

Effects of an adapted swimming program with visual prompts on executive functions in children with Autism Spectrum Disorder (ASD) and Intellectual Disability (ID)

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Abstract

Executive functions (EF) are higher-order cognitive processes that support goal-directed behavior, learning, and adaptation. Children with autism spectrum disorder (ASD) and intellectual disability (ID) often show EF deficits that affect attention, planning and self-regulation. Although visual and physically engaging interventions can improve EF, their combined use in aquatic programs remains underexplored. This study investigated the effects of an adapted swimming program with visual prompts on EF and frontal lobe activation in children with ASD and ID. Twenty-nine children aged 6–15 years (19 with ASD, 10 with ID) were randomly assigned to an experimental group (EG; $n = 17$) or control group (CG; $n = 12$). The EG completed a 14-week adapted swimming program (two 60-minute sessions/week) with visual supports that include picture cards and short video prompts. Executive performance was assessed pre- and post-intervention using an exergame ('Squid Hero for Kinect' by Visual Air Guitar Company) that measured score and completion time, while dorsolateral prefrontal cortex activation was monitored via fNIRS (HbDiff). Post-intervention, the EG showed significantly higher exergame scores than the CG ($p = .012$), with improvements observed in both ASD and ID subgroups; ID participants in the EG outperformed their CG counterparts ($p = .011$). No group differences were found in completion time or overall HbDiff, though post-intervention HbDiff differed between ASD and ID within the EG, which indicated distinct neural engagement patterns. Overall, the findings indicate that an adapted swimming program enriched with visual prompts may support improvements in visual-motor processing and executive task performance in children with ASD and ID. Although neurophysiological changes in prefrontal activation were limited, the results highlight the potential of visually structured aquatic interventions as a complementary approach for enhancing cognitive and motor functioning in children with neurodevelopmental disorders.

Keywords: Children, ASD, ID, Executive function, Adapted Swimming, Visual Prompts

Introduction

Executive Function (EF) comprises higher-order cognitive processes that enable adaptation, decision-making, and goal-directed behavior in novel or complex situations (Ceruti et al., 2024; Pasqualotto et al., 2021). It includes working memory, inhibitory control, cognitive flexibility, planning, organization, attention, and self-regulation (Demetriou et al., 2019; Diamond, 2020; Salehinejad et al., 2021). EF is essential for learning, emotional regulation, and social functioning, and deficits are common in neurodevelopmental disorders (NDs), particularly autism spectrum disorder (ASD) and intellectual disability (ID) (Oi, 2025; Townes et al., 2023). Given its central role in adaptive behavior, EF has increasingly been recognized as a critical target for intervention, particularly in children with neurodevelopmental disorders.

Children with ASD often show difficulties in flexibility, planning, problem-solving, and behavioral regulation, reflected in restricted behaviors and resistance to change (American Psychiatric Association [APA], 2013). Children with ID commonly experience impairments in working memory, organization, and inhibitory control, affecting multistep task performance and impulse regulation (Schalock, et al., 2021). Although distinct, ASD and ID share EF-related challenges that restrict autonomy, academic progress, and social participation (Sadozai et al., 2024; Townes et al., 2023). Deficits in executive functions may significantly compromise daily living skills, independence, classroom participation, and the ability to follow structured routines in children with ASD and ID. Such difficulties may further restrict engagement in physical activity and participation in adaptive educational settings, highlighting the need for supportive intervention approaches that address both cognitive processes and functional outcomes (Sung et al., 2022). Thus, identifying intervention strategies that simultaneously target cognitive and functional domains constitutes a major priority in current research efforts that this study seeks to address.

Since EF difficulties hinder processing of verbal instructions, structured visual supports are particularly beneficial since they reduce cognitive load and externalize executive processes, allowing children with ASD and

ID to better engage with more complex or sequential tasks (Macoun et al., 2021; Oi, 2025). Methods such as picture schedules and video-based instruction facilitate organization, retention, and task completion (Hume et al., 2021; Park et al., 2019; Shepley et al., 2018). Furthermore, visual prompts enhance learning, communication, skill acquisition and generalization, and task performance (Cannella-Malone et al., 2018; Wu, et al., 2016).

Video Modeling (VM) and Video Prompting (VP) are widely used visual approaches (Kellems et al., 2020). VM provides full demonstrations for imitation (Jaffal, 2023), offering consistent cues effective for learners with ASD and ID (Hume et al., 2021; Park et al., 2019) with increased engagement when observing self or peers (Chen et al., 2016). VP presents sequential task steps with feedback, reducing cognitive load and improving mastery, especially in ASD and ID (Cruz-Torres et al., 2020; Cullen et al., 2017; Hume et al., 2021; Kellems et al., 2018; Stierle et al., 2023; Yakubova et al., 2015). Overall, visually based methods effectively support functional, social, and academic skills (Bross et al., 2021; Kellems et al., 2016; Mödinger et al., 2022; Park et al., 2019; Petursdottir & Gudmundsdottir, 2023; Sun & Brock, 2023; Yakubova et al., 2015). However, despite their established effectiveness, their integration within swimming settings and their potential influence on executive functioning of children with ASD and ID remains underexplored.

Exergames are video games that combine exercise and gameplay, requiring players to use physical activity to interact with and progress through the game environment (Papastergiou, 2009). Exergames involving physical interaction with video games benefit individuals with ASD by enhancing communication, reducing repetitive behaviors, and improving working memory, fitness, executive functioning, and self-perception (Fang et al., 2019; Hilton et al., 2015; Jozkowski & Cermak, 2020; Lima et al., 2020; Miranda, 2025; Pan et al., 2017). However, research using exergames in individuals with ID mainly targets cardiovascular, strength, fitness and motor skill outcomes of exergame play (Markus, 2016; Suárez-Iglesias et al., 2021). Thus, there is limited focus on cognitive effects although exergames offer high motivation and enjoyment and a unique opportunity to simulate sport-specific motor sequences in controlled environments (Hsu, 2016; Ryuh et al., 2022), thereby providing a promising tool of bridging the gap between motor execution and cognitive assessment in children with ASD and ID.

EF improvements may relate to increased cerebral blood flow and neuroplasticity (Mulser & Moreau, 2023; Renke et al., 2022). Atypical prefrontal cortex (PFC) activation during EF tasks has been observed in ASD (Han et al., 2022; Krishnamurthy et al., 2020; Macoun et al., 2021; Rafiei Milajerdi et al., 2021). Chen et al. (2024) used functional near-infrared spectroscopy (fNIRS) during sports interventions in ASD, reporting increased activation in PFC regions linked to executive processes (Pinti et al., 2020), supporting cognitively engaging physical activity. Importantly, changes in prefrontal hemodynamics such as reduced oxygenated hemoglobin following training may reflect improved familiarity with task demands, indicating enhanced executive functioning in these children.

Comparable evidence in adapted swimming is scarce. Although swimming promotes psychomotor, adaptive, and social development in ASD and ID (Ansari et al., 2021; Battaglia et al., 2019; Caputo et al., 2018; Chu & Pan, 2012; Marzouki et al., 2022; Milligan et al., 2022; Pan, 2011; Tsolaki et al., 2023; van 't Hooft et al., 2024; Vodakova et al., 2022; Yilmaz et al., 2004), only two studies integrated visual supports in aquatic programs, focusing solely on motor outcomes (Pan, 2010; Yanardag et al., 2013). Pan (2010) utilized visual schedules such as a board with pictures and words to describe the routine and the daily aquatic activity to facilitate participation, whereas Yanardag et al. (2013) used video prompting to teach specific aquatic play skills. However, none have examined executive function using fNIRS and no study to date has investigated executive function in adapted swimming settings using neurophysiological measures, highlighting a significant gap in the literature regarding the cognitive impact of aquatic interventions with visual prompts in children with ASD and ID.

Further research is needed to investigate intervention approaches that combine visually supported physical activity with cognitive and executive function assessment in children with ASD and ID. Although previous aquatic interventions have demonstrated benefits in motor and adaptive functioning, the potential effects of such interventions on executive functioning and associated frontal lobe activation remain unclear. Understanding how structured adapted swimming interventions with visual prompts influence neural efficiency may provide valuable insights for designing interventions that optimize both motor learning and cognitive development. Addressing this gap may contribute to the development of more effective and cognitively oriented adapted physical activity programs for children with neurodevelopmental disorders.

Since fNIRS cannot be applied during aquatic activity, it was used as an assessment tool of executive performance prior to and following an adapted swimming program with visual prompts. To reflect the cognitive and sequential demands of the intervention during assessment, an exergame-based procedure was used to mirror the structure of the swimming intervention, involving visual prompting and subsequent performance of swimming-related tasks. Thus, this study follows a novel methodological approach as it allows for the indirect examination of executive function improvements associated with adapted swimming training through simulated, water-based tasks performed in a controlled environment that exergames provide. The use of exergaming enables for the first time the investigation of prefrontal hemodynamic responses related to swimming tasks, overcoming the technical limitation of fNIRS use in aquatic settings.

The purpose of this study was to examine the effect of an adapted swimming program with visual prompts on executive functions and associated frontal lobe activation in children with ASD and ID, addressing a gap in the literature. It is hypothesized that reduced prefrontal activation following intervention will reflect increased task familiarity, indicating improvements in executive functioning. Thus, this study aims to provide the first empirical evidence of the impact of an adapted swimming program combined with visual prompts on executive function, highlighting its potential as an effective and valid intervention for children with ASD and ID and underscoring its practical implications in adapted swimming settings.

Materials and Methods

Participants

Twenty-nine children with developmental diagnoses of intellectual disability (ID) and autism spectrum disorder (ASD) participated in the present study. Nineteen (19) were diagnosed with ASD and ten (10) with ID, based on prior formal assessments conducted by the Centers for Interdisciplinary Assessment, Counseling & Support. Participants were aged between 6 and 15 years and included 20 boys and 9 girls. The ID group comprised six boys and four girls, while the ASD group included fourteen boys and five girls.

Participants were randomly assigned to an experiment group (EG; N = 17), consisting of 11 children with ASD and 6 with ID, and a control group (CG; N = 12), consisting of 8 children with ASD and 4 with ID. Recruitment followed official permission to contact parents of children attending integration classes, inclusive education settings, or special education schools, granted by the Department of Primary Education.

Parents were informed about the combined adapted swimming program with visual prompts by the principal researcher. Prior to participation, legal parents/guardians read—or had read to them—the informed consent form, which they subsequently signed. The study protocol and procedures were approved by the Bioethics Committee of the University of Thessaly (protocol number 2366-3/4-2024).

Instruments

Exergame

For the purposes of the study, a specific level of Squid Hero for Kinect (Xbox One) was selected, since its avatar-based visual feedback closely replicated the structure of the intervention, allowing systematic evaluation of visual prompting effects and responses to visual stimuli. The principal researcher chose this level due to its structured design, which consists of clearly defined stages, each introduced by visual prompts delivered through a virtual avatar. The avatar models the correct movements for each task, with visual demonstrations presented for a few seconds to support comprehension and imitation.

This format closely paralleled the intervention program, in which participants first received visual prompts and subsequently performed each exercise. During gameplay, the researcher also provided verbal reinforcement of the on-screen instructions, guiding participants as they replicated the avatar's modeled actions. The game required players to raise, lower, or shift their arms and lean their bodies to avoid obstacles - movements consistent with the motor skills emphasized in the intervention. The main objective was to break ice blocks by matching their colors and ultimately shatter a larger ice formation, thereby fostering coordination, timing and sustained visual attention.

Time and Exergame score

Task duration (time) was recorded using a digital timer to measure the completion time that each participant spent in completing the exergame level. Participants' responses to visual stimuli were additionally assessed through an objective performance indicator derived from an exergame. Exergame scores were recorded to evaluate the accuracy and timing of participants' movements. The selected exergame ('Squid Hero for Kinect' by Visual Air Guitar Company) simulated the structure and sequence of the intervention program and functioned as an indicator of visual attention performance. It was administered both before and after the intervention to assess potential improvements resulting from the combined adapted swimming program with visual prompts.

The use of exergame-derived metrics as assessment tools is supported by emerging evidence on game-based and virtual environments for cognitive evaluation. Non-immersive virtual reality and serious games allow standardized administration, precise control of stimulus presentation, and continuous recording of behavioral responses while maintaining strong ecological validity (Bassano et al., 2022). Performance indicators such as accuracy, reaction time, and movement timing (Rüth & Kaspar, 2020), reflect attentional allocation, response regulation, and adaptation to dynamic visual stimuli—processes closely associated with executive functioning. Furthermore, validation studies report significant correlations between gameplay performance and standardized cognitive measures, supporting the construct validity of game-based assessments (Kirkham et al., 2024). Empirical findings also demonstrate that movement-based exergames are closely related to motor-cognitive status, as they require integration of sensory processing, motor planning, and inhibitory control (Guimarães et al., 2023). Collectively, this evidence supports the use of exergame scores as complementary and objective indicators of task performance within intervention-based evaluation protocols.

Near-infrared spectroscopy (fNIRS)

A portable functional near-infrared spectroscopy (fNIRS) system (Portalite, Artinis Medical Solutions, Netherlands) was employed to monitor hemodynamic changes in the dorsolateral prefrontal cortex (DLPFC), measuring total hemoglobin (tHb) and the difference between oxygenated and deoxygenated hemoglobin

(HbDiff = O₂Hb – HHb). The NIRS probe was placed over the right DLPFC, corresponding to Brodmann area 46 (Perlman et al., 2016).

fNIRS is a non-invasive, safe, and portable optical neuroimaging technique that assesses cortical activity by detecting changes in light attenuation proportional to fluctuations in oxyhemoglobin and deoxyhemoglobin concentrations. These measurements rely on continuous-wave near-infrared light emitted at multiple wavelengths. Importantly, fNIRS is particularly appropriate for pediatric research, as it does not require complete immobility and causes no physical discomfort. This makes it well suited for studies involving children, allowing real-time monitoring of cerebral oxygenation during task performance and providing meaningful insights into brain function and neuroplasticity (Pinti et al., 2020).

Procedure

The combined adapted swimming program with visual prompting lasted 14 weeks, with two 60-minute sessions per week, conducted in the small pool of the municipal swimming complex in Trikala. The intervention integrated adapted swimming activities with visual supports, including picture cards and short video prompts (maximum duration of 30 seconds per exercise) displayed on a tablet. All participants in both the control group (CG) and experiment group (EG) completed the first level of the interactive exergame Squid Hero for Kinect before and after the intervention period, playing the game in a Microsoft Xbox One console which was equipped with a Microsoft Kinect motion-sensing device and connected to a 55-inch display screen via an HDMI cable. The study commenced with the pre-intervention assessment. Participants were first given time to familiarize themselves with the environment and the game, including five minutes of free interaction with the exergame. During the assessment, the primary researcher positioned the fNIRS device, after which the participant began gameplay. The researcher observed performance and provided verbal guidance when necessary. Upon completing the level, each participant repeated the same level to enhance the reliability and consistency of performance data. The entire procedure was video - recorded to allow subsequent verification of implementation fidelity by the research team.

The post-intervention assessment followed the identical protocol to ensure methodological consistency across time points. Assessments were conducted individually, with waiting times for other participants kept under two minutes to maintain engagement. All measurements took place at the Laboratory of Biomechanics and Ergonomics, Department of Physical Education and Sport Science, University of Thessaly.

Statistical Analysis

Data were analyzed using non-parametric statistical procedures. The Wilcoxon signed-rank test was applied to examine differences between pre- and post-intervention measurements within each group. The Mann-Whitney U test was used to identify differences between independent groups (experiment vs. control) and between disability categories (ID vs. ASD). The level of statistical significance was set at $p < 0.05$. All analyses were conducted using IBM SPSS Statistics, version 29.

Results

Mann-Whitney results revealed statistically significant differences between EG (N=17) and CG (N=12) in post-measures of the exergame score ($U=45.000$, $p=.012$), in favour of EG participants. No statistically significant differences were observed in pre- and post- measurements between the two groups in terms of time (Table I).

Table I. EG and CG differences in pre- and post- exergame measures

Factor	Group	N	Mean Rank	Mann-Whitney U	Asymp. Sig.
Exergame score pre	EG	17	15.53	93.000	.690
	CG	12	14.25		
Exergame score post	EG	17	18.35	45.000	.012
	CG	12	10.25		

Additional Mann Whitney analysis between the ID participants of EG and CG group and the ASD individuals of the EG and CG group in pre- and post- measures of the exergame score, revealed statistically significant differences between the ID participants of EG and CG group in post measures in favor of the EG group, whereas no differences were noted concerning ASD participants between the two groups (Table II).

Table II. EG and CG differences in pre- and post- exergame measures for ID participants

Factor	Group	N	Mean Rank	Mann-Whitney U	Asymp. Sig.
Exergame score pre	EG	6	15.53	10.500	.747
	CG	4	14.25		
Exergame score post	EG	6	7.50	0	.011
	CG	4	2.50		

Mann-Whitney analysis revealed no statistically significant results between the EG (N=17) and CG group (N = 12) in terms of oxygenated and deoxygenated hemoglobin (HbDiff) in pre- and post- values. No differences of HbDiff pre and post values were also noted between the ID participants of EG and CG group and the ASD individuals of the EG and CG group.

Furthermore, Mann–Whitney analysis between the ID and ASD individuals of the CG and EG group, located statistically significant differences in favor of the ID individuals of the EG group in post measures of oxygenated and deoxygenated hemoglobin (HbDiff), whereas no such differences were noted between the ID and ASD individuals of the CG group (Table III).

Table III. ID and ASD differences for the EG group participants in pre- and post- HbDiff values

Factor	Group	N	Mean Rank	Mann-Whitney U	Asymp. Sig.
HbDiff PRE	ASD	11	9.45	28.000	.615
	ID	6	8.17		
HbDiff POST	ASD	11	10.91	12.000	.037
	ID	6	5.50		

On the total sample of all participants with ID and ASD, non-parametric Wilcoxon analysis revealed statistically significant differences between pre- and post-exergame scores only for the EG group in post measures. No other significant differences were observed between pre- and post-measures concerning time in each group (Table IV).

Table IV. Wilcoxon results between pre and post exergame scores for the EG group

Factor	Group	N	Measures	Mean Rank	Z	p
Exergame Score	EG	17	pre	9	-3.622 ^b	.001
			post			

Similar Wilcoxon results were noted between pre and post exergame scores for the group of participants with ASD of the EG group (Table V).

Table V. Wilcoxon results between pre and post exergame scores for ASD participants of the EG group

Factor	Group	N	Measures	Mean Rank	Z	p
Exergame Score	EG	11	pre	6	-2.934	.003
			post			

Similarly, Wilcoxon analysis showed statistically significant difference between pre and post exergame scores for the ID participants of the EG group only (Table VI).

Table VI. Wilcoxon results between pre and post exergame scores for ID participants of the EG group

Factors	Group	N	Measures	Mean Rank	Z	p
Exergame Score	EG	6	pre	3.50	-2.201 ^b	.028
			post			

Finally, no statistically significant differences were noted in terms of oxygenated and deoxygenated hemoglobin (HbDiff) between pre- and post- values in each group.

Discussion

The purpose of this study was to examine the effects of an adapted swimming program incorporating visual prompts on executive functions (EF) in children with ASD and ID, using exergame scores and fNIRS measures collected before and after the intervention. EF encompasses higher-order processes such as working memory, inhibitory control, cognitive flexibility, planning, attention, and self-regulation, which enable adaptive, goal-directed behavior in complex situations (Ceruti et al., 2024; Demetriou et al., 2019; Diamond, 2020; Pasqualotto et al., 2021; Salehinejad et al., 2021). Given that EF deficits are central features of neurodevelopmental disorders (Oi, 2025; Townes et al., 2023), particularly ASD and ID, interventions targeting these processes are of considerable clinical and educational importance.

The comparison between the EG and the CG revealed significant differences in post-intervention exergame scores, with participants in the EG achieving higher scores. This finding suggests improved accuracy and coordination in responding to visual stimuli and visual information during the exergame, potentially reflecting enhancements in visual–motor processing and task execution. This interpretation aligns with previous evidence demonstrating strong links between motor coordination, attention, and executive functioning in children (Cortese et al., 2023). Within this framework, interventions incorporating visual stimuli during movement, such as exergaming, have been shown to support executive functioning through improvements in visual–motor integration and attentional control, particularly in individuals with ASD (Fang et al., 2019).

Further comparison between the EG and CG among participants with ID revealed significant post-intervention differences in exergame scores, with participants in the EG achieving higher scores. These findings

indicate that the effects of the intervention may have varied across diagnostic categories, with participants with ID demonstrating greater improvements than those with ASD.

Regarding oxygenated and deoxygenated hemoglobin values in the pre- and post-intervention measurements, no significant differences were found between the experiment and control group. However, when differences between ASD and ID participants within the experiment group were examined, significant differences in HbDiff values were observed in the post-intervention measurements, indicating that EG participants with ID exhibited distinct hemodynamic responses compared to those with ASD.

This finding suggests differential engagement of prefrontal neural resources during task performance following intervention. These differences between ASD and ID participants of the EG, may reflect disorder-specific neural strategies. More specifically, children with ID may rely more heavily on visual–motor pathways, whereas children with ASD may require sustained cognitive effort, potentially affecting skill transfer—a challenge commonly reported in ASD (APA, 2013). Children with ID demonstrated distinct oxygenation patterns, possibly indicating a greater reliance on visual–motor pathways during task execution, whereas children with ASD may experience difficulties transferring acquired skills, thus, continue to display sustained cognitive effort throughout the intervention despite repeated exposure to the task.

Cognitively enriched physical activity interventions that require continuous updating of motor commands and integration of new information have been shown to promote improvements in executive functions in children with ASD (Chen et al., 2024). In addition, meta-analytic evidence supports the effectiveness of structured movement-based interventions in enhancing inhibitory control, working memory, and cognitive flexibility across neurodevelopmental disorders (Corey, 2025). Overall, the observed differences between the ASD and ID groups are consistent with research indicating significant dysfunctions in executive tasks, particularly in working memory (Crucitti et al., 2022; Krishnamurthy et al., 2020; Leisman et al., 2023; Rafiee et al., 2022). Comparison of pre- and post-intervention exergame scores showed that all participants in the experiment group exhibited significant improvements in accuracy and coordination when responding to visual stimuli and visual information during the exergame, potentially reflecting enhancements in visual–motor processing and task execution. A similar pattern of improvement in the EG was observed when the analysis focused specifically on participants with ASD within the experiment group. Likewise, participants with ID within the experiment group also demonstrated significant improvements in exergame scores between the pre- and post-intervention measurements.

Children with neurodevelopmental disabilities often experience difficulties processing verbal instructions and therefore benefit from structured visual supports (Macoun et al., 2021; Oi, 2025). Visual schedules, modeling, and prompting strategies facilitate task initiation, organization, and completion by clearly presenting sequential information (Shepley et al., 2018). The present findings extend the body of evidence supporting visual-based instructional methods—including video modeling (VM) and video prompting (VP)—as effective tools for enhancing skill acquisition, generalization, and task performance in ASD and ID (Bross et al., 2021; Cannella-Malone et al., 2018; Chi & Lin, 2021; Hume et al., 2021; Kellems et al., 2020; Park et al., 2019; Wu et al., 2016). Similar to the step-by-step structure of VP, the swimming program’s systematic visual cues likely reduced cognitive load while promoting anticipatory planning and response selection (Cruz-Torres et al., 2020; Kellems et al., 2018).

Twelve-week interventions have been shown to improve inhibitory control, working memory, and cognitive flexibility (Pan et al., 2017; Tse et al., 2019), and meta-analytic findings confirm positive effects of exercise on EF domains in ASD (Liang et al., 2022). Exergaming studies incorporating visual prompts similarly report gains in working memory, executive functioning, and reductions in repetitive behaviors (Fang et al., 2019; Hilton et al., 2015; Lima et al., 2020; Pan et al., 2017). Although research involving individuals with ID remains limited and often focuses on physical outcomes (Markus, 2016), executive processes in ID are strongly associated with visual–motor integration and attentional control (Memisevic & Sinanovic, 2013; Otterman et al., 2019; Zagaria et al., 2021), supporting the plausibility of EF improvements through visually guided aquatic tasks. Importantly, although adapted swimming has demonstrated broad psychomotor, adaptive, and social benefits in individuals with ASD and ID (Ansari et al., 2021; Battaglia et al., 2019; Caputo et al., 2018; Marzouki et al., 2022; Milligan et al., 2022; Pan, 2011; van ’t Hooft et al., 2024; Vodakova et al., 2022; Yilmaz et al., 2004), its effects on executive functions had not previously been examined. Prior aquatic studies incorporating visual supports have primarily focused on motor outcomes (Pan, 2010; Yanardag et al., 2013).

Overall, the adapted swimming program incorporating visual prompts was effective in supporting visual processing and executive functioning in children with ASD and ID. Participants demonstrated improved ability to process and respond to visual information, indicating enhanced executive control and visual attention. Visual prompts probably contributed to these improvements by reducing reliance on verbal instructions and supporting anticipatory planning, response selection, and reduced cognitive load.

Despite the observed benefits, children with ASD may still experience difficulties transferring acquired skills across tasks. Thus, a longer intervention period may allow for the detection of more robust neurophysiological changes in prefrontal activation. The relatively small sample size of the present study also limits the generalizability of the findings. Furthermore, the inclusion of participants with both ASD and ID may have introduced variability in responses to the intervention.

Conclusions

Overall, the adapted swimming program incorporating visual prompts showed promise in enhancing executive functioning, visual processing, and motor efficiency in children with ASD and ID. Participants demonstrated improved ability to process and respond to visual information, indicating gains in executive control and visual attention. These improvements may be attributed to the use of visual prompts, which likely reduced reliance on verbal instructions while facilitating anticipatory planning and response selection during task performance.

Most important, this study expands current knowledge on adapted swimming interventions by examining executive function through the combined use of exergame performance and fNIRS assessment, offering a novel approach to investigating cognitive outcomes in aquatic settings. Future research should investigate the long-term effects of such interventions, include other populations with neurodevelopmental disabilities, and examine how variations in intervention intensity and cognitive load influence cognitive and neurophysiological outcomes. Overall, the adapted swimming programs incorporating visual prompts in this study, appeared to provide a practical and effective approach for supporting both cognitive and motor development in children with ASD and ID.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors didn't use of AI in the writing of the article.

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Conflicts of interest

The authors declare no conflict of interest.

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