- Rules were flexible and modifiable to align with tactical learning goals.

2. Goal-Oriented Approach:

This method emphasized instructor-led, structured learning with the following characteristics:

- The instructor acted as the primary guide, providing direct explanations and demonstrations for every exercise.
- Exercises were standardized and repetitive, and children had no opportunity to modify or adapt the activities.
- Sensory–motor exercises were performed exactly as instructed, with no flexibility in rules, sequence, or method.
- Children's performance was measured against the prescribed method rather than their own prior performance, focusing on correct execution.
- Instructions and corrections were provided only by the instructor, with minimal discussion, questioning, or reflection by the children.
- Exercises were repeated multiple times to reinforce correct motor patterns.
- The instructor maintained a directive role, ensuring that all children followed the task instructions precisely, without promoting independent problem-solving or tactical thinking.

A detailed overview of the exercise protocols for each group is presented in Table 1.

During this period, the control group continued their usual activities. After explaining the intervention phase, the dependent variables were measured again in the post-test phase.

Statistical Analysis

Descriptive statistics (mean and standard deviation) were calculated for all variables.

All statistical analyses were performed using SPSS version 26, with a significance level set at $p < 0.05$.

To examine the effect of the sensory–motor integration exercising program based on the Game Sense educational approach on working memory and fine motor skills, a 3 × 2 repeated measures multivariate analysis of variance (MANOVA) was conducted, with group (Game Sense, Goal-Oriented, Control) as the between-subjects factor and time (pre-test, post-test) as the within-subjects factor.

Table 1. Exercising Protocol of the Groups.

Weeks	Game-Sense Group	Goal-Oriented Group
1	Warm-up: Stork balance. Combined exercises with fixed wooden balance board, pendulum ball, spiked half-dome, balls of various sizes, sandbags, step platform, yoga bricks, cardboard boxes, building blocks. Children choose preferred activity; guided discussion and questions during play.	Warm-up: Stork balance. Same equipment as Game-Sense. Instructor demonstrates and explains each task; children repeat exactly as instructed. No modifications or choices; feedback only to correct errors; no discussion or problem-solving.
2	Warm-up: Stork balance. Combined exercises with seesaw balance board, spiked half-dome, sandbags, pendulum/static balls, dolls, swing, bowling pins. Discussion and task adapted to skill level; children encouraged to explore.	Warm-up: Stork balance. Same equipment. Instructor demonstrates each task; children follow instructions exactly. Performance monitored against standard; no adaptation or discussion.
3	Warm-up: Stork balance. Combined exercises with fixed balance board, balance beam, pendulum ball, ruler, therapy balls, colored slime/ribbons, dolls, numbered mats, geometric shapes. Game adapted to goal; children encouraged to think.	Warm-up: Stork balance. Same equipment. Instructor demonstrates sequence; children repeat exactly. Repeated practice to reinforce correct execution; no problem-solving or reflection.
4	Warm-up: Stork balance. Combined exercises with seesaw board, balance beam & basketball hoop, sandbags, agility rings & hula hoops, parachute, string & colored coins. Children involved in problem-solving and discussion.	Warm-up: Stork balance. Same equipment. Instructor demonstrates and instructs; children repeat exactly. Feedback limited to correction; no discussion or strategy development.
5	Warm-up: Stork balance. Combined exercises with fixed & seesaw boards, trampoline, spiked half-dome, swing, cones, numbered mats, geometric shapes, paper & pencils. Children provide solutions and answer questions.	Warm-up: Stork balance. Same equipment. Instructor demonstrates and instructs; children repeat exactly. No child input; feedback only from instructor.
6	Warm-up: Stork balance. Combined exercises with movable/fixed boards, sandbags, balance beam, foam noodles, balls, therapy balls. Children asked about strategies; encouraged to ask questions and participate.	Warm-up: Stork balance. Same equipment. Children repeat exercises as instructed; instructor monitors and gives direct feedback. No discussion or strategy questions.
7	Warm-up: Stork balance. Combined exercises with fixed board, half-dome, wheeled board, balance beam & hoop, rings & hula hoops, modeling clay. Children create questions and discuss rules; reflection encouraged.	Warm-up: Stork balance. Same equipment. Instructor demonstrates and instructs; children repeat exactly. Repeated practice for skill reinforcement; no discussion or reflection.
8	Warm-up: Stork balance. Combined exercises with seesaw board, balance beam, balls, parachute, wheeled board, trampoline, tangram puzzles. Children develop tactical awareness; involved in explaining tasks.	Warm-up: Stork balance. Same equipment. Instructor demonstrates and instructs; children repeat exactly. Feedback only for correction; no tactical awareness or child explanation.

RESULTS

The study included 36 female children diagnosed with learning disorder, who were randomly assigned to three groups: Game Sense (n = 12), Goal-Oriented (n = 12), and Control (n = 12). The mean age of participants was 8.39 ± 0.49 years. Baseline demographic characteristics, including height and weight, are summarized in Table 2. No significant differences were observed among the groups at baseline, indicating comparability prior to the intervention. The demographic characteristics of the participants are presented in Table 2.

Table 2. Baseline demographic characteristics of participants by group.

Group	Age (years) Mean ± SD	Female (n, %)	Height (cm) Mean ± SD	Weight (kg) Mean ± SD
Game Sense	8.50 ± 0.50	(100%) 12	128 ± 2.5	26.7 ± 6.7
Goal-Oriented	8.42 ± 0.42	(100%) 12	127 ± 2.5	26.5 ± 5.0
Control	8.25 ± 0.25	(100%) 12	127 ± 1.7	25.9 ± 9.2
Total	8.39 ± 0.49	(100%) 36	—	—

Data are presented as mean ± standard deviation for continuous variables and n (%) for categorical variables.

The main effect of Time on working memory was significant, as was the Group × Time interaction, while the main effect of Group was not significant. For fine motor skills, significant main effects of Time and Group, as well as significant Group × Time interactions, were observed for most components, whereas the main effect of Group was not significant for upper-limb speed and agility.

Before conducting the main statistical analyses, the assumptions of normality and homogeneity of variances were assessed. The Shapiro–Wilk test confirmed the normality of the distribution ($p > 0.05$), and Levene's test verified the homogeneity of variances across groups ($p > 0.05$). Table 3 presents the means and standard deviations of working memory scores in the N-back test for all groups, while Table 4 shows the means and standard deviations of fine motor skills.

Table 3. Means and standard deviations of working memory scores in the N-back test for the game sense, goal-oriented, and control groups.

Group	Pre-Test Mean ± SD	Post-Test Mean ± SD
Game Sense	183.69 ± 78.22	221.01 ± 56.55
Goal-Oriented	198.13 ± 76.09	212.22 ± 60.32
Control	181.68 ± 71.74	178.17 ± 75.85

Table 4. Mean and standard deviation of fine motor skills scores in the Bruininks–Oseretsky test among the game sense, goal-oriented, and control groups.

Variables	Group	Pre-test Mean ± SD	Post-test Mean ± SD
Response Speed	Game Sense	5.00 ± 1.90	1.92 ± 1.24
	Goal-Oriented	6.42 ± 2.53	3.42 ± 1.73
	Control	5.58 ± 2.02	6.00 ± 2.00
Visual-Motor Control	Game Sense	3.00 ± 1.12	6.17 ± 1.19
	Goal-Oriented	2.67 ± 1.23	4.42 ± 1.50
	Control	2.50 ± 1.31	2.50 ± 1.31
Upper Limb Speed and Agility	Game Sense	7.08 ± 2.10	9.17 ± 1.94
	Goal-Oriented	5.50 ± 1.73	8.00 ± 1.75
	Control	6.83 ± 2.03	6.08 ± 2.35

As shown in Table 5, the main effect of Group was not significant ($F(2,33) = 4.68$, $p = 0.120$, $\eta^2p = 0.201$), indicating that, when collapsing across time points, the three groups did not differ significantly in N-back performance. In contrast, there was a significant main effect of Time ($F(1,33) = 16.79$, $p = 0.007$, $\eta^2p = 0.320$), reflecting general improvement from pre-test to post-test across the sample. More importantly, the Group × Time interaction was significant ($F(2,33) = 11.05$, $p = 0.005$, $\eta^2p = 0.389$), showing that the magnitude of improvement varied between groups.

Given this interaction, Bonferroni post-hoc tests were conducted. The Bonferroni correction was chosen to control for Type I error due to multiple comparisons, by adjusting the significance level for the number of pairwise tests. Within-group comparisons revealed that both the Game Sense and Goal-Oriented groups exhibited significant increases in total N-back scores from pre-test to post-test ($p < 0.05$), whereas the Control group showed no significant change ($p > 0.05$). Between-group comparisons indicated no differences at baseline ($p > 0.05$). However, at post-test, the Game Sense group outperformed the Control group ($p < 0.05$), while no significant differences were observed between the Game Sense and Goal-Oriented groups or between the Goal-Oriented and Control groups ($p > 0.05$).

Table 5. Results of 3 × 2 repeated measures multivariate analysis of variance (MANOVA) on the N-back test scores (working memory) in the Game Sense, Goal-Oriented, and Control groups.

Source of Variation	Sum of Squares	df	Mean Square	F	p-value (Sig.)	Partial η²
Group	102199.25	2	51099.62	4.68	0.120	0.201
Test Phase (Time)	15716.07	1	15716.07	16.79	0.007*	0.320
Group × Test Phase (Interaction)	19544.84	2	9772.42	11.05	0.005*	0.389

* $p < 0.05$. Significant main effect of Time and significant interaction effect (Group × Time) were observed.

As presented in Table 6, the MANOVA showed significant effects for most fine motor skill components. For response speed, the main effect of Group was significant ($F(2,33) = 7.44$, $p = 0.002$, $\eta^2p = 0.311$), indicating that the type of intervention explained approximately 31% of the variance in outcomes. The main effect of Time was also significant ($F(1,33) = 20.79$, $p = 0.001$, $\eta^2p = 0.387$), suggesting that all groups improved across the intervention period. Importantly, the Group × Time interaction effect was significant ($F(2,33) = 7.74$, $p = 0.002$, $\eta^2p = 0.320$), showing that the degree of improvement varied by group. Post-hoc tests revealed that both the Game Sense and Goal-Oriented groups significantly reduced response time from pre-test to post-test ($p < 0.05$), but only the Game Sense group demonstrated superior post-test performance compared with the Control group ($p < 0.05$).

For visual–motor control, all effects were highly significant. The main effect of Group ($F(2,33) = 8.48$, $p = 0.001$, $\eta^2p = 0.340$) indicated strong differences among groups, accounting for 34% of the variance. The main effect of Time was particularly large ($F(1,33) = 200.47$, $p = 0.001$, $\eta^2p = 0.859$), reflecting substantial gains across sessions. the Group × Time interaction effect was also robust ($F(2,33) = 62.60$, $p = 0.001$, $\eta^2p = 0.791$). Bonferroni comparisons showed that the Game Sense group achieved the greatest improvements, significantly outperforming both the Goal-Oriented and Control groups ($p < 0.05$). The Goal-Oriented group also showed a significant advantage over the Control group. This pattern highlights that visual–motor skills were especially sensitive to the interactive and learner-centered nature of the Game Sense approach.

In contrast, for upper-limb speed and agility, the main effect of Group was not significant ($F(2,33) = 1.83$, $p = 0.176$, $\eta^2p = 0.100$), suggesting no overall differences between groups. However, the main effect of Time was significant ($F(1,33) = 56.92$, $p = 0.001$, $\eta^2p = 0.633$), indicating substantial improvement across the study period, with time alone accounting for 63% of the variance. The Group × Time interaction effect was also significant ($F(2,33) = 10.47$, $p = 0.001$, $\eta^2p = 0.388$), confirming that the degree of improvement varied by group. Post-hoc tests revealed that both intervention groups improved from pre- to post-test ($p < 0.05$), but only the Game Sense group showed significantly higher scores than the Control group at post-test ($p < 0.05$). No significant differences were observed between the Game Sense and Goal-Oriented groups ($p > 0.05$).

Given the significant Group × Time interaction in the MANOVA, Bonferroni post-hoc tests were conducted to clarify pairwise differences, and the outcomes are reflected in the overall pattern of improvements described in the Results section.

Table 6. Results of the 3 × 2 repeated measures multivariate analysis of variance (MANOVA) on Bruininks–Oseretsky test scores (fine motor skills) in the Game Sense, Goal-Oriented, and Control groups.

Source of Variation	Variable	Sum of Squares	df	Mean Square	F	p-value (Sig.)	Partial η²
Group	Response Speed	66.69	2	33.34	7.44	0.002*	0.311
	Visual-Motor Control	52.08	2	26.04	8.48	0.001*	0.340
	Upper Limb Speed and Agility	26.36	2	13.18	1.83	0.176	0.100
Test Phase (Time)	Response Speed	64.22	1	64.22	20.79	0.001*	0.387
	Visual-Motor Control	48.34	1	48.34	200.47	0.001*	0.859
	Upper Limb Speed and Agility	46.72	1	46.72	56.92	0.001*	0.633
Group × Test Phase (Interaction)	Response Speed	47.86	2	23.93	7.74	0.002*	0.320
	Visual-Motor Control	30.19	2	15.09	62.60	0.001*	0.791
	Upper Limb Speed and Agility	17.19	2	8.59	10.47	0.001*	0.388

* $p < 0.05$. Significant main effects of Group and Time, and significant interaction effects were found for most fine motor components.

DISCUSSION

The present study examined the effects of sensory–motor integration exercises based on the Game Sense Approach on working memory and fine motor skills in children with learning disorders. The results demonstrated significant improvements in both cognitive and motor domains, particularly in working memory, visual-motor control, and upper limb agility, in children participating in the Game Sense-based intervention compared to the goal-oriented and control groups.

While existing literature has typically examined either sensory–motor or cognitive-motor interventions separately, few studies have combined these components into a unified, play-based program. This study provides novel evidence supporting the synergistic effect of integrating sensory–motor exercises with the Game Sense Approach, an educational model emphasizing tactical understanding, decision-making, and learner engagement through play [28]. Such integrative interventions appear to enhance not only motor coordination but also executive functioning, particularly working memory, which is foundational for academic success. The Game Sense-based intervention in this study included a series of structured, multimodal exercises emphasizing balance, bilateral coordination, hand–eye and foot–eye coordination, and task variability. Exercises required children to solve problems, make tactical decisions, and adapt strategies during gameplay. Practice intensity was carefully moderated to prevent fatigue while maintaining engagement, with sessions repeated over multiple weeks to consolidate learning.

Recent studies also support the benefits of sensory–motor integration for children with LD. For instance, Ghasemian and Mohammadzadeh [29], Ghasemian and Sohrabi [9], and Ghasemian et al. [23] reported that Game Sense-based sensory–motor exercises significantly improved working memory and fine motor skills in children with LD. Similarly, Punar et al. [30] found that targeted sensory–motor training over 16 sessions (8 weeks) enhanced fine motor skills, working memory, attention, and problem-solving skills in children with LD. These findings align with the cognitive benefits observed in the present study, suggesting that interventions that actively engage multiple sensory systems may exert broader cognitive benefits.

In contrast, some previous studies reported less pronounced effects. For example, Baradaran et al. [31] focused on perceptual–motor games and observed that computer-based training was more effective for improving working memory. The divergence highlights the importance of cognitive engagement, interactive decision-making, and motivational factors in physical activity interventions. In Game Sense-based exercises, children actively participate in problem-solving and decision-making, which likely enhances cognitive processing and neural engagement, particularly in prefrontal cortex regions associated with executive functions [32].

The mechanisms underlying the observed improvements may relate to the interactive and variable practice environments used in this study. By simultaneously engaging the proprioceptive, vestibular, and visual systems and requiring decision-making and adaptation, these exercises likely promoted neural integration and interhemispheric communication. The enriched, variable practice inherent in Game Sense fosters greater neuroplasticity and schema formation than repetitive, uniform tasks, directly contributing to enhanced motor planning, attentional control, and working memory. Many of the exercises involved balance challenges, bilateral movements, and hand–eye coordination tasks, all of which stimulate proprioceptive, vestibular, and visual systems simultaneously. Such multimodal engagement is known to promote neural integration and interhemispheric communication, processes that are crucial for both motor planning and executive functioning. Furthermore, the varied and enriched practice inherent in the Game Sense model may foster greater neuroplasticity and enhance schema formation compared with highly repetitive, uniform activities.

The superiority of the Game Sense group in fine motor and working memory also reflects the importance of environmental interaction and variability in practice. Unlike the repetitive exercise sets used by Firouzjah et al. [33] the present intervention employed diverse activities and equipment. Research suggests that varied and enriched motor experiences enhance neuroplasticity, schema development, and learning generalization more effectively than constant practice. Exercise intensity was moderated to avoid fatigue and maintain engagement, particularly important in children with limited endurance and attention [34]. learner-centered, problem-solving–based tasks may better support cognitive processing than instructor-driven, rule-bound methods. By encouraging children to make decisions, reflect on their performance, and adapt strategies during gameplay, the Game Sense approach likely increases prefrontal engagement and attentional control—factors essential for working memory development.

Working memory, a core component of executive function, plays a central role in learning and problem-solving. Dysfunction in working memory is widely recognized as a major contributor to academic underachievement in children with learning disorders. The combination of physical activity and the play-based, motivational Game Sense structure likely contributed to improvements in working memory through increased attentional control, cognitive flexibility, and self-regulation [35].

Children with learning disorders often experience comorbid motor impairments, including delays in coordination, fine motor skills, and balance [36,37]. These impairments are exacerbated by task complexity and additional neurodevelopmental conditions such as ADHD. Interventions targeting both cognitive and motor domains simultaneously may therefore provide greater benefits. Exercises emphasizing hand–eye and foot coordination, as in the present study, effectively stimulate brain regions involved in both movement planning and executive processing [23,38].

A further important aspect of this intervention is the positive psychological environment it fosters. The Game Sense model promotes autonomy, competence, and relatedness, key components of intrinsic motivation according to self-determination theory. By actively engaging children in the learning process and providing variable challenges within a supportive framework, the intervention likely enhanced motivation, enjoyment, and sustained participation—critical for long-term engagement and skill acquisition, especially in children with LD.

From a developmental perspective, elementary school years represent a sensitive period for neuroplasticity, emotional growth, and cognitive maturation. Implementing structured, play-based physical activity programs during this window can help compensate for early sensory–motor deficits, preventing further cognitive and academic delays. Beyond physical and cognitive benefits, these strategies also contribute to the development of emotional resilience, social interaction skills, and self-efficacy [10,13].

In summary, this study demonstrates that sensory–motor exercises based on the Game Sense Approach provide a uniquely effective, integrated framework for enhancing both cognitive and motor outcomes in children with learning disorders. The combination of multisensory stimulation, variable practice, problem-solving, and learner-centered engagement appears to underlie the observed improvements, highlighting the potential of this model for targeted educational and therapeutic interventions.

Nevertheless, the current study is not without limitations. The study included only female participants, which limits the generalizability of the findings to boys. Future studies should include mixed-sex samples to examine potential sex differences in working memory and fine motor performance. In addition, the sample size was relatively small due to limited access to the target population, which may have affected the statistical power of the study. Furthermore, the assessments (including both the N-back and BOTMP tests) were not blinded; however, random group allocation minimized the risk of intentional bias.

Additionally, factors such as medication usage, daily psychological state, and prior experience with motor tasks were not rigorously controlled and could have influenced the outcomes. Future research should aim to include male participants and consider cross-sex comparisons. Further investigations are also needed to examine the impact of sensory–motor interventions based on the Game Sense Approach on other domains of executive functioning (e.g., cognitive flexibility, inhibition), as well as on academic performance and emotional regulation.

CONCLUSION

This study highlights the promising effects of a sensory–motor integration program rooted in the Game Sense Approach on both working memory and fine motor proficiency in children with learning disorders. By combining interactive, child-centered activities with varied sensory–motor challenges, this approach supports cognitive engagement, motor coordination, and intrinsic motivation simultaneously. Educators and therapists working with children with learning disorders are encouraged to adopt such integrative, game-based strategies under professional supervision to promote holistic development. This approach not only addresses the multifaceted challenges faced by these children but also contributes to improved academic achievement and overall quality of life.

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