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Effectiveness of computerized lumosity® tasks to improve executive functions in children with ASD

Efectividad de tareas computarizadas de Lumosity® para mejorar las funciones ejecutivas en niños con TEA

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ABSTRACT

The use of digital tools for cognitive training in children with autism spectrum disorder has shown potential as a complement to traditional therapies, although supporting evidence remains limited. This study aimed to evaluate the effectiveness of a computerized executive function stimulation program using the Lumosity® platform in a sample of 47 children aged 6 to 12 years with a clinical diagnosis of level 1 ASD and normative cognitive functioning. A quasi-experimental design was used with non-probabilistic assignment to an experimental group, which received digital training over 16 weeks, and an active control group with a psychoeducational intervention. Standardized assessments were administered pre- and post-intervention, focusing on working memory, inhibitory control, and planning. Results showed significant improvements in the experimental group compared to the control group, with moderate to large effect sizes, particularly in inhibitory control and planning. It is concluded that the use of gamified digital platforms may be an effective alternative to strengthen cognitive skills related to autonomy, learning, and functional adaptation. These findings provide support for the integration of technology-based interventions into neuropsychological programs aimed at promoting cognitive development in children with ASD.

Keywords: autism spectrum disorder; executive functions; cognitive training; digital interventions; lumosity.

RESUMEN

El uso de herramientas digitales para el entrenamiento cognitivo en niños con trastorno del espectro autista ha mostrado potencial como complemento a las terapias tradicionales, aunque su evidencia aún es limitada. Este estudio tuvo como objetivo evaluar la efectividad de un programa computarizado de estimulación de funciones ejecutivas mediante la plataforma Lumosity®, en una muestra de 47 niños entre 6 y 12 años con diagnóstico clínico de TEA nivel 1 y funcionamiento cognitivo normativo. Se utilizó un diseño cuasiexperimental con asignación no probabilística a un grupo experimental, que recibió entrenamiento digital durante 16 semanas, y a un grupo control activo con intervención psicoeducativa. Se aplicaron evaluaciones estandarizadas antes y después de la intervención, centradas en memoria de trabajo, control inhibitorio y planificación. Los resultados mostraron mejoras significativas en el grupo experimental frente al control, con tamaños de efecto moderados a grandes, destacando un impacto mayor en control inhibitorio y planificación. Se concluye que el uso de plataformas digitales con enfoque lúdico puede ser una alternativa eficaz para fortalecer habilidades cognitivas asociadas a la autonomía, el aprendizaje y la adaptación funcional, aportando evidencia a favor de su incorporación en programas de intervención dirigidos a niños con TEA.

Palabras clave: trastorno del espectro autista; funciones ejecutivas; entrenamiento cognitivo; intervenciones digitales; lumosity.

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INTRODUCTION

Autism spectrum disorder (ASD) is a neurodevelopmental condition that typically emerges in early childhood and is characterized by persistent difficulties in social communication and interaction, along with restricted and repetitive patterns of behaviors and interests (American Psychiatric Association, 2013). The clinical features of ASD are highly variable, often including differences in language acquisition, cognitive functioning, and neuropsychological profiles (Lord *et al.,* 2020). Notably, many children with ASD may have preserved intellectual abilities, yet still present with significant challenges in higher-order cognitive processes, even when global cognitive delay is not apparent (Hajri *et al*., 2022).

Among these challenges, impairments in executive functioning have been increasingly recognized as a central neurocognitive trait of the condition (Hemmers *et al.*, 2022). Executive functions refer to a complex set of mental abilities that support goal-directed behavior, including planning, organization, decision-making, impulse control, emotional regulation, and flexible adaptation to novel situations. These functions are sustained by key components such as planning, inhibitory control, cognitive flexibility, and working memory, among others (Papazian *et al.,* 2006; Rosselli *et al.,* 2008; Verdejo-García y Bechara, 2010).

In recent decades, the global prevalence of ASD has increased substantially. Current estimates suggest that arround 1% of the child population is affected, although figures vary depending on the region and the methodological criteria (Talantseva *et al.,* 2023). Higher rates have been reported in high-income countries. For instance, surveillance data from the United States indicated a prevalence of 2.8% among 8-year-old children in 2020 (1 in 36), compared to 2.3% in 2018 (Maenner *et al.,* 2023).

In Chile, this upward trend has also become evident. Although representative national studies were lacking for years, an analysis based on Global Burden of Disease data estimated a prevalence of 1.06% in 2021. That study also found prevalence to be approximately 2.2 times higher in boys than in girls (1.47% vs. 0.65%) (Lopez-Espejo, 2025), consistent with the international male-to-female diagnostic ratio of nearly 4:1 (Tafolla *et al*., 2025). Similarly, a previous study in an urban pediatric population reported a prevalence of 1.96% (1 in 51 children), again with a 4:1 sex ratio (Yáñez *et al*., 2021); placing Chile among the countries with the highest reported rates. Although these estimates may vary by source, they reflect a growing recognition of ASD and underscore the increasing burden on health and education systems, which must adapt to provide timely diagnosis and specialized support to this population.

A key focus within ASD research involves understanding how executive functions (EF) contribute to everyday functioning. EF includes advanced cognitive mechanisms such as working memory (the ability to retain and manipulate information), inhibitory control (the suppression of automatic or inappropriate responses), cognitive flexibility (the adaptive shifting of strategies or attention), and planning (the sequential organization of actions to achieve a goal) (Demetriou *et al.,* 2019). Empirical comparisons have consistently shown that children with ASD tend to underperform on EF-related tasks in contrast to their typically developing counterparts (Pardo-Salamanca *et al*., 2024). While executive impairments vary considerably among individuals, specific components appear to be more affected than others. Recent findings highlight that challenges in planning, working memory, inhibitory control, and cognitive flexibility are especially pronounced in this population (Gentil-Gutiérrez *et al*., 2022; Talero-Gutiérrez *et al.,* 2023).

These EF impairments are not merely theoretical constructs, they exert a concrete influence on how children with ASD adapt to everyday demands. Poor executive functioning may manifest as difficulties in organizing routine activities, adapting to changes in the environment, regulating impulses, or learning

effectively in school settings. Consistently, children with more compromised executive profiles have been observed to show greater limitations in daily adaptive skills and a higher frequency of disruptive behaviors, phenomena that are, in turn, associated with increased caregiver stress (Barton y McIntyre, 2022; Igliozzi *et al*., 2024). These findings highlight the clinical relevance of EF in ASD. Beyond the core social and communicative symptoms, executive dysfunctions constitute a critical component that amplifies the need for support in daily life. In some cases, the severity of symptoms necessitates clinical interventions, particularly when disruptive behaviors and low levels of adaptive functioning are present (Benedetti-Isaac *et al*., 2023; Herrera-Pino *et al*., 2024).

However, the comprehensive management of autism spectrum disorder (ASD) requires sustained, multidisciplinary interventions. Currently, non-pharmacological strategies are the cornerstone of treatment in children with ASD, including behavioral, educational, and psychotherapeutic approaches (Qiu *et al.,* 2023). Among the modalities with the strongest empirical support are early intensive behavioral interventions, such as Applied Behavior Analysis (ABA), and structured psychoeducational programs like the TEACCH model, which aim to enhance social, communication, and functional autonomy skills (Creem *et al*., 2023; Virues-Ortega *et al.,* 2022). Additionally, cognitive-behavioral therapies have shown evidence of effectiveness in children with ASD, particularly those with higher intellectual functioning, in addressing co-occurring emotional issues (e.g., anxiety, irritability) and in promoting self-regulation and cognitive flexibility strategies (Sharma *et al*., 2021).

In recent years, interest has steadily increased in interventions designed to enhance the foundational cognitive functions affected in ASD (Petrolo *et al.,* 2025). Specifically, executive function training has been explored as a therapeutic complement, with the goal of enhancing self-regulation and, ultimately, promoting greater independence in daily life (Liang *et al.,* 2022; Acero-Ferrero y Escolano-Pérez, 2024). Various studies have evaluated cognitive training programs, many of delivered via computerized platforms or "serious" video games, focusing on enhancing domains such as working memory, attentional processes, and mental flexibility in children on the autism spectrum (DiPietro *et al.,* 2019; Luz *et al.,* 2024; Malpartida y Rodrigues, 2025). Results in this area have been promising. It has been documented that some digital interventions with playful components (including exergames or active video games) produce significant improvements in inhibitory control, task-switching ability, and other executive function domains in young individuals with ASD (Doulou *et al*., 2025; Husna *et al*., 2025).

A recent review of the literature (Cavalli *et al.,* 2022), examined interventions aimed at improving executive functioning in people diagnosed with ASD, found that among the most frequently applied strategies are computerized cognitive training and cognitive-behavioral therapies. Overall, these interventions were found to yield positive effects on working memory performance, mental flexibility, and the reduction of associated behavioral problems. These findings suggest that cognitive-behavioral interventions and digital training programs can complement traditional therapies by addressing specific neuropsychological deficits in ASD that purely environmental behavioral approaches may not consistently modify.

In this context, technological cognitive training platforms have emerged as accessible tools for systematically exercising executive functions. A prominent example is Lumosity® (Lumos Lab, n.d.), a software that offers a library of over 40 interactive games based on cognitive tasks, covering domains such as memory, attention, cognitive flexibility, processing speed, and problem-solving (Lumos Lab, n.d.; Mam Khezri y Mikaeli Manieh, 2021). The program, available via web and mobile applications, dynamically adjusts task difficulty based on the user's performance and provides feedback through composite indices (such as the Lumosity Performance Index), which allow users to monitor their progress

across the various trained areas (Lumos Lab, n.d.).

The rationale for using platforms and software such as Lumosity® in children with ASD is grounded in the principles of brain neuroplasticity. Repetitive, graded, and targeted practice of specific cognitive skills has the potential to strengthen the neural circuits involved in these functions, which could lead to sustained improvements in executive performance. From an empirical standpoint, preliminary evidence supports the benefits of Computer-based cognitive training programs for children and teens with neurodevelopmental disorders (Robb *et al*., 2018; Badillo-Jiménez y Iguarán-Jiménez, 2020; Pasqualotto et al., 2021). In particular, similar multidomain interventions have shown positive effects on working memory, cognitive flexibility, and adaptive behavior in children with ASD and other diagnoses, compared to non-intervention groups (Corti *et al*., 2023).

Additionally, the digital and game-based format of Lumosity® may be particularly advantageous for children with ASD, as many of them exhibit a natural affinity for electronic devices and respond positively to structured and predictable learning environments (Marques y Nunes, 2025). This suggests that adherence to a game-based training program may be high in this population, maximizing practice opportunities. Although commercial platforms like Lumosity® have been evaluated in various contexts (Shute *et al*., 2015; Bainbridge y Mayer, 2018; Mam Khezri y Mikaeli Manieh, 2021; Cerra Rúa *et al.,* 2024; Ershadi Chahardeh *et al.,* 2024), their specific application in children with ASD has been scarcely explored and still requires stronger empirical support. Therefore, the present study seeks to assess the impact of a cognitive training program using Lumosity® on key executive domains such as working memory, inhibitory control, and planning in children with ASD, with the expectation that this intervention may support improvements in their everyday functioning and overall quality of life.

METHODOLOGY

A quasi-experimental design was employed, involving assessments both before and after the intervention in two groups of children diagnosed with autism. The design included an experimental group (EG), which received a computerized cognitive training program using the Lumosity® platform, and a control group (CG), which received a traditional psychoeducational intervention based on cognitive-behavioral strategies. The intervention lasted for 16 consecutive weeks, with weekly 30-minute sessions conducted under equivalent conditions for both groups.

Participants

The sample consisted of 47 children (six girls and 41 boys) aged between six and 12 years (M = 8.9; SD = 1.6), all with a confirmed clinical diagnosis of autism spectrum disorder, classified as Level 1 severity according to DSM-5 criteria. This classification corresponds to children who require support but do not present significant impairments in language or intellectual functioning. All participants were enrolled in urban schools (either public or government-subsidized) located in the municipality of Osorno, Los Lagos Region, Chile, and were part of School Integration Programs (PIE). Adaptive functioning was assessed using instruments regularly applied in PIE contexts, primarily the Inventory for Client and Agency Planning (ICAP), which was available for all cases. Cognitive performance was measured using the Wechsler Intelligence Scale for Children – Fifth Edition (WISC-V).

Two parallel groups were formed, comparable in size and clinical characteristics: the experimental group (EG), with 24 children, and the control group (CG), with 23 children. Participant selection was conducted through non-probabilistic convenience sampling, applying the following inclusion criteria: clinical

diagnosis of Level 1 ASD, age between six and 12 years, active enrollment in an urban school participating in a PIE program, IQ within the normal range, no history of grade repetition, no visual or auditory impairments, attendance of at least 90% of intervention sessions, and signed informed consent from parents or legal guardians. Children with severe intellectual disability, uncontrolled neurological comorbidities, or repeated absences were excluded.

Instruments

For the pre- and post-intervention assessment of executive functions, two standardized instruments validated in Spanish-speaking pediatric populations were used, both with empirical support in the Chilean context: WISC-V and the Neuropsychological Evaluation of Executive Functions in Children (ENFEN).

The Wechsler Intelligence Scale for Children, Fifth Edition (Wechsler, 2014), is one of the most widely used psychometric instruments for assessing overall cognitive performance in children aged 6 to 16 years. In the present study, the following subtests were administered: for working memory, Digit Span (DS); Picture Span (PS); and Letter-Number Sequencing (LNS); and for processing speed, Coding (COD); Symbol Search (SS), and Cancellation (CAN).

The Chilean version of the version of the WISC-V was standardized by Pearson Chile (2018) in a nationally representative sample. Reported psychometric properties include Cronbach's alpha coefficients ranging from 0.88 to 0.96 for composite scores, and test–retest reliabilities between 0.84 and 0.94, supporting both internal consistency and temporal stability. Additionally, the instrument demonstrates strong convergent validity with earlier editions and other established cognitive assessment tools (Rosas *et al.,* 2022).

Additionally, the Neuropsychological Evaluation of Executive Functions in Children (Portellano *et al*., 2009) was used to assess specific executive function domains in participants aged six to 12 years. The subtests administered focused on inhibitory control: Gray Paths (GP), Colored Paths (CP), and the Interference Index (INT), and planning, through the Ring Test (RT). Although the ENFEN has been applied in clinical and educational contexts throughout Latin America, only one formal validation study has been published in the region, conducted in Colombia.

That study reported adequate factorial validity and provided normative data stratified by age and geographic area (urban/rural), though it did not include internal consistency metrics (e.g., Cronbach's alpha) or clinical group comparisons. Despite these limitations, the ENFEN remains widely used as a reference tool for evaluating executive functioning in children. Its factorial structure has been replicated in various Latin American samples, reinforcing its utility in both clinical assessments and educational settings. These factors highlight the importance of further validation studies in diverse sociocultural contexts. Both instruments were administered by trained psychologists in controlled environments, following standardized administration protocols rigorously.

Procedure

The intervention was implemented in two modalities: a computerized cognitive training program for the experimental group (EG) using the Lumosity® platform, and a traditional psychoeducational program for the control group (CG). Both programs were conducted over 16 consecutive weeks (from September to December 2023), with two individual sessions per week, totaling 32 sessions per participant. Each

session lasted approximately 30 minutes, amounting to around 16 hours of intervention per child. Activities were carried out individually in designated educational spaces provided by each school, characterized by a quiet environment, adequate lighting, and minimal distractions. These standardized conditions ensured the quality and consistency in the delivery of both the digital training and the psychoeducational intervention.

In the experimental group (EG), a preparatory session ("Session 0") was conducted prior to the start of the regular training program to familiarize participants with the Lumosity® platform. During this initial session, an interactive tutorial introduced the children to the basic use of the software, followed by the administration of a built-in initial level test. This diagnostic assessment established a baseline of each child's cognitive performance, identifying strengths and weaknesses in domains such as working memory, inhibitory control, and planning. Based on these results, the system generated a personalized set of exercises tailored to the specific cognitive profile of each participant.

In the following sessions, the platform automatically adjusted the difficulty based on each child's performance, gradually increasing task complexity as progress was observed. Each session followed a standardized protocol: a welcome, explanation of instructions, a brief practice if needed, task execution, and final feedback. During the exercises, the software provided immediate feedback (both visual and auditory), along with a performance score, which helped maintain motivation. Additionally, it automatically recorded accuracy and response time, allowing for continuous monitoring of the child's progress.

The Lumosity® program included specific games targeting each executive function. Working memory was stimulated through visuospatial tasks such as "Memory Hotel" and "Memory Matrix"; inhibitory control was trained with Stroop-like games such as "Color Comparison" and "Star Connect"; and planning was addressed with sequencing exercises like "Garden Order" and "Electric Logic." Additional tasks were incorporated to enhance sustained attention and processing speed. All games featured an engaging, playful interface designed to maintain motivation without causing sensory overload.

The psychoeducational intervention delivered to the control group (CG) was structured in parallel with the experimental group's (EG) training, matching the number, duration, and intensity of sessions to ensure equivalent conditions. The content of the CG sessions focused on traditional neuropsychological exercises using concrete materials (e.g., pencil, paper, tokens), aimed at enhancing working memory, attention, inhibitory control, and planning, based on each child's individual needs. Cognitive-behavioral strategies and evidence-based rehabilitation techniques were applied, including the reinforcement of adaptive behaviors, modeling of appropriate actions, self-instruction training, and, in specific cases, procedures such as systematic desensitization to reduce task-related anxiety.

The sessions followed a standardized protocol analogous to that of the experimental group (EG), beginning with a greeting and explanation of the day's activity, followed by task execution under professional supervision tailored to each child's needs, and concluding with verbal feedback and a positive closing. All activities were carried out in quiet settings with proper lighting and minimal distractions, fostering the child's concentration. In both groups, strict attendance monitoring was implemented, allowing a maximum of 10% absences from the total scheduled sessions. Participants exceeding this threshold were excluded from the final analysis, thus ensuring the internal validity of the results.

Statistical analysis

Descriptive analyses were performed to describe the characteristics of the sample and assess baseline group equivalence. To evaluate differences between pre- and post-intervention measures, Student's t tests were applied to both independent and paired samples, with statistical significance established at $p < 0.05$. Moreover, effect sizes were estimated using Cohen's d, with interpretation based on conventional benchmarks: small ($d \geq 0.20$), moderate ($d \geq 0.50$), and large ($d \geq 0.80$). All analyses were conducted using SPSS software, version 25.0.

Ethical Considerations

This study received approval from the Scientific Ethics Committee of Los Ríos Health Service (Resolution No. 370, dated 08/04/2023) and by the Ethics Committee of Universidad Internacional Iberoamericana de México (Resolution No. CR-194, dated 04/28/2023). All procedures were conducted in compliance with the ethical standards established in the Declaration of Helsinki. Informed consent was formally obtained from the parents or legal guardians of each participant, and the confidentiality of the collected data, along with the protection of the children's welfare, was maintained throughout the research process.

RESULTS

Table 1 displays the sociodemographic, educational, and clinical profiles of the 47 participants, categorized by experimental group (EG; n = 24) and control group (CG; n = 23). No statistically significant differences were identified between the groups for any of the variables analyzed, confirming adequate baseline homogeneity and reinforcing the internal validity of the quasi-experimental design.

The experimental and control groups were comparable in key sociodemographic variables such as sex, age, and educational level, with no statistically significant differences observed. Similarly, no relevant differences were found in intellectual level or in the type of educational institution attended, reinforcing the baseline equivalence between both samples. Additionally, no significant differences were identified between groups in terms of duration of enrollment in the School Integration Program (PIE) or the types of professional services received.

Regarding the primary caregiver, 100% of the participants in the experimental group (EG) were under the care of their mother, while in the control group (CG), 22 participants were represented by their mother and one by their father. In terms of medical comorbidities, 25% of the children in the EG had no comorbidities, whereas this proportion was 17.5% in the CG. The distribution of the number of comorbidities (one, two, or three associated conditions) was similar across both groups.

Taken together, these data indicate adequate baseline equivalence between conditions, which strengthens the internal validity of the quasi-experimental design by minimizing the risk of bias due to initial group differences.

Table 1. Sociodemographic, educational, and clinical information of the participants.

Variables		EG	CG	*t*	*p/ X²*
		M/SD/F/%	M/SD/F/%		
No		24	23		
Sex	Girls	4	2	1.54	0.000
	Boys	20	21		

Age		8.75 ± 1.97	8.73 ± 1.83	0.38	0.78
Education	Level	4	4	1.05	0.923
Intellectual level	IQ	97.48 ± 5.75	97.81 ± 6.04	0.94	0.871
Educational system	Public School	10/41.66%	7/30.43%		
	Subsidized Private	14/ 58.34%	16/69.57		
Time in PIE Program	In years	2.75 ± 1.45	2.34 ± 1.26		
Professional services	Ps	13/54.2%	8/30.8%		
	Ps+ST	6/25%	5/21.7%		
	Ps+ST+OT	5/20.8%	12/52.2%		
Caregiver	Mother	24	22		
	Father		1		
Comorbidities	0	6/25	4/17.5		
	1	8/33.4	11/47.8		
	2	8/33.4	5/21.7		
	3	2/8.32	3/13		

ME: Mean. **SD**: Standard Deviation. **F**: Frequency. **IQ**: Intelligence Quotient. **Ps**: Psychological care. **ST**: Speech therapy. **OT**: Occupational therapy. *t*: Student's t-test. χ^2: Chi-square test. **p**: Significance value for data analysis. Significant when $p < 0.005$.

Table 2 presents the results of the comparative analysis between participants in the experimental group (EG; n = 24) and those in the control group (CG; n = 23) in the pre-intervention assessment of executive functions, based on subscales from the WISC-V and ENFEN instruments.

No statistically significant differences were found between the experimental and control groups on the working memory subtests—Digit Span (DS), Picture Span (PS), and Letter-Number Sequencing (LNS)—with all p-values exceeding 0.05. Likewise, performance on planning tasks (Gray Paths, Colored Paths, and Ring Test) and inhibitory control measures (CP, GP, and Interference Index) showed no group differences ($p > 0.20$ for all tests).

The only statistically significant difference between the groups at the beginning of the study was observed in the Coding subtest of the WISC-V Processing Speed Index, where the control group outperformed the experimental group. This finding indicates a slight initial advantage for the control group in that specific cognitive subdomain. Overall, the data indicate that both groups exhibited comparable levels in most executive functions prior to the intervention, supporting the homogeneity of initial conditions and allowing the effects observed afterward to be attributed to the applied interventions, particularly in the trained executive domains.

Table 2. Between-Group Comparisons, Pre-Intervention, in Executive Functions.

Test	Indices	Subscale	EG Lumosity®		CG Psychoeducational		t	*p*
			M	SD	M	SD		
WISC-V	Working memory	**DS**	6.12	1.87	5.73	2.45	067	0.51
		PS	6.33	1.40	5.95	2.49	0.68	0.50
		LNS	6.08	1.52	5.26	2.28	1.52	0.14
	Processing speed	**COD**	4.87	1.45	6.13	2.15	-2.38	0.02*
		SS	5	1.58	5.52	2.33	-0.93	0.36
		CAN	3.83	1.92	4.56	2.40	-1.19	0.24
	Planning	**GP**	3.16	1.90	3	1.50	0.33	0.74
		CP	2.37	1.49	2.65	1.22	-0.74	0.46

ENFEN		**RT**	1.91	1.01	2.30	1.14	-1.31	0.20
	Inhibitory control	**GP**	3.16	1.90	3.00	1.50	0.33	0.74
		CP	2.37	1.49	2.65	1.22	-0.74	0.46
		INT	2.62	1.71	2.43	1.47	0.42	0.68

P: less than 0.05. EG: Experimental Group; **CG:** Control Group; **M:** Mean; **SD:** Standard Deviation; **DS:** Digit Span; **PS:** Picture Span; **LNS:** Letter-Number Sequencing; **COD:** Coding; **SS:** Symbol Search; **CAN:** Cancellation; **GP:** Gray Paths; **CP:** Colored Paths; **RT:** Ring Test; **INT:** Interference Index.

Finally, post-intervention comparisons (see Table 3) revealed significant improvements in the WISC-V working memory index in favor of the experimental group. Differences were evident across all three subtests comprising this index, with effect sizes ranging from moderate to large, suggesting a substantial gain in this executive function following the computerized training program.

Regarding processing speed, statistically significant differences were found only in the Cancellation subtest, favoring the experimental group, with a moderate-to-large effect size. The Coding and Symbol Search subtests did not show significant differences, although a positive trend was observed in the experimental group.

Regarding performance on the ENFEN battery, significant improvements were observed in all three planning indicators in favor of the experimental group. All tests (Gray Paths, Colored Paths, and Ring Test) yielded statistically significant results with large effect sizes, suggesting a positive and consistent impact of the cognitive training on this executive function.

Regarding inhibitory control, highly significant differences were also observed in all three ENFEN subtests. In Gray Paths (GP) and Colored Paths (CP), t-values of 5.33 ($p = 0.000$; $d = 1.59$) and 3.24 ($p = 0.002$; $d = 0.98$) were recorded, respectively. In the Interference Index (INT), the experimental group achieved a mean score of 8.83 (SD = 2.25), compared to 3.95 (SD = 1.06) in the control group, with a highly significant difference ($t = 9.47$; $p = 0.000$) and a very large effect size ($d = 2.78$), the highest observed in the study.

Overall, these results demonstrate significant improvements across all evaluated executive functions in the experimental group, with large effects particularly in inhibitory control and planning.

Table 3. Between-Group comparisons, post-intervention.

TEST	**Indices**	**Sub-Test**	**EG Lumosity®**		**CG Psychoeducational**		**t**	***p***	**Cohen's *d***
			M	**SD**	**M**	**SD**			
WISC-V	Working memory	**DS**	8.16	1.92	7.0	2.08	2.05	0.045	0.58
		PS	7.91	1.28	6.91	2.15	2.01	0.041	0.59
		LNS	8.07	1.21	6.30	1.82	3.89	0.000	1.25
	Processing speed	**COD**	7.20	1.06	6.60	1.80	1.45	0.154	0.41
		SS	6.92	1.38	6.13	1.84	1.72	0.09	0.49
		CAN	6.79	1.64	5.26	2.28	2.70	0.010	0.79
ENFEN	Planning	**GP**	6.70	1.39	4.69	1.22	5.33	0.000	1.59
		CP	5.66	2.05	4.13	0.96	3.24	0.002	0.98
		RT	5.87	1.77	4.30	1.06	3.67	0.001	1.09
	Inhibitory control	**GP**	6.70	1.39	4.69	1.22	5.33	0.000	1.59
		CP	5.66	2.05	4.13	0.96	3.24	0.002	0.98

		INT	8.83	2.25	3.95	1.06	9.47	0.000	2.78

Cohen's d: Effect size. Identified according to the methodological proposal by Thalheimer y Cook (2002).
The numerical interpretation is: small effect (0.15–0.40), medium effect (0.40–0.75), and large effect (+0.75).
EG: Experimental Group; **CG:** Control Group; **M:** Mean; **SD:** Standard Deviation; **DS:** Digit Span; **PS:** Picture Span; **LNS:** Letter-Number Sequencing; **COD:** Coding; **SS:** Symbol Search; **CAN:** Cancellation; **GP:** Gray Paths; **CP:** Colored Paths; **RT:** Ring Test; **INT:** Interference Index.

Figure 1 illustrates the between-group comparison of average executive function scores before and after the intervention, highlighting the performance of the experimental group (EG), which received cognitive training through Lumosity® software tasks, and the control group (CG), which underwent a conventional psychoeducational intervention. The pre- and post-test means are presented for the domains of working memory, processing speed, inhibitory control, and planning. The dark blue bars represent scores obtained in the pre-intervention assessment (Pre-Test), while the light blue bars reflect scores after the intervention (Post-Test).

The graphical results show a notable increase in the experimental group's scores across all evaluated executive functions, particularly in inhibitory control and planning, where post-intervention improvements were more pronounced compared to the control group. This pattern is consistent with the statistical analyses presented in Tables 2 and 3, which showed significant post-intervention differences in favor of the Lumosity group, with large effect sizes in most subtests. In contrast, the control group maintained a relatively stable pattern between the initial and final assessments, with slight increases that did not reach statistical significance in most of the evaluated domains, reinforcing the specific impact of the computerized cognitive training.

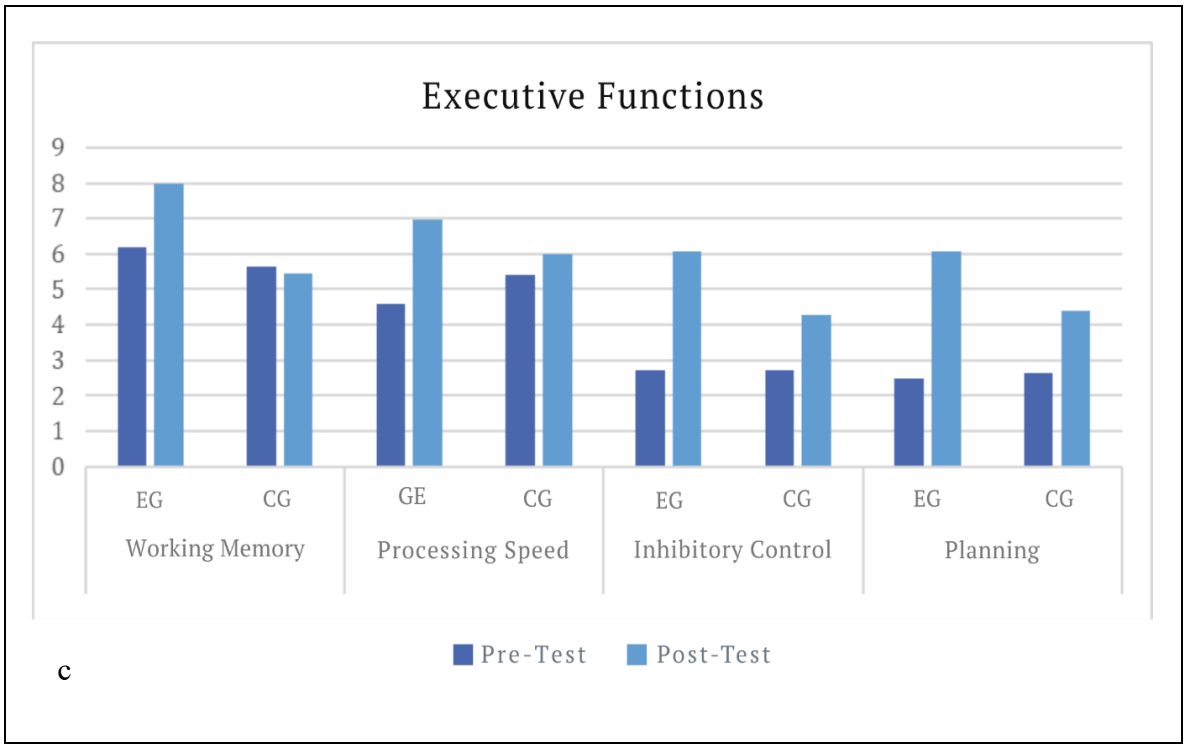


Figure 1. Pre- and Post-Intervention comparison of executive function indices.

DISCUSSION

The current investigation assessed the impact of a computerized cognitive training program on executive functions in children diagnosed with ASD. The results showed that the experimental group, trained with digital tasks, exhibited significant improvements in working memory, inhibitory control, and planning compared to the active control group. Moderate to large effect sizes were observed, particularly notable in inhibitory control (d = 2.78), planning (d = 1.09), and working memory (d = 0.58). These findings reinforce the idea that structured digital programs can be effective tools to enhance executive functions in children with ASD, complementing traditional approaches *(Marques y Nunes, 2025; Pasqualotto et al.,* 2021).

Regarding working memory, a moderate effect size was observed after the cognitive training (d = 0.6), aligning with previous research that supports the plasticity of this function through intensive intervention (Cao *et al.,* 2020; Delage *et al.,* 2022). Although the gains were smaller compared to other executive domains, they remain clinically meaningful, given the central role of working memory in following instructions, solving problems, and processing complex language. These results suggest that the structured tasks offered by Lumosity® were effective in promoting improvements in this area among children with ASD.

However, the relatively modest magnitude of change indicates that certain components of working memory may require longer or more targeted interventions to achieve comparable outcomes. In contrast, non-digital strategies such as physical activity have shown inconsistent effects on this domain in similar populations (Ji *et al*., 2022; Liang *et al*., 2022; Wu *et al*., 2024), further emphasizing the need for adapted and sustained approaches. Overall, the findings support the idea that structured digital cognitive training can strengthen working memory in children with ASD, an outcome of particular clinical relevance, as improved performance in this domain may lead to better academic achievement and communication skills (Calub *et al.,* 2022; Lim *et al*., 2023).

Significant improvements were observed in inhibitory control, with an exceptionally large effect size (d = 2.8) in the group trained with Lumosity®. This suggests a substantial impact on the ability of children with ASD to suppress impulsive responses and regulate their behavior, skills that are essential for emotional and behavioral self-regulation (Taylan y Çarşanbalı, 2025). These finding are consistent with previous studies demonstrating the efficacy of both digital interventions (Macoun *et al*., 2021) and exercise-based programs (Varigonda *et al*., 2020; Liang *et al.,* 2022) in enhancing inhibitory control in this population.

The magnitude of the observed effect suggests that computerized training, by requiring sustained attention and the inhibition of automatic responses, directly engages the neural mechanisms underlying inhibitory control, a function known for its high plasticity during childhood (Carriedo *et al.,* 2025; Lu *et al.,* 2025). From a clinical standpoint, enhancing this executive domain may not only reduce repetitive behaviors and cognitive interference commonly seen in ASD but also facilitate better school adjustment. These results highlight the potential of digital cognitive interventions to effectively address executive deficits that have historically been difficult to remediate.

Significant and substantial improvements were found in planning abilities within the experimental group (d = 1.1), reinforcing existing evidence that this higher-order executive function, essential for problem-solving, strategic thinking, and the execution of sequential tasks, can be enhanced through computerized training. Planning deficits are common in children with ASD and often compromise both academic performance and functional autonomy (Qian *et al*., 2025), making these results clinically meaningful.

While the present findings support the effectiveness of Lumosity®-based cognitive training in improving executive functions, they should be considered in light of studies reporting more modest outcomes with similar interventions. Some have found gains limited to memory, without significant changes in attention, language, or other executive processes (Kim y Lee, 2023), while others have observed no transfer to everyday memory or emotional regulation (Finn & McDonald, 2011). Effects are often small to moderate and restricted to tasks closely resembling the training, with no notable age-related differences (Ng *et al.,* 2021). These observations underscore the variability in outcomes and the need to better understand which mechanisms drive improvements in specific functions, such as inhibitory control, where particularly robust effects have been found.

Our findings align with previous interventions, such as the AIMS program (Tamm *et al*., 2024), which reported small to moderate gains in organizational skills using behavioral strategies. The larger effect observed in our study may be attributed to the structure of Lumosity® tasks, which engage sequencing, puzzle-solving, and strategic planning (Cerra Rúa *et al.,* 2024; Lumos Lab, n.d.). Furthermore, the motivational appeal of the gamified digital format may have sustained children's engagement in cognitively demanding activities, thereby strengthening their planning abilities. Given that impairments in this domain affect both academic and social functioning in ASD, these results suggest that, following intervention, children may be better prepared to manage everyday tasks requiring organization and exhibit increased cognitive flexibility in novel situations.

This study also offers relevant implications and methodological considerations. Overall, the findings support the integration of interactive digital programs as a complementary tool alongside traditional therapies for children with ASD. The improvements observed in both basic and higher-order executive functions in the Lumosity® group suggest that this form of computerized training can be effectively incorporated into neuropsychological rehabilitation plans to enhance daily cognitive functioning.

One notable aspect is the high level of engagement observed during the intervention. The gamified and motivating nature of Lumosity® likely contributed to strong adherence, minimizing the frustration commonly associated with repetitive cognitive tasks. These observations align with the growing body of literature highlighting the potential of digital tools to structure executive function interventions in ASD populations (Pasqualotto *et al*., 2021; Marques y Nunes, 2025), by combining intensive stimulation with a format that maintains user motivation and sustained participation.

From a clinical and educational standpoint, digital tools like Lumosity® could expand the range of available interventions for children with ASD by offering low-risk, scalable options that are adaptable to individual cognitive profiles and feasible across diverse settings. The improvements observed in standardized tasks suggest a near-transfer effect, as the targeted cognitive processes overlapped with those trained during the intervention (Cao *et al*., 2020).

However, achieving far transfer to untrained domains, such as functional communication or autonomy, remains a challenge. The literature highlights that such outcomes are unlikely without the integration of ecological strategies (Ferreira *et al.,* 2025). This underscores the importance of complementing digital interventions with real-world activities involving parents, teachers, and daily contexts.

Another key consideration concerns the sustainability of the gains. Recent studies (Shalev *et al.,* 2016; Scionti *et al.,* 2020) have reported partial declines in executive function performance following the discontinuation of virtual training. To address this, periodic reinforcement, through booster sessions or complementary physical activities that stimulate similar cognitive functions, is recommended to maintain

long-term benefits.

Regarding the study design, the inclusion of an active control group receiving a standard intervention added methodological rigor, as it allowed improvements to be attributed specifically to the Lumosity® training, rather than to nonspecific effects such as therapist attention or the passage of time. Nevertheless, due to the quasi-experimental nature of the design, the risk of undetected baseline differences or selection bias cannot be fully ruled out, despite the general comparability of the groups, except for a slight initial advantage in processing speed in the control group.

The absence of random assignment limits the strength of causal inferences. Future research should implement randomized controlled trials (RCTs) under stricter methodological conditions to confirm these findings. In addition, the use of blinded evaluators during post-intervention assessments is recommended to further reduce potential assessment bias.

Although this study employed standardized cognitive measures (WISC-V, ENFEN), it did not include ecological rating scales or indicators of functional adaptation, such as the BRIEF or parent/teacher behavior reports. Including such instruments would allow for a more precise evaluation of the transferability of cognitive gains to real-world functioning in children with ASD.

Limitations

This study presents several limitations that should be taken into account. First, the quasi-experimental design and the small sample size (n = 47) limit the generalizability of the findings. Although the groups were comparable at baseline and the improvements in the experimental group were clear, random assignment was not possible due to logistical constraints within the school institution. This methodological limitation requires the results to be interpreted with caution, as there remains a risk of selection bias.

Secondly, no longitudinal follow-up was conducted, so the duration of the observed effects remains unknown. Without ongoing reinforcement, it is possible that some of the gains in executive functions may diminish over time, as noted in previous studies (Huynh *et al*., 2025). Medium- and long-term assessments would be necessary to determine the actual sustainability of the observed benefits.

The absence of follow-up and randomization may have also influenced the observed results. Without tracking the persistence of improvements over time, it is uncertain whether the effects reflect temporary gains linked to the novelty or intensity of the intervention. Similarly, non-random group allocation increases the likelihood of selection bias, potentially affecting baseline equivalence or group responsiveness. While no major differences were found at baseline, except for a minor advantage in processing speed in the control group, caution is warranted in attributing causal relationships. Future studies should incorporate randomization and follow-up assessments to ensure stronger internal validity and determine the long-term ecological relevance of the findings.

Another relevant limitation is that outcome measures focused exclusively on formal cognitive tests (WISC-V, ENFEN), without including ecological scales or observer reports (e.g., from parents or teachers). This limits the ability to determine whether the improvements in memory, inhibition, and planning effectively translated into functional changes in the children's daily lives.

Moreover, the composition of the sample limits the extrapolation of the results. The study included only

children with level 1 ASD (high-functioning), without severe intellectual disability, and who were enrolled in school, which restricts the applicability of the findings to other subgroups within the spectrum. As noted in the literature, the feasibility of interventions largely depends on the level of adaptive functioning, with cognitive training being more viable in children who do not exhibit severe aggressive behaviors or profound deficits that interfere with the use of computerized platforms (Fernández-Menéndez *et al.,* 2022).

Finally, it is important to consider the ongoing debate between entertainment and effectiveness in gamified interventions. Although Lumosity® proved to be highly motivating in this study, some authors warn that overly playful programs may yield more modest improvements compared to more structured training approaches (Cao *et al*., 2020). Although this effect was not observed in our case, it remains an area that warrants future research in order to optimize the balance between user engagement and cognitive rigor.

Despite the significant outcomes observed in standardized cognitive measures, one notable limitation of this study is the absence of ecological assessments that could help determine whether the improvements in executive functions translated into meaningful changes in real-life contexts. Including functional rating scales—such as the BRIEF—or structured reports from parents and teachers would have provided valuable insight into whether the gains in working memory, inhibitory control, and planning were reflected in everyday behaviors at home or in school. This limitation constrains the ecological validity of the findings. Future research should consider integrating these types of complementary evaluations to better establish the practical relevance and generalizability of computerized cognitive training in children with ASD.

Taking these limitations into account, the results of this study indicate that a neuropsychological rehabilitation program based on computerized tasks (Lumosity®) can significantly improve executive functions in children with ASD. After training, participants showed greater ability to manipulate information, inhibit impulses, and plan actions compared to those who received a traditional intervention. These improvements, in addition to being statistically significant, have clinical relevance, as executive functions are essential for learning, self-regulation, and autonomy. For future research, it is recommended to conduct studies with larger samples and more rigorous designs—such as randomized controlled trials—to confirm the efficacy and replicability of this intervention and to explore its impact on different subpopulations within the spectrum.

It is also necessary to investigate the duration of the observed effects and the need for periodic reinforcement. Longitudinal studies could determine whether improvements in executive functions are sustained over time and how to consolidate them—for example, by integrating cognitive video games into therapeutic or school routines. Likewise, future research should evaluate functional outcomes beyond cognitive tests, incorporating measures of adaptation, quality of life, and ASD symptomatology to determine whether cognitive gains translate into meaningful changes in daily life. Finally, our findings support the development of hybrid interventions that combine digital, motor, and psychoeducational strategies, which would allow executive functions to be addressed from multiple approaches and promote the generalization of the gains achieved.

CONCLUSION

This study demonstrates that digital cognitive training, delivered through the Lumosity® platform, can significantly enhance executive functions in children with a clinical diagnosis of Level 1 ASD, particularly working memory, inhibitory control, and planning. The improvements observed following

the intervention reflect clinically relevant effects in core domains essential for self-regulation, learning, and functional adaptation. Moreover, the program's engaging and motivating structure fostered high adherence without compromising training rigor. These findings support the integration of digital tools as a complement to conventional therapies, offering an accessible and replicable alternative that combines advances in neuropsychology, educational technology, and inclusive care. Nevertheless, further research is needed to strengthen this evidence through controlled studies with larger sample sizes, longitudinal follow-up, and assessments in ecological contexts to determine the sustainability and real-world impact of such interventions on the daily lives of children with ASD.

DECLARATION REGARDING CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest. During the execution of the work and the writing of the article, no personal or external interests have influenced their actions, including misconduct or values that deviate from the usual and ethical standards of research.

AUTHORS' CONTRIBUTION

Andrea Nicol Caldichoury Obando: He contributed to the complete construction of the manuscript.
Klency González Hernández: Assisted in the review and analysis of data.

STATEMENT OF ARTIFICIAL INTELLIGENCE USE

The authors declare that they used artificial intelligence tools only to support the style review and preliminary drafting. The analysis, interpretation of the results, and final version of the manuscript were performed and approved by the authors.

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