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Effects of an Enriched Physical Education Program on Cognitive and Motor Performance in Children with Mild Intellectual Disabilities

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1. Introduction

Intellectual Disability (ID) is a neurodevelopmental disorder involving challenges in intellectual functioning and adaptive behavior (APA, 2013, 2021). Intellectual functioning encompasses significant difficulties in general mental abilities such as learning, abstract thinking, and planning. Adaptive behavior challenges manifest in daily real-life activities, such as social aspects like empathy and practical skills such as self-care (APA, 2021; Boat & Wu, 2015).

Moreover, previous studies have shown a strong association between ID and significant difficulties in cognitive control (e.g., Danielsson et al. 2012; Lanfranchi et al., 2010). Cognitive control is the ability to achieve goal-directed behavior instead of choosing more habitual or persuasive responses (Cohen, 2017). Cognitive control significance extends across various dimensions; for instance, it is relevant to the quality of life (Davis et al., 2010), mental health (Tavares et al., 2007), physical health risk factors (Riggs et al., 2010), school readiness and success (Nayfeld et al., 2013), among others. The cognitive control difficulties in persons with ID are reflected in low performance in underlying abilities, such as cognitive flexibility, inhibitory control, and attention (e.g., Hopper et al., 2008; Menghini et al., 2010; Traverso et al., 2018).

Inhibitory control is essential to suppress responses no longer relevant to pursuing the goal (Diamond, 2013). Aligned with Friedman and Miyake's theoretical frame (2004), we focused on prepotent response inhibition and resistance to distractor interference functions. Inhibition of a prepotent response, also called response inhibition, is the capacity to actively suppress an ongoing, habitual, or dominant behavior that is no longer relevant to pursuing the goal. Resistance to distractor interference refers to the ability to avoid being distracted by irrelevant external stimuli when executing a task (Friedman & Miyake, 2004).

Cognitive flexibility is the capacity to quickly reconfigure our cognitive system in response to changing situations and internal demands and execute apparently unlimitedly different behaviors (Braver et al., 2009; Cohen, 2017). Within the cognitive control framework, the task-switching paradigm has become important for studying goal-directed behaviors encompassing frequent switches between tasks or rules (Diamond, 2013; Vandierendonck et al., 2010). Furthermore, attention is inevitably related to cognitive control due to its role in the controlled selection of some processes over others to achieve goal-oriented behavior (Cohen, 2017; Garon et al., 2008). The present study focuses on the alerting function of attention, which is responsible for helping us to achieve and maintain an increased vigilance state to imminent incoming stimuli prior to a target event (Petersen & Posner, 2012; Posner & Fan, 2008).

The literature acknowledges well-recognized challenges in the mentioned cognitive control functions among individuals with ID (e.g., Menghini et al., 2010; Traverso et al., 2018). Nevertheless, there is a diversity of findings regarding these difficulties, reflecting the complex interplay of several factors. For example, the meta-analysis of the current literature performed by Spaniol and Danielsson (2022) showed that the performances in cognitive flexibility, inhibitory control, and attention in populations with ID compared to age-matched control groups are statistically significantly lower. Besides, there is great heterogeneity between the studies' effect sizes that the ID etiology moderator could somewhat explain. The population with ID is a very heterogeneous group as a consequence of the wide range of etiologies and severities (mild-profound) of the ID raising many questions and mixed findings in the literature that require further research for resolution in the different developmental trajectories. In this sense, the limited research related to cognitive control has focused on people with syndromes associated with ID (e.g., Down syndrome, Williams syndrome). Studies with people with ID with non-specific etiology (i.e., non-syndromic, without atypical neurological development) are even more scarce. Additionally, research on people with ID commonly has a comparison with age-matched control groups. However, this approach has been criticized for being insufficient because it is based on the notion of a development delay without considering other factors, such as motor abilities and lifelong experiences, that make the groups different already (Burack et al., 2012).

Regarding motor abilities, individuals with ID may also be characterized by a delay in reaching motor milestones and difficulties in sensorimotor function, which can be observed at early ages (APA, 2013; Pellegrino, 2007). For example, studies reported challenges in gross motor skills (GMS) compared to typically developed populations (e.g., Hartman et al., 2010; Westendorp et al., 2011; Wuang et al., 2008). GMS are goal-focused movement patterns employing large muscles of our body (Haywood & Getchell, 2009) and are the basic building blocks for more complex motor skills (Stodden et al., 2008) and all physical activity throughout our lives.

Existing research indicates a correlation between GMS delays and the degree of ID severity (e.g., Westendorp et al., 2011; Wuang et al., 2008). Individuals with a more severe ID level exhibit more significant motor delays than those with a lower ID level. This is attributed to cognitive and perceptual difficulties (e.g., attention, obtaining and processing environment information, planning and selecting a movement) in executing accurate and/or fast motor function responses compared to the quantitative and qualitative standards of typically developing children (Kurtz, 2007; Payne & Isaacs, 2012; Pellegrino, 2007; Schmidt & Wrisberg, 2008).

Despite the significance of cognitive control and GMS development, especially concerning the challenges faced by children with ID compared to typically developing peers, there is a surprising scarcity of high-quality research examining the efficacy of programs targeting these domains. Although the cognitive and motor relation has had pronounced attention in the last decades with evidence suggesting a positive association between the two, the experimental studies that focus on the causal effects of these variables are still limited, and most of them have been carried out on populations with typical development (e.g., Fisher et al., 2011; Kamijo et al., 2011; Pesce et al., 2016). Nevertheless, the existing studies exploring the potential cognitive and motor benefits stemming from physical activity interventions have yielded promising results among individuals with ID. Maïano et al. (2019) and St. John et al. (2020), for example, conducted distinct systematic reviews on motor skill interventions for individuals with ID. Maïano et al. (2019) focused on young populations with ID, finding that consistent physical activity, lasting from 6 weeks to 1 ½ years, can promote robust enhancements in balance and overall fundamental motor skills. St. John et al. (2020) concentrated on physical and mental outcomes in populations with ID, showing modest and inconclusive evidence of physical fitness parameters (e.g., body composition, muscular strength, aerobic capacity, and flexibility), and significant effects of physical interventions on anxiety, depression, and self-efficacy measurements; however, outcomes were broad and imprecise. Both systematic reviews incorporated rigorous methodologies, emphasizing quality studies and minimizing confounding factors. The authors stressed the need for improved research on physical education interventions for this population and highlighted the importance of exploring specific GMS effects. None of the studies addressed locomotor and object control motor skills in individuals with ID, leaving the effectiveness of related interventions unclear.

In the literary review made for this research, only three studies (Fotiadou et al., 2020; Javan et al., 2014; Yılmaz & Soyer, 2018) examined the effects of physical activity interventions on the cognitive control functions in young populations with ID (only studies on attention and inhibitory control but not on cognitive flexibility were found) with promising results. However, a degree of caution is warranted due to potential shortcomings in methodology, documentation, or statistical analysis of the mentioned studies. The very scarce quality research carried out with participants with ID with different etiologies and severities prevents us from drawing firm conclusions on the distinctive profiles.

With this background and taking into account that mostly all the studies presented highlight the importance of early intervention and the need for more well-designed research in this field, the present investigation seeks to improve the understanding of the cognitive and motor relationship determining whether the practice of enriched physical activity has an effect on the cognitive control and motor skill performance of children with mild ID with non-specific etiology.

2. Purpose of the Research and General Hypotheses

Considering the clinical significance of an enhancement in cognitive functions in children with ID, the primary aim of the present study was to examine whether the effects of a 6-week enriched physical education program contribute to an improvement in cognitive control performance in children with mild ID, using measures of inhibitory control, vigilance, and cognitive flexibility. A further aim was to explore the effectiveness of the physical education program in the development of GMS by evaluating intentional and directed large muscles groups' involvement movements.

In accordance with the aims of this study, the following general hypotheses were formulated after the enriched physical education program:

- Larger performance enhancements in vigilance (accuracy and reaction time [RT]), inhibitory control (accuracy), and cognitive flexibility (accuracy and RT) were expected for the intervention group. These findings would be in agreement with previous research (based on cognitive control findings by Afshari, 2012; Chang et al., 2014; Fotiadou et al., 2020; Javan et al., 2014; Pan et al., 2019; Pesce et al., 2016; Schmidt et al., 2015)
- Improvement with higher scores in overall GMS and subtests performances (locomotor skills and object-control skills) for the intervention group (based on GMS finding by Pan et al., 2019; Verret et al., 2012; Zhang et al., 2021).

3. Methods

3.1 Study design and participants

Thirty students with ID participated in this study. All children were screened for eligibility and were randomly assigned to the Intervention Group (n=15) or the Control Group (n=15). Participants' inclusion criteria were mild ID with non-specific etiology and chronological age between 10 and 14 years. With non-specific etiology, we refer to the presence of a non-syndromic ID without accompanying congenital abnormalities such as physical and/or neurological (Kochinke et al., 2016).

The exclusion criteria were significant limitations that could affect their participation (e.g., injuries, visual impairment) and medical history of coexisting developmental/psychiatric conditions (e.g., schizophrenia). These criteria were considered to minimize confounding factors that could negatively affect the results and safeguard the participants' health.

The control and intervention groups did not show significant differences in terms of age and gender distribution (See Table 1).

Table 1. *Descriptive statistics of the sample and comparison between groups*

	Intervention Group		**Control Group**		**Statistics**
N (male, female)	15 (7, 8)		15 (9, 6)		χ^2 = 0.536, p = 0.464
	Mean (Min, Max)	***SD***	***Mean (Min, Max)***	***SD***	***Statistics***
Age (years)	12.733 (10, 14)	1.438	12.600 (10, 14)	1.298	U = 113.5, p = 0.967

3.2. Stimuli and Procedures

3.2.1 Assessment of Cognitive Control Function

All tasks to assess cognitive control functions were administered through a laptop using E-Prime 2.0 software to present stimuli and record responses (RT and accuracy data). The tasks were created in the Cognition and Language Laboratory at the Graduate Center of the City University of New York. Participants were seated in front of the computer in a school office without any interference or distraction. A random ordering of the tests (Latin square design) was used; they were presented as computer games and were individually administered. The same test and procedures were followed before and after the 6-week enriched physical education intervention. There were breaks between the different conditions and each test execution took approximately 15-25 minutes per child.

3.2.1.1. Nonverbal Attention, Distractor Interference and Response Inhibition Tasks

For examining vigilance (alerting attentional network function), resistance to distractor interference, and prepotent response inhibition, three subtasks from the information processing battery described by Szöllősi and Marton (2016) were used. We used three Specs Switch Jellybean buttons with an auditory click and an activation surface with tactile feedback. A red button was located in the center, and two black buttons on the sides, one on the left and the other on the right.

The Vigilance task required children to identify a target stimulus (a green circle) on either the left or right side of the screen and respond by pressing the corresponding black button for that side. In the Resistance to distractor interference condition, participants were tasked with pressing the black button corresponding to the target stimuli's location (right or left), as in the prior vigilance task. However, a new interfering element, a blue circle (distractor stimulus), was simultaneously presented on the screen, requiring them to ignore it. Finally, a single circle, randomly blue or green, appeared in the Prepotent response inhibition condition. Participants had to press the corresponding side black button when the green circle (target) showed up. However, for the blue circle (distractor), they had to withhold their response and press the central red start button to continue.

3.2.1.2. Task-Switching

For studying cognitive flexibility through the task-switching paradigm, we used a variation of the widely used Dimensional Change Card Sort task (Zelazo, 2006). Participants were required to sort bivalent stimuli and switch rules according to different dimensions. We used two Switch Jellybean buttons with an auditory click and activation surface. The response buttons had stimuli pictures overlays; the left had a blue dinosaur, and a green flower was on the right button.

In the Single block-color condition, participants were required to sort the pictures on the screen according to the color dimension by pressing the matching button that contains the target color item (blue or green). In the Single block-shape condition, children were instructed to sort the items according to the shape dimension by pressing the matching shape item button (dinosaur or flower). Finally, participants were required to change dimensions in the mixed block condition, adjusting their responses by sorting by shape or color.

3.2.2. Gross Motor Skills Assessment

The study used the Test of Gross Motor Development–Second Edition (TGMD-2) proposed by Ulrich (2000). The TGMD-2 evaluates twelve gross motor performance skills encompassed in two subtests. The locomotor subtest focuses on coordinated body movements involving displacement from one place to another, including jumps and turns. The instrument comprises the following locomotor skills: run, gallop, hop, leap, horizontal jump, and slide. The object control subtest focuses on movements in which the fundamental action implies managing and mastering objects, including throws and receptions. The instrument comprises the following object control skills: striking a stationary ball, stationary dribble, catch, kick, overhand throw, and underhand roll.

The test was administered in the educational institution's multiple-use sports field, had a duration of 15-20 minutes per child in one testing session, and was video-recorded with the permission of the parents to review the performance criteria for each skill. We used random ordering of the GMS skills (Latin square design). The same test and procedures were followed before and after the 6-week enriched physical education intervention.

3.2.3. Intervention Features and Procedures.

All the children with mild ID assigned to the intervention group participated in the physical education program for six weeks. The frequency of the sessions in the program was two times a week with a total of 12 sessions; each session lasted one hour. The instructor–child ratio was 1:5 (number of children by the number of instructors).

The intervention took place in the school's multiple-use sports field and was developed based on the Ecuadorian physical education curriculum, specifically on the first curricular block, "Playful practices: games and play" (Ministry of Education of Ecuador, 2016). The program integrated cognitive-enhancing physical activity games from Tomporowski et al. (2015a), specifically targeting children aged 3 to 6 years with typical development.

3.3. Data Analysis

The study utilized the R statistical computing system version 4.0.3 and IBM SPSS Statistics Version 26 as the statistical analysis software.

For the cognitive control measurements, we investigated two dependent variables: accuracy, measured on a binary scale (0 or 1), and RT. We employed mixed-effects logistic regression models to analyze the binary accuracy data. We estimated a series of models using the lmerTest open-source package in R (Kuznetsova et al., 2017) for each nonverbal attention, inhibition, and distractor interference tasks and switching tasks condition, with a decreasing degree of complexity. The fixed factors comprised session (session 1/session 2) and group (intervention/control), with subject serving as a random factor. The selected model was based on the Akaike Information Criterion (AIC). The RTs were log-transformed before data analysis; and then underwent analysis using robust linear mixed models with the DASvar method (R package robustlmm; Koller, 2016), as the residual normality criterion was not met. To select the best model, we employed the standard error of the Session x Group interaction estimate due to the unavailability of information criteria such as AIC for this method. We calculated p-values for all effects.

Regarding the motor skills assessment, the sum of the raw score values for the Locomotor skill and Object control skill subtests were calculated, as well as the total score values of the entire test. In order to verify if the enriched physical education program had an impact on the GMS, we ran mixed-design variance of analyses (ANOVAs) for the subtest scores and the individual skills as dependent variables, session (session 1/session 2) as a within-subject variable, and group (intervention/control) as between-subject variable. A pairwise comparison with Bonferroni correction was performed in case of significant results. Alpha level was determined at 0.05.

4. Main Results

Results from the nonverbal attention, inhibition, and distractor interference tasks have been published in Mero Piedra, A. L., Pesthy, O., & Marton, K., Effects of a physical education intervention on attention and inhibitory control in Ecuadorian children with intellectual disabilities, Journal of Intellectual Disabilities (Vol. 0(0) pp. 1–14). Copyright © 2023 (The Authors). DOI: https://doi.org/10.1177/17446295231189018.

4.1. Cognitive Control Results

4.1.1. Nonverbal Attention, Inhibition and Distractor Interference Tasks

In the Vigilance Task, the findings indicate significant Session x Group interactions for accuracy and RT. Compared to the control group, children in the intervention group demonstrated significantly greater enhancements concerning both measured variables after the participation in the physical education program (Table 2).

Table 2. *Results of the Vigilance task*

VIGILANCE ATTENTION TASK				
Reaction time				
Fixed effects	**β**	**Standard Error**	**t-value**	**p-value**
Intercept	7.314	0.111	65.76	< 0.001
Session	0.006	0.033	0.18	0.857
Group	0.169	0.157	1.07	0.289
Session x Group	-0.247	0.047	-5.24	< 0.001
Accuracy				
Fixed effects	**β**	**Standard Error**	**z-value**	**p-value**
Intercept	1.087	0.405	2.682	<0.05
Session	0.288	0.209	1.377	0.169
Group	-0.769	0.575	-1.337	0.181
Session x Group	0.639	0.305	2.092	< 0.05

Note: Random intercept models for both RT and accuracy measurements are presented.

No significant intervention-related interactions were observed for RT or accuracy measurements in the Distractor Interference and Prepotent Response Inhibition Conditions. All participants with mild ID, both in the intervention and control groups, showed significantly decreased RT during the second administration of both tasks. Besides, in the Prepotent Response Inhibition Condition, there was a significant Group main effect on accuracy; participants in the control group performed better during pre-intervention testing than those in the intervention group.

4.1.2. Task-Switching

In both the intervention and control groups, all participants with mild ID exhibited notable reductions in RT during the second administration of the Single blocks' conditions (color and shape tasks) after the physical education program. In the mixed block condition, a significant main effect for Session in RT was observed; all participants with mild ID displayed increased RT during the second task administration (Table 3). No significant interactions related to the intervention were observed for either RT or accuracy measurements in the Task-Switching task.

Table 3. *RT results of the mixed block task*

MIXED BLOCK TASK				
Reaction time				
Fixed effects	**β**	**Standard Error**	**t-value**	**p-value**
Intercept	7.353	0.055	132.64	< 0.001
Session	0.078	0.029	-1.31	<0.05
Group	-0.107	0.082	-1.31	0.199
Session x Group	-0.038	0.043	-0.87	0.385

4.2. Gross Motor Performance Results

4.2.1. Overall Gross Motor Skill

Analysis of the total GMS scores showed a significant Session x Group interaction (F (1, 28) = 5.875, p = .022, η^2_p = .173). The intervention group performed significantly better than controls during the second task administration after the participation in the physical education program.

4.2.2. Gross Motor Skill Subtests

On the Locomotor skill subtest, we found that the Session x Group interaction reached significance (F(1, 28) = 13.405, p = .001, eta2 = 0.324). There was a higher performance of the intervention group after participation in the program in comparison with the control group. Considering the individual locomotor skills results, there was a significant Session x Group interaction in the case of galloping and horizontal jumping (Table 4); the intervention group performed significantly better than the controls during the second task administration.

Table 4. *Galloping and horizontal jumping results*

Effect	**F**	**p**	**η^2_p**
Galloping			
Session	11.544	.002	.292
Group	1.291	.265	.044
Session x Group	5.338	.028	.160
Horizontal jumping			
Session	12.393	.001	.307
Group	.125	.727	.004
Session x Group	12.393	.001	.307

Note: degrees of freedom are in each case 1 and 28.

Regarding the Object Control Skills Subtest, no significant intervention-related interactions were observed because the Session x Group interaction did not reach significance (F(1, 28) = .038, p = .846, η2p = .001). Considering the individual object control skills results, we found a significant improvement in the intervention group in catching skills after participation in the program (Table 5).

***Table 5**. Catching results*

Effect	F	p	η^2_p
Catching			
Session	0.714	.405	.025
Group	.426	.519	.015
Session x Group	6.429	.017	.187

Note: degrees of freedom are in each case 1 and 28.

5. Discussion

For the first time, this research has provided valuable evidence about the effectiveness of a physical education program enriched with cognitively engaging games in children with mild ID with non-specific etiology. The research aimed to better understand the associations between motor and cognitive skills by analyzing the contribution of the intervention program on the cognitive control functions and GMS.

5.1. Cognitive Control

5.1.1. Nonverbal Vigilance Attention

Overall, findings supported our hypothesis about the enriched physical education program's influence on vigilance performance, in the sense that the children with mild ID became more accurate and faster in the vigilance task to the imminent incoming stimuli, increasing the cognitive readiness state (Fan et al., 2009).

The present study is in accordance with two previous physical activity intervention studies that have demonstrated enhancements across different attention networks in young populations with ID. Javan et al. (2014) rhythmic play intervention showed improvements in attention problems and general attention, and Fotiadou et al. (2020) psychomotor education program also showed positive school behavioral changes in activities that required attention.

However, the novelty of the present research is that it addresses some of these previous studies' limitations, such as including only participants with mild ID with non-specific etiology with a stricter selection criterion in order to analyze their developmental trajectories. Javan et al. (2014) and Fotiadou et al. (2020) studies, for example, do not specify participants' criteria related to associations with a syndrome or co-existing developmental disorders (e.g., autism spectrum disorder), which prevents us from drawing firm conclusions on the distinctive profiles. Another point that contrasts between the studies mentioned and the present study is the attentional assessment tools. Javan et al. (2014) and Fotiadou et al. (2020) studies used behavior questionnaires and scales designed to be completed by parents and teachers, while this is the first physical activity intervention study that administered directly a computer-based attentional task to the children with mild ID with non-specific etiology.

Considering that the evidence has shown the attentional difficulties of people with ID, these results have important implications for their attentional development and learning processes (Posner & Rothbart, 2014). Attention is essential in achieving and maintaining focus in any goal-directed behavior, is involved in behavior and emotional regulation, and is a fundamental component to develop more complex cognitive control functions (Cohen, 2017; Garon et al., 2008; Posner & Rothbart, 2005).

5.1.2. Resistance to Distractor Interference and Response Inhibition

Contrary to our expectations, this study did not find a significant accuracy difference when comparing post-intervention with pre-intervention testing results between the two groups' performances in either of the inhibitory control functions. Therefore, outcomes revealed non-significant statistical intervention-related accuracy effects from the enriched physical education program.

There are several possible explanations for these results related to qualitative and quantitative aspects of the intervention. These findings could be because our program did not reach the appropriate cognitive engagement to promote inhibitory control enhancements in children with mild ID. Despite including a substantial number of cognitively demanding motor tasks, such as games that require suppression or delay of motor responses or inhibition of ongoing actions, this type of physical activity may not be optimal for eliciting significant cognitive benefits in children with mild ID between 10-14 years old. It is possible that physical activity that requires different motor demands in terms of exercise type and intensity may be more effective. In this sense, there is a current agreement in the literature about the need for more research in this field to examine the cognitive, emotional, and motor engagement required in physical activity interventions in order to have an impact on children’s cognitive control capacity (Diamond & Ling, 2016; Tomporowski et al., 2015b). Due to the scarce quality research in this matter and the mixed results, it is challenging to identify the best methods and procedures considering the different research contexts and participants (Diamond & Ling, 2016; St. John et al, 2020; Tomporowski et al., 2015b). Secondly, regarding quantitative aspects of the intervention, essential elements to consider are the duration and the frequency. In particular, the most salient factor appears to be a more extended intervention duration in weeks, based on studies that have demonstrated positive intervention outcomes in populations with diverse developmental trajectories (e.g., Chang et al., 2014; Pesce et al., 2016).

One unanticipated finding in the response inhibition condition was the main group effect in accuracy, showing that the children with mild ID in the intervention group had a significantly lower performance in the pre-intervention testing condition compared to the control group. However, this difference was not shown in the post-intervention testing condition, suggesting that the children in the intervention group showed more accuracy improvement across sessions than the control children, but these post-intervention results did not reach statistical significance. This might suggest that the small sample size of this study may have contributed to the outcomes (i.e., finding only a trend of improvement but not intervention-related significant change). Additionally, if we take into account the attention ability results discussed above, these trends toward improvement in the intervention group may be due to the significant attentional function enhancements. Attention has an essential role in cognitive control conflict resolution by controlling and emphasizing task-relevant stimuli and is a fundamental component of more complex cognitive abilities, including inhibitory control and cognitive flexibility (Burgoyne, & Engle, 2020; Cohen, 2017; Garon et al., 2008). This possibility of physical intervention effectiveness on inhibitory control accuracy results induced by the moderator function of attention has been emphasized in Chang et al. (2014) study with children with attention-deficit hyperactivity disorder.

Additionally, it was hypothesized there was no difference between the groups in RT, which was supported by this study's findings. Results showed a RT performance improvement in post-intervention testing compared to pre-intervention testing in all participants regardless of the group they belonged to. A possible explanation for these results might be related to a learning/practice effect due to repeated exposure to the test conditions (Dutilh et al., 2009).

5.1.3. Task-Switching

Our findings did not support our hypothesis about the enriched physical education program's influence on cognitive flexibility performance. Contrary to our expectations, no significant intervention-related effects were found in either of the two dependent measures studied (RT and accuracy) in the switching task conditions.

This capacity has scarcely been studied in physical activity intervention settings, and to the author's knowledge, there is no study of intervention-related effects in participants with mild ID. Our outcomes are in contrast to Schmidt et al.'s (2015) and Pan et al.'s (2019) studies, which found significant improvements in cognitive flexibility capacity. Schmidt et al. (2015) focused on a 6-week cognitively engaging physical education program with typically developing children using a modified Flanker task to assess this construct. Although typically, the Flanker task is not a task-switching paradigm but rather a test to assess resistance to distractor interference, the authors included measurement of inhibition control and cognitive flexibility in a single modified Flanker task (Jäger et al., 2014). On the other hand, Pan et al. (2019) performed a 12-week table tennis exercise with children with attention deficit hyperactivity disorder using the Wisconsin Card Sorting Test (Heaton & PARStaff, 2003). These contradictions can partly be explained by the main difference between the studies related to the participants' characteristics, the cognitive flexibility assessment tools used, and the nature of the interventions. In the last one, we can highlight that Schmidt et al. (2015) and Pan et al. (2019) were focused on a sport ball games (floorball, basketball, and table tennis), which have more competitive and regulatory connotations than the recreational games used in this study.

Future interventions could then focus on activities related to ball sports games to see if they also promote cognitive flexibility benefits in children with ID. However, it is important to mention that these games often have greater gross and fine motor skills demands than our current intervention, and those skills are usually delayed in populations with ID (Westendorp et al., 2011; Wuang et al., 2008).

Furthermore, results also showed that all children regardless of the groups decreased their RT in the two single conditions (color and shape) but increased their RT in the mixed condition when we compared the post-intervention testing results with the pre-intervention testing ones. An explanation of these outcomes might be a learning/practice effect from the task-switching paradigm due to the repeated exposure to the same items. This would suggest that children did not require much practice to obtain significant gains in cognitive flexibility because they performed the test only twice with a break of at least six weeks between the two testing sessions. Considering that previous research has shown cognitive flexibility difficulties of people with ID, this learning effect explanation has potentially important clinical implications, particularly in special education settings. Cognitive flexibility is essential to face changing environmental situations and internal demands quickly and effectively and to generate appropriate responses throughout our lives (Braver et al., 2009; Cohen, 2017; Meiran et al., 2015).

5.2. Gross Motor Skills

5.2.1. Overall Gross Motor Skill

As expected, the findings supported our hypothesis about the enriched physical education program's impact on overall GMS performance. Children that participated in the enriched physical education program performed significantly better in the post-intervention testing than the children from the control group. Therefore, the intervention group participants produced better quality movement patterns to achieve the GMS performance criteria examined in this study compared to the controls.

To the author's knowledge, only one recent experimental design study with a physical activity intervention analyzed the effect on the same GMS performances in children with ID. Zhang et al. (2021) studied a one-year program with 42 boys with severe ID between 7 to 12 years old. Children in the intervention group participated in a physical activity program including locomotor and object control exercises. Outcomes showed a significant positive enhancement in the total TGMD-2 scores in the intervention group compared with the control.

Although Zhang et al. study and our research show important differences, such as the severity of the ID of the participants and the nature and duration of the intervention, both studies share positive results in GMS performance. An explanation of the differences could be that children with severe ID needed a considerably longer intervention in order to obtain significant results. In this sense, the literature suggests that there is a relationship between the severity of ID and motor delay in populations with ID; the greater the severity, the greater the motor difficulties (Hartman et al., 2010; Vuijk et al., 2010; Wuang et al., 2008).

GMS are essential for general movement competence and developing more complex motor skills (Stodden et al., 2008). Therefore, the literature emphasizes the necessity for research on physical activity interventions such as the one utilized in this study (Maïano et al., 2019) in view of the exhibited motor delays of children with ID when compared to their typically developing peers (e.g., Westendorp et al., 2011; Wuang et al., 2008). The findings of this study hold significant implications for the implementation of similar enriched physical education programs aimed at promoting GMS benefits in children with mild ID with non-specific etiology between 10 and 14 years.

5.2.2. Gross Motor Skill Subtests

Our hypothesis of intervention-related enhancements in the GMS subtests was partially supported. Locomotor subtest results showed that children who participated in the enriched physical education program performed significantly better in post-intervention testing than the children from the control group. In the object control skill subtest, contrary to our expectations, there were similar changes in the two groups showing that the enriched physical education program did not have an influence on children's performance.

Considering the limited experimental research on physical activity interventions' effectiveness on locomotor and object-control GMS in children with ID (Maïano et al., 2019; St. John et al., 2020), we based our hypothesis on the effects of the 10-week physical activity intervention study from Verret et al. (2012) on children with attention-deficit hyperactivity disorder. Our results regarding the locomotor subtest are in line with their research since both studies found significant intervention-related improvements in the locomotor subtest. However, the outcomes of the object control skills subtest are inconsistent, we expected intervention-related trends of enhancements that were observed in their study, but we did not find the positive tendencies after our intervention. Likewise, the results of this study partially coincide with those of Pan et al. (2019), who found significant improvements in both the locomotor subtest and the object control in children with attention deficit hyperactivity disorder after a 12- week table tennis exercise program.

The difference in the object control results may be related to the participants' characteristics and the fact that Verret et al. (2012) and Pan et al.'s (2019) interventions were based on different aims and components. Their intervention aimed to maintain a moderate to vigorous intensity (e.g., heart-rate) with various aerobic and sports activities (e.g., table tennis, basketball, tag games, soccer), conditioning and/or motor skills exercises. In our case, our program mainly integrated recreational games with varying intensity, requiring locomotor skills but did not include manipulating objects such as balls or directly explicitly training the motor skill.

Besides, it is important to consider that the literature suggests that object control skills require more cognitive functioning than locomotor skills (Latash & Turvey, 1996; Westendorp et al., 2011), probably because the motor movements require the coordination of the own body and the manipulation of external objects. This is perhaps why, in Hartman et al. (2010) comparison study, results showed that object control skills performance was positively associated with cognitive functioning (i.e., decision-making, planning, and solving problem skills). Children with ID with the lowest object-control skills subtest scores also had lower cognitive functioning scores.

Other possible explanations for object-control skills subtest results may be personal factors that may influence intervention efficiency on these motor skills performances. Physical fitness and lifestyle habits may contribute to the results. The Westendorp et al. (2011) comparison study with children with mild ID, borderline ID, and typically developing children is a good example of this matter. The authors found that the higher object-control skills subtest scores in the three groups belonged to children with higher participation in organized sports. The authors also highlighted that children with ID participate considerably less in sports than the typically developing children.

Furthermore, when we analyzed the individual locomotor skills, results showed that galloping and horizontal jump locomotor skills significantly improved in the intervention group compared to the control. Additionally, results from the individual object control skills showed larger intervention-related enhancement in catching skills. Individual locomotor skills results are not entirely surprising since most of the games required movements involving displacement from one place to another, especially walking and running at different paces and under different conditions. On the other hand, our intervention did not include any catching movement training or any activity with manipulation of objects. However, this difference between the two groups can be linked to the significant attentional increases in the children who participated in the intervention. The important role of attention in catching skills has been pointed out for some decades now research (Davids et al., 2005; Populin et al., 1990).

6. Conclusions

6.1. Limitations and Future Research

The most significant limitation is the relatively small sample size and consequently insufficient statistical power to detect potential intervention-related small effects and differences; and increase the probability of sampling biases. The sample size constraint, together with the limited number of trials, and the typical heterogeneous nature of the ID groups, restrict the study findings' generalizability to the larger young population. Therefore, although this research represents an improvement over the past most comparable studies on this population, it would be beneficial for future research to consider a larger sample and a greater number of trials to increase the statistical power and decrease sampling biases.

Furthermore, the participants' IQs were not available, which is an important factor to consider in this population (DSM-IV Criteria; APA, 1994). Unavailability of IQ scores is a common limitation in studies performed in schools (e.g., Frey & Chow, 2006; Rintala & Loovis, 2013). Future research could include IQs to better understand the differences between the participants.

We used the games from Tomporowski et al. work (2015a) based on three principles of mental engagement: contextual interference, mental control, and discovery play. However, no validated standardized instrument to measure the cognitive control engagement components of the games for the sample was used, and to the author's knowledge, such instruments are not available.

Future research could consider additional individual factors and physical activity components. In the first one, it would be beneficial to include physical fitness measurements (e.g., body composition, strength) and lifestyle habits (e.g., physical activity routines/patterns, deliberate play, diet) to analyze if there is an association or if they are moderating the efficiency of the program, as has been seen in other research (Gapin & Etnier, 2010; Hsu et al., 2021; Pan et al., 2019; Pesce et al., 2016; Salse-Batán et al., 2021; Sulton & Jajat, 2019; Tomporowski et al., 2011; Westendorp et al., 2011). Additionally, it would be important for future research to evaluate and analyze the participants’ socioeconomic status (SES) since the literature suggests a relationship between SES and health, achievement, learning, and development (e.g., Darin-Mattsson et al., 2017; Naeem et al., 2018; Sweeney, 2015). Regarding physical activity components, more studies are recommended to explore the best practices in physical activity interventions (e.g., frequency, intensity, volume, movement patterns) to generate cognitive and motor gains.

Despite the limitations of this study, findings can thus provide preliminary encouraging evidence on the potential of enriched physical education programs to enhance attention control and locomotor performance in children with non-specific mild ID. However, the interpretability and generalizability of the results to a larger young population are limited. Despite the constraints, it is believed that this study is a valuable contribution to the sparse literature available on this topic, providing a useful reference for replication and future research directions.

6.2. Conclusion and Practical Implications

The study findings offer encouraging evidence of the potential of physical activity to promote significant enhancements in locomotor skills and attentional control functions, suggesting that the latter one had an emerging modulatory role due to tendencies of improvements in more complex control functions and object control motor skills (i.e., catching skill).

Both the attentional and motor enhancements associated with the enriched physical education program are of great importance, considering the challenges shown by children with mild ID and the implications that these entail in the daily life of children. For example, attention is essential in children’s learning processes (Posner & Rothbart, 2014), achieving and maintaining focus in goal-directed behaviors (Cohen, 2017), regulation of emotions, and the development of more complex cognitive control functions (Garon et al., 2008; Posner & Rothbart, 2005). The literature also highlights its importance as a prerequisite for complex motor patterns (Populin et al., 1990). This suggests that future physical education programs could strategically integrate activities that specifically target attentional improvement, offering meaningful support to children with mild ID, potentially fostering their cognitive development and equipping them with enhanced capabilities to participate effectively in various aspects of life.

Furthermore, GMS are fundamental for movement competence and are the basic building blocks for more complex motor skill development (Stodden et al., 2008) and all physical activity and sports participation throughout our lives. Therefore, forthcoming physical education strategies promoting GMS to enhance movement competence and to counteract the sedentary lifestyle tendencies and overweight issues often prevalent in this population (Engel et al., 2018; Foley & McCubbin, 2009; Slevin et al., 2014) play an essential role.

The enriched physical education program’s potential applicability can be extended beyond the cohort initially targeted, opening doors for children with other eligibility criteria such as Down Syndrome. The intervention's versatility lies in its adaptability; its implementation can be seamlessly integrated into various educational settings in an open and safe space in any school, as well as be employed as a a complementary physical therapy program.

7. Publications

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Appendix 1

EÖTVÖS LORÁND UNIVERSITY

DECLARATION FORM for disclosure of a doctoral dissertation

I. The data of the doctoral dissertation:

Name of the author: Angélica Liseth Mero Piedra

MTMT-identifier: 10072042

Title and subtitle of the doctoral dissertation: Effects of an Enriched Physical Education Program on Cognitive and Motor Performance in Children with Mild Intellectual Disabilities.

DOI-identifier[87]: 10.15476/ELTE.2023.199

Name of the doctoral school: Doctoral School of Education

Name of the doctoral programme: Special Education Programme

Name and scientific degree of the supervisor: Dr. Klára Marton, Ph.D., Professor

Workplace of the supervisor: -Bárczi Gusztáv Faculty of Special Needs Education, Eötvös Loránd University.
-Brooklyn College, City University of New York, Brooklyn, NY, USA.
-Graduate School and University Center, City University of New York, USA.

II. Declarations

1. As the author of the doctoral dissertation,[88]

a) I agree to public disclosure of my doctoral dissertation after obtaining a doctoral degree in the storage of ELTE Digital Institutional Repository. I authorize ……………………………….., the administrator of the ……………………………..…………..…… Office of the Doctoral School to upload the dissertation and the abstract to ELTE Digital Institutional Repository, and I authorize the administrator to fill all the declarations that are required in this procedure.

b) I request to defer public disclosure to the University Library and the ELTE Digital Institutional Repository until the date of announcement of the patent or protection. For details, see the attached application form;[89]

c) I request in case the doctoral dissertation contains qualified data pertaining to national security, to disclose the doctoral dissertation publicly to the University Library and the ELTE Digital
Institutional Repository ensuing the lapse of the period of the qualification process.;[90]

[87] Filled by the administrator of the faculty offices.
[88] The relevant part shall be underlined.
[89] Submitting the doctoral dissertation to the Disciplinary Doctoral Council, the patent or protection application form and the request for deferment of public disclosure shall also be attached.
[90] Submitting the doctoral dissertation, the notarial deed pertaining to the qualified data shall also be attached.

d) I request to defer public disclosure to the University Library and the ELTE Digital Institutional Repository, in case there is a publishing contract concluded during the doctoral procedure or up until the award of the degree. However, the bibliographical data of the work shall be accessible to the public. If the publication of the doctoral dissertation will not be carried out within a year from the award of the degree subject to the publishing contract, I agree to the public disclosure of the doctoral dissertation and abstract to the University Library and the ELTE Digital Institutional Repository.[91]

2. As the author of the doctoral dissertation, I declare that
a) the doctoral dissertation and abstract uploaded to the ELTE Digital Institutional Repository are entirely the result of my own intellectual work and as far as I know, I did not infringe anyone's intellectual property rights.;
b) the printed version of the doctoral dissertation and the abstract are identical with the doctoral dissertation files (texts and diagrams) submitted on electronic device.

3. As the author of the doctoral dissertation, I agree to the inspection of the dissertation and the abstract by uploading them to a plagiarism checker software.

Budapest, 23 July, 2023

Signature of dissertation author

[91] Submitting the doctoral dissertation, the publishing contract shall also be attached.