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ORIGINAL ARTICLE

Transferability of an executive function intervention in children with cerebral palsy: A randomized controlled trial

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Abstract

Aim: To evaluate the transfer effects of a home-based computerized executive function intervention on non-targeted cognitive functions (visual perception and memory), quality of life (QoL), and participation in children with cerebral palsy (CP), and to determine whether any improvements were maintained 9 months after the intervention.

Method: Sixty children with CP (aged 8–12 years) were randomly allocated to the intervention (15 females/15 males, mean age 10 years 4 months [SD = 1 years 8 months], age range 8–12 years) or waitlist (control) (15 females/15 males, mean age 10 years [SD = 1 years 9 months], age range 8–12 years) group. The intervention group underwent a home-based executive function intervention programme for 30 minutes per day, 5 days a week, for 12 weeks. All participants were assessed before the intervention, immediately after and 9 months after the intervention was completed.

Results: After the intervention was completed, performance in immediate verbal memory, verbal learning, and visual perception (object and picture recognition) was significantly better in the intervention group than in the waitlist (control) group. No improvements were found in visual memory, visuospatial perception, QoL, or participation after the intervention. Scores at the follow-up showed that any beneficial effects were not maintained 9 months after the intervention was completed.

Interpretation: A home-based computerized executive function intervention produced transfer effects on memory and visual perception immediately after the intervention in children with CP, although any beneficial effects were not sustained at the 9-month follow-up.

Abbreviations: MACS, Manual Ability Classification System; NEPSY-II, Developmental NEuroPSYchological Assessment, Second Edition; QoL, quality of life.

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Cerebral palsy (CP) is the leading cause of physical disability in childhood, with an estimated prevalence of approximately 1.6 per 1000 live births.[1] CP refers to a group of permanent movement or posture development disorders due to brain injury during the antenatal, perinatal, or early postnatal period that persists throughout the lifespan. These motor symptoms are often accompanied by disturbances of sensation, communication, perception, behaviour, and cognition, and by epilepsy.[2]

Individuals with CP exhibit a heterogenous neuropsychological profile characterized by varying degrees of cognitive impairment, depending on CP type and severity.[3] Notably, mild-to-moderate impairments in executive function are common among individuals with CP.[4] Executive function consists of a set of interrelated mental skills that control, organize, and direct cognitive activity, emotional response, and behaviour to achieve specific goals.[5] Diamond's model distinguishes between three core executive functions: inhibitory control, working memory, and cognitive flexibility.[6] These core functions support higher-order executive functions, including planning, reasoning, and problem-solving.[6] Individuals with CP often show impairments in both core and higher-order executive functions.[7,8] Addressing impairments in executive function is particularly important in individuals with CP given their common occurrence as comorbidities. Beyond impairments in executive function, visual perception and memory skills are also significantly affected in the population with CP,[9] leading to difficulties in academic achievement and everyday motor skills.[10-12]

Given the cognitive impairments experienced by individuals with CP, it is crucial to explore the transfer effects of interventions on several cognitive functions in this population. Transfer refers to the generalization of the skills or knowledge learned in one specific context to a new or different context.[13] This transfer can occur in different ways, and it is common to differentiate between near-transfer and far-transfer effects.[13,14] Near-transfer effects refer to abilities learned in a specific context or domain that are transferred to a related or similar task or domain, whereas far-transfer effects involve applying knowledge or skills from one task or domain to a dissimilar or unrelated task or domain.[15,16] In the context of CP, achieving both near-transfer and far-transfer effects is crucial because of the widespread cognitive impairments observed in this population. Optimizing these transfer effects can help address a wide range of motor and non-motor impairments, making interventions more effective and resource-efficient.[17] Studies on transfer effects in children with CP can contribute to a greater understanding of brain development and neuropsychological rehabilitation in populations with neurodevelopmental disorders.

Recent research investigated the far-transfer effects of physical interventions on cognitive function in individuals with CP.[18] Despite the high heterogeneity in intervention characteristics, some beneficial effects were found. A dance intervention improved general cognitive function in adolescents and young adults with spastic CP.[19] Equine-assisted therapy produced improvements in a core executive function domain, specifically inhibitory control.[20] However, computerized physical interventions have not been shown to enhance visual perception.[21] The potential effects of physical interventions on memory skills in individuals with CP remain unexplored.

On the other hand, multimodal computerized interventions, combining physical and cognitive tasks, have demonstrated improvements in visual perception in individuals with unilateral spastic CP, although not directly targeted by these interventions.[22,23] Moreover, a study examining the impact of virtual reality on individuals with spastic CP found changes in executive function, specifically in the domain of reasoning.[22] Goals, Activity and Motor Enrichment therapy improved general cognitive function.[24] Despite these findings, to our knowledge, no study on individuals with CP has investigated the effects of multimodal interventions on memory skills.

While physical and multimodal interventions in CP have been extensively studied, cognitive interventions targeting executive function are less explored. To date, only two randomized controlled trials explored the impact of cognitive intervention in the population with CP, primarily focusing on children with bilateral spastic CP.[25,26] These studies revealed near-transfer effects on working memory and far-transfer effects on other core executive functions,[25,26] visual perception,[26] and language.[25] However, no significant changes were reported in learning and memory, in either the verbal or visual modalities.[25,26] Nevertheless, the potential of executive function interventions to enhance memory skills has been demonstrated in other paediatric populations.[27]

Given the crucial role of executive functioning in everyday life and the potential to induce a positive cascade effect on other cognitive functions, emphasizing interventions that specifically target these functions is imperative.[16] Executive functions are essential for completing tasks, adapting to new challenges, and pursuing goal-oriented activities effectively. Moreover, these functions significantly contribute to quality of life (QoL) and participation in activities of daily living for individuals with CP, being pivotal factors in evaluating the therapeutic effectiveness of interventions.[28-32]

Therefore, the main purpose of this study was to explore whether a home-based computerized executive function

What this paper adds

- A home-based computerized executive function intervention produced beneficial effects in children with cerebral palsy.
- Improvements in the domains of verbal memory and visual perception were observed after 12 weeks of executive function intervention.
- Quality of life and participation were not enhanced after the intervention.

intervention for children with CP would produce transfer effects on memory, visual perception, QoL, and participation. The second aim was to determine whether these transfer effects, if any, would be maintained 9 months after the intervention.

METHOD

Study design and procedure

The present study was a single-blind, randomized, waitlist-controlled trail. The design, implementation, and reporting of this study followed the CONSORT statement.[33] The protocol was registered at ClinicalTrials.gov (NCT04025749) and published.[34] Ethics approval was obtained from the University of Barcelona's Institutional Ethics Committee, Institutional Review Board (no. 00003099, assurance no. FWA00004225), and Sant Joan de Déu-Barcelona Children's Hospital Ethics Committee (no. PIC-45-20). The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from the participants' parents or legal guardians. The primary outcomes (near-transfer effects) of our study were published recently.[35]

Participants

Participants were recruited from the Sant Joan de Déu-Barcelona Children's Hospital, Vall d'Hebron University Hospital, and Fundació ASPACE Catalunya in Barcelona. Participants were also recruited from our project website and from a previous study.[36] The inclusion criteria were: (1) diagnosis of CP; (2) age between 8 years and 12 years; (3) classified in Manual Ability Classification System (MACS) levels I to III;[37] (4) ability to understand simple instructions as assessed by the Screening Test of Spanish Grammar;[38] (5) availability to participate in the study for a year; and (6) internet access at home. Exclusion criteria were severe or visual difficulties that precluded cognitive assessment and intervention.

Randomization

Participants were matched in pairs based on age bands (8 years–10 years 6 months and 10 years 7 months–12 years), sex, MACS level (I and II/III), and IQ (< 80 or ≥ 80). Intellectual functioning was measured using the non-verbal Raven's Coloured Progressive Matrices test.[39] Each paired participant was randomly allocated to one of two groups (intervention or waitlist [control]). Randomization was performed using an in-house programme written in R (R Foundation for Statistical Computing, Vienna, Austria). Participants were informed of their group allocation after baseline assessment. The researcher who conducted the neuropsychological assessment was blinded to the group status of participants until data collection was completed.

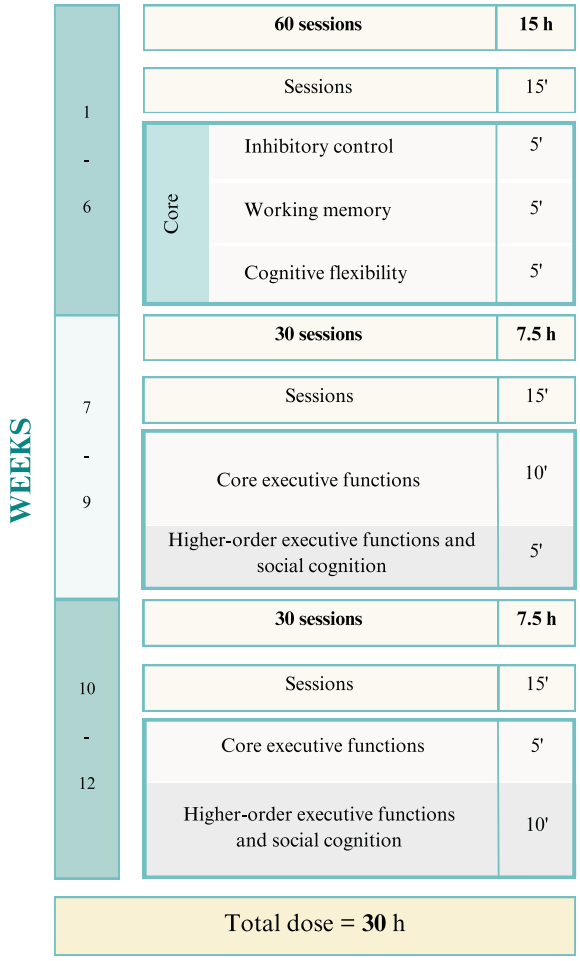

FIGURE 1 Structure of the intervention.

Intervention group

Participants randomized to the intervention group underwent a home-based computerized executive function intervention using NeuronUP (www.neuronup.com). The intervention was specifically created for this research project by carefully selecting the tasks. The executive intervention included core executive functions (inhibitory control, working memory, and cognitive flexibility), higher-order executive functioning (planning), and social cognition tasks (Figure 1). Two psychologists from the study team independently analysed the NeuronUP tasks and categorized them based on the main executive function domain targeted. Subsequently, tasks were meticulously selected to create sessions according to the domains to be worked on in each session. During the initial stages of training (weeks 1–6), each core executive function was included; higher-order and social cognition tasks were introduced in the seventh week (weeks 7–9). Higher-order and social cognition tasks increased in the last 3 weeks (weeks 10–12). Examples of the intervention tasks are shown in Figure 2. The tasks included both verbal and visual modalities. Verbal information was delivered orally. The difficulty level of each task was gradually adjusted

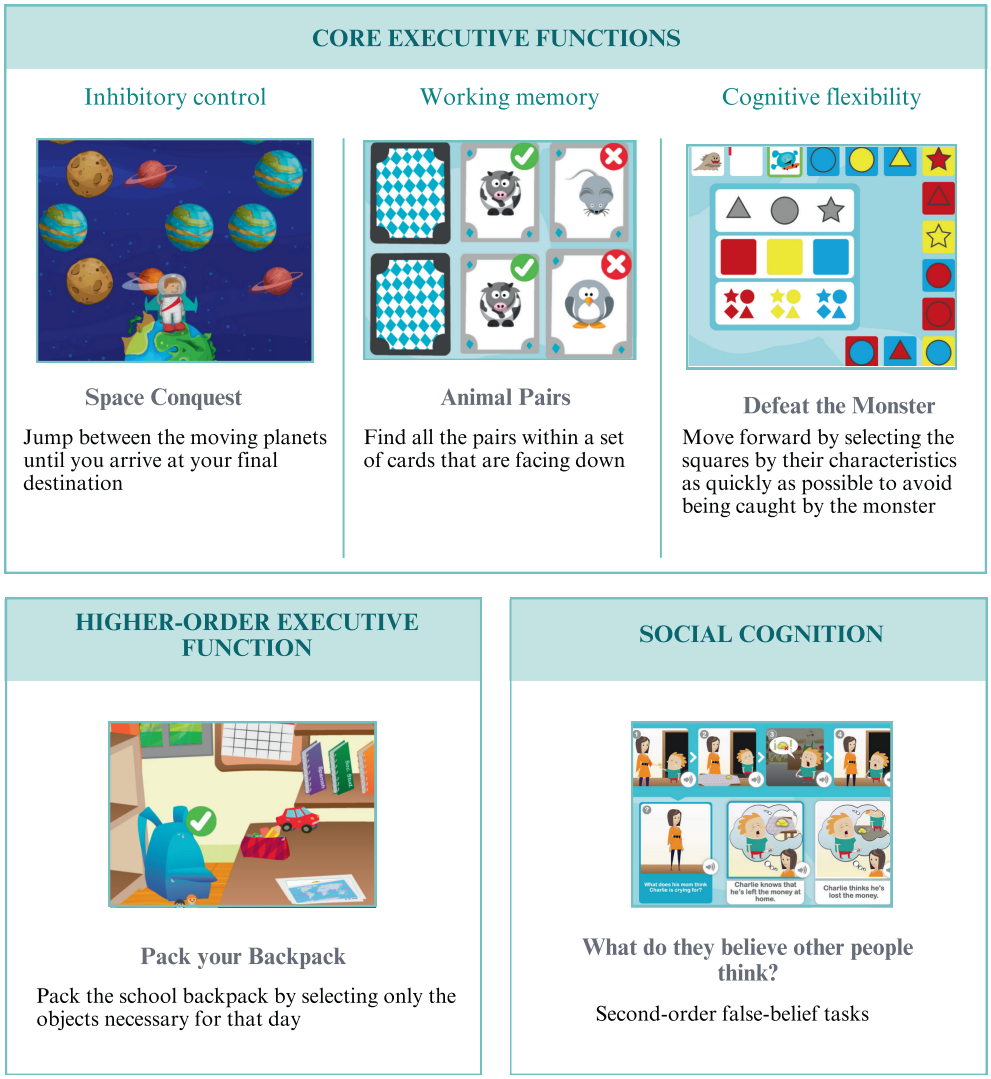

FIGURE 2 Example of NeuronUP tasks included in the intervention.

automatically by the programme depending on the child's level of performance during each session. The intervention consisted of 15 minutes per session and 10 sessions per week for 12 weeks. The total dose was 30 hours, including 20.6 hours of core executive functions and 9.4 hours of higher-order executive function and social cognition. Participants received the intervention via a computer using a mouse or touchscreen. Adherence was monitored by a health professional using website reports after each intervention session.

Several adherence strategies were implemented: (1) a personalized schedule was created according to the children's interests, including programme instructions, weekly sessions, and neuropsychological assessment appointments. Additionally, a space was provided to record the daily activities of the child; (2) participants and their families were given the option to choose within a week to complete the sessions; (3) tasks resembling video games were selected to make them more engaging; (4) personalized follow-up was conducted over the phone to highlight the positive aspects of the child's performance; and (5) participants were informed that on completion of the intervention, they would obtain a diploma.

Waitlist (control) group

The participants randomized to the waitlist (control) group maintained their usual care. The intervention was offered to the waitlist (control) group once participants had completed their standard care period in our study and after the follow-up (T2) assessment was completed.

Assessment

Clinical data

Clinical information was collected from clinical histories and interviews with parents. Gross motor function status

was assessed using the Gross Motor Function Classification System.[40] Apart from the MACS, manual ability was also measured using the Bimanual Fine Motor Function Scale.[41] Everyday communication ability was evaluated using the Communication Function Classification System.[42] Speech production was assessed using the Viking Speech Scale.[43] Other clinical data included motor CP type, distribution of motor impairment, gestational age, pain, and the presence of epilepsy.[44]

Neuropsychological assessment

A comprehensive neuropsychological assessment was carried out before the intervention (T0, baseline), immediately after the intervention finished (T1, after the intervention), and 9 months after the intervention (T2, follow-up). Standard paper-and-pen neuropsychological tests were used to assess memory and visual perception skills. Raw scores were converted to standardized scores (z-scores). Reliability was good across the different neuropsychological tests.[34]

Verbal and visual immediate memory skills were assessed using the Digit Forward Span from the Wechsler Intelligence Scale for Children, Fifth Edition[45] and the Spatial Forward Span from the Wechsler Non-Verbal Scale of Ability[46] respectively. Verbal learning and long-term memory skills were evaluated using the Word Selective Reminding of the Test of Memory and Learning.[47] Visual learning and long-term memory were assessed using the Memory for Designs from the Developmental NEuroPSYchological Assessment, Second Edition (NEPSY-II).[48] Regarding visuoperceptual dimensions,[49] object and picture recognition and visual-spatial perception were assessed using the Facial Recognition Test[50] and the Arrows subtest (NEPSY-II)[48] respectively.

QoL and assessment of participation

Proxy-reported questionnaires about QoL and participation were completed by the parents and caregivers at the same three time points as the neuropsychological assessment: baseline (T0), after the intervention (T1), and at the follow-up (T2). QoL was measured using the CP QoL-Child questionnaire.[51] The CP QoL total score was calculated by adding up the seven domains. Participation was assessed using the Participation and Environment Measure for Children and Youth questionnaire,[52] including the level of participation in the home, at school, and in the community.

Assessment of potential covariates

Variables that could influence the effectiveness of the intervention were considered as potential covariates: pain, autism spectrum disorder, psychological adjustment, family QoL, and parental stress. These variables were selected considering their influence on cognition and QoL in children with CP[53-56] and in other paediatric populations.[57-62] Physical pain was measured using the Bodily Pain and Discomfort Scale of the Child Health Questionnaire.[63] Autism spectrum disorder was assessed using the Autism Spectrum Screening Questionnaire.[64] Psychological adjustment was examined using the Strengths and Difficulties Questionnaire.[65] Family QoL and parental stress were measured using the Family Quality of Life Scale[66] and the Parental Stress Scale.[67]

Statistical analysis

SPSS v27 (IBM Corp., Armonk, NY, USA) was used for the statistical analysis. Graphs were generated with R (v4.2.2). Analysis of covariance (ANCOVA), with neuropsychology, QoL, and participation baseline scores (T0) as the covariates and group as the factor, was performed to assess group differences in performance gains right after finishing the intervention (T1) and 9 months after the intervention (T2). To ensure that the estimated effects of the executive intervention were fully independent of the effects of other variables, the characteristics of CP, pain, autism spectrum disorder, psychological adjustment, family QoL, and parental stress were considered as potential covariates. Bivariate correlations (Pearson, Spearman, and Kendall) were conducted and Bonferroni correction was applied ($p = 0.01$). Subsequently, only variables showing significant correlations after Bonferroni correction were included as covariates, along with baseline outcomes, in the ANCOVA analysis. The significance level was set at $p < 0.05$. The effect size for ANCOVA was assessed using partial eta squared η_p^2 considering effects as small (≥0.01), medium (≥0.06), and large (≥0.14).[68]

In addition to the per-protocol analysis, intention-to-treat analyses were performed with R (v4.2.2). The intention-to-treat analysis included participants with baseline measures for each outcome.[69,70]

RESULTS

Participants

Of the 63 participants who completed the baseline assessment, 60 were assessed after the intervention and at the follow-up (Figure S1). Thirty participants were included in the intervention group (15 females/15 males, mean age 10 years 4 months [SD = 1 years 8 months], age range 8–12 years) and 30 in the waitlist (control) (15 females/15 males, mean age 10 years [SD = 1 years 9 months], age range 8–12 years) group.

There were no significant group differences in terms of demographic and clinical characteristics (Table 1). The descriptive statistics for potential covariates are shown in Table 2. No significant group differences in potential covariates were found. Neuropsychological, QoL, and participation scores at T0, T1, and T2 are presented in Table S1.

TABLE 1 Descriptive statistics of the demographic and clinical data.

Characteristic	Intervention group ($n=30$)	Waitlist (control) group ($n=30$)
Age, years:months, mean (SD), range	10:4 (1:8), 8:1–12:11	10:0 (1:9), 8:0–12:11
Sex		
Female	15 (50.0)	15 (50.0)
Male	15 (50.0)	15 (50.0)
Gestational age, weeks		
Born extremely preterm (<28)	4 (13.3)	3 (10.0)
Born very preterm (28–31)	6 (20.0)	7 (23.3)
Born moderate-to-late preterm (32–36)	4 (13.3)	10 (33.3)
Born at term (≥37)	12 (40.1)	8 (26.7)
Unknown	4 (13.3)	2 (6.7)
Epilepsy[a]		
No epilepsy	24 (80.0)	18 (60.0)
Active epilepsy	6 (20.0)	12 (40.0)
Type of CP		
Spastic		
Unilateral	17 (56.7)	15 (50.0)
Bilateral	10 (33.3)	11 (36.7)
Dyskinetic		
Ataxic	3 (10.0)	2 (6.7)
Unknown	0 (0)	1 (3.3)
GMFCS level		
I	20 (66.7)	14 (46.7)
II	6 (20.0)	12 (40.0)
III	4 (13.3)	2 (6.7)
IV	0 (0)	2 (6.7)
MACS level		
I	11 (36.7)	14 (46.7)
II	16 (53.3)	13 (43.3)
III	3 (10)	3 (10)
BFMF level		
I	18 (60.0)	14 (46.7)
II	8 (26.7)	12 (40.0)
III	3 (10.0)	4 (6.7)
IV	1 (3.3)	0 (0)
CFCS level		
I	20 (66.7)	16 (53.3)
II	9 (30.0)	10 (33.3)
III	1 (3.3)	2 (6.7)
IV	0 (0)	2 (6.7)
VSS level		
I	26 (86.7)	18 (60.0)
II	3 (10.0)	9 (30.0)
III	1 (3.3)	3 (10.0)
IQ, mean (SD), range	100.42 (15.17), 75–125	95.88 (9.33), 75–110

Note: All data are presented as *n* (%) unless otherwise indicated.

Abbreviations: BFMF, Bimanual Fine Motor Function; CFCS, Communication Function Classification System; CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; MACS, Manual Ability Classification System; VSS, Viking Speech Scale.

[a]The International League Against Epilepsy criteria were used to determine epilepsy status.[44]

TABLE 2 Descriptive statistics of the potential covariates.

Covariate	Intervention group	Waitlist (control) group	Group differences	
			z/t	*p*
Pain frequency, *n* (%)				
Never	8 (26.7)	16 (29.1)	−1.71[a]	0.087
A few times	14 (46.7)	10 (18.2)		
Often	4 (13.3)	3 (5.4)		
Unknown	4 (13.3)	1 (1.8)		
ASSQ, median (range)	5 (0–36)	9 (0–25)	−0.30[b]	0.768
SDQ, mean (SD)	13.9 (6.2)	13.7 (5.2)	−0.16[c]	0.873
FQoL, mean (SD)	3.8 (0.7)	3.8 (0.6)	0.004[c]	0.997
PSS, median (range)	22 (13–43)	25 (17–45)	1.114[c]	0.270

Abbreviations: ASSQ, Autism Spectrum Screening Questionnaire; FQoL, Family Quality of Life Scale; PSS, Parental Stress Scale; SDQ, Strengths and Difficulties Questionnaire.

[a]χ^2 test.

[b]Mann–Whitney *U* test.

[c]Student's *t*-test for independent samples.

Regarding adherence to the intervention, the mean attendance and total dose were 114 sessions (106–120 sessions) and 28.35 hours (range: 26.30–30 hours) respectively. Hence, the mean rate of adherence for the completed sessions was 95%, ranging from 87% to 100%.

Group performance after the intervention and at the follow-up

Immediately after the intervention (T1) scores for each group and the ANCOVA results are presented in Table 3. The intervention group performed significantly better on immediate verbal memory (Digit Span Forward, Wechsler Intelligence Scale for Children, Fifth Edition) and verbal learning (Word Selective Reminding, Test of Memory and Learning) than the waitlist (control) group after the intervention, with large ($F=13.79$, $p\leq0.001$, $\eta_p^2=0.20$) and medium ($F=7.36$, $p=0.009$, $\eta_p^2=0.12$) effect sizes respectively. No significant verbal long-term memory (Word Selective Reminding Delayed, Test of Memory and Learning) differences were found between groups after the intervention. No significant differences between groups were found regarding visual memory. More specifically, no differences were found regarding immediate memory (Spatial Span Forward, Wechsler Non-Verbal Scale of Ability), and learning and long-term memory (Memory for Designs, NEPSY-II). Object and picture recognition (Facial Recognition Test) was significantly improved after the intervention, with a medium effect size ($F=4.14$, $p=0.047$, $\eta_p^2=0.07$). However, visuospatial

TABLE 3 Analysis of covariance comparing the intervention and waitlist (control) groups after the intervention.

Outcome	Intervention group	Waitlist (control) group	ANCOVA			After the intervention (T1)		
	Estimated marginal mean (SD)		Mean difference	95% LCI	95% UCI	*F*	*p*	η_p^2
Learning and memory								
Immediate memory								
Verbal: Digit Span Forward (WISC-V)	−0.53 (0.11)	−1.13 (0.12)	0.60	0.29	0.93	13.79	<0.001	0.20
Visual: Spatial Span Forward (WNV)	−0.79 (0.21)	−0.85 (0.21)	0.06	−0.55	0.66	0.04	0.853	<0.01
Learning								
Verbal: Word Selective Reminding (TOMAL)	0.32 (0.19)	−0.44 (0.20)	0.75	0.20	1.31	7.36	0.009	0.12
Visual: Memory for Designs (NEPSY-II)	−0.68 (0.19)	−0.87 (0.19)	0.19	−0.36	0.74	0.47	0.496	0.01
Long-term memory								
Verbal: Word Selective Reminding Delayed (TOMAL)	0.14 (0.12)	0.08 (0.13)	0.07	−0.29	0.43	0.15	0.697	<0.01
Visual: Memory for Designs Delayed (NEPSY-II)[a]	−0.89 (0.18)	−1.00 (0.18)	0.12	−0.39	0.64	0.23	0.634	0.01
Visual perception								
FRT	0.81 (0.24)	0.14 (0.24)	0.68	−0.11	−1.34	4.14	0.047	0.07
Arrows (NEPSY-II)	−0.95 (0.13)	−1.16 (0.13)	0.22	−0.17	0.60	1.26	0.267	0.02
QoL								
CP QoL[a–c]	73.77 (1.24)	70.97 (1.21)	2.79	−0.77	6.36	2.50	0.121	0.05
Participation								
Home (PEM-CY)[b,d]	5.76 (0.12)	5.59 (0.12)	0.17	−0.19	0.52	0.91	0.346	0.02
School (PEM-CY)	4.00 (0.24)	4.19 (0.24)	−0.18	−0.87	0.50	0.28	0.596	0.01
Community (PEM-CY)	2.96 (0.18)	2.76 (0.18)	0.20	−0.31	0.72	0.29	0.572	0.01

Abbreviations: ANCOVA, analysis of covariance; ASSQ, Autism Spectrum Screening Questionnaire; CP, cerebral palsy; CP QoL, CP Quality of Life ; FQOL, Family Quality of Life Scale; FRT, Facial Recognition Test; LCI, lower confidence interval; NEPSY-II, Developmental NEuroPSYchological Assessment, Second Edition; PEM-CY, Participation and Environment Measure for Children and Youth; PSS, Parental Stress Scale; SDQ, Strengths and Difficulties Questionnaire; TOMAL, Test of Memory and Learning; UCI, upper confidence interval; WISC-V, Wechsler Intelligence Scale for Children, Fifth Edition; WNV, Wechsler Non-Verbal Scale of Ability.

[a]ASSQ covariate.

[b]PSS covariate.

[c]SDQ covariate.

[d]FQOL covariate.

perception (Arrows, NEPSY-II) did not improve significantly. There were no after-intervention differences between groups for QoL (CP QoL-Child) and participation (Participation and Environment Measure for Children and Youth). Follow-up after intervention scores (T2) for each of the two groups and the ANCOVA results are presented in Table 4. No significant differences between the intervention and waitlist (control) groups were found for any of the outcomes. Tables S2 and S3 present the intention-to-treat analysis. Significant differences between groups in the intention-to-treat analysis were the same as the ones found in the ANCOVA analysis.

Graphical representation of results

Participants' performance is graphically presented in Figures 3–5. Estimated marginal differences between groups immediately after the intervention (T1) and at the 9-month follow-up (T2) are shown in the boxes. Estimated marginal differences are differences between the groups' estimated marginal means. Although differences between groups were not statistically significant in all neuropsychological outcomes at the 9-month follow-up after the intervention (T2), the intervention group showed higher performance than the waitlist (control) group (estimated marginal differences above zero). It is noteworthy that participation and QoL scores did not increase in the intervention group compared with the waitlist (control) group.

DISCUSSION

Children with CP who underwent a home-based computerized executive function intervention programme for

TABLE 4 Analysis of covariance comparing the intervention and waitlist (control) groups at the follow-up.

	Intervention group	Waitlist (control) group	ANCOVA			Follow-up intervention (T1)		
Outcome	Estimated marginal mean (SD)		Mean difference	95% LCI	95% UCI	*F*	*p*	η_p^2
Learning and memory								
Immediate memory								
Verbal: Digit Span Forward (WISC-V)	−0.52 (0.16)	−0.85 (0.16)	0.33	−0.13	0.79	2.11	0.152	0.04
Visual: Spatial Span Forward (WNV)	−0.78 (0.16)	−0.87 (0.16)	0.09	−0.36	0.53	0.15	0.699	<0.01
Learning								
Verbal: Word Selective Reminding (TOMAL)	0.38 (0.22)	0.35 (0.23)	0.03	−0.61	0.66	0.01	0.936	<0.01
Visual: Memory for Designs (NEPSY-II)	−0.32 (0.22)	−0.51 (0.22)	0.19	−0.44	0.82	0.38	0.540	0.01
Long-term memory								
Verbal: Word Selective Reminding Delayed (TOMAL)	0.51 (0.11)	0.33 (0.12)	0.18	−0.15	0.51	1.21	0.276	0.02
Visual: Memory for Designs Delayed (NEPSY-II)[a]	0.09 (0.27)	−0.76 (0.27)	0.67	−0.10	1.44	3.06	0.087	0.06
Visual perception								
FRT	0.76 (0.22)	0.29 (0.22)	0.47	−0.16	1.10	2.21	0.142	0.04
Arrows (NEPSY-II)	−1.01 (0.13)	−1.07 (0.14)	0.06	−0.33	0.45	0.10	0.759	<0.01
QoL								
CP QoL[a–c]	69.30 (1.60)	72.17 (1.56)	−2.87	−7.74	1.70	1.60	0.213	0.03
Participation								
Home (PEM-CY)[b,d]	5.57 (0.14)	5.57 (0.14)	0.05	−0.33	0.42	<0.01	0.974	<0.01
School (PEM-CY)	4.20 (0.20)	4.11 (0.20)	0.10	−0.47	0.67	0.12	0.730	<0.01
Community (PEM-CY)	2.48 (0.15)	2.65 (0.15)	−0.17	−0.60	0.26	0.66	0.422	0.01

Abbreviations: ANCOVA, analysis of covariance; ASSQ, Autism Spectrum Screening Questionnaire; CP, cerebral palsy; CP QoL, Cerebral Palsy Quality of Life; FQOL, Family Quality of Life Scale; FRT, Facial Recognition Test; LCI, lower confidence interval; NEPSY-II, Developmental NEuroPSYchological Assessment, Second Edition; PEM-CY, Participation and Environment Measure for Children and Youth; TOMAL, Test of Memory and Learning; UCI, upper confidence interval; WISC-V, Wechsler Intelligence Scale for Children, Fifth Edition; WNV, Wechsler Non-Verbal Scale of Ability.

[a]ASSQ covariate.

[b]PSS covariate.

[c]SDQ covariate.

[d]FQOL covariate.

12 weeks showed improvements in immediate verbal memory, verbal learning, and visual perception (specifically, object and picture recognition) skills immediately after the intervention (T1). However, this intervention did not enhance visual memory, visuospatial perception skills, QoL, or participation.

Our study, which consisted of an average total intervention duration of 28.35 hours and covered several executive function domains, yielded significant enhancements in immediate verbal memory and verbal learning. These findings align with previous research in other paediatric populations, where improvements in immediate verbal memory were observed after 18 hours of a working memory intervention.[27] In contrast, previous studies on children with CP did not report enhancements in verbal memory after 8 to 18 hours of a working memory intervention.[25] These results suggest that the observed improvements may be attributed to the total dose of the working memory intervention administered. It is important to note that these enhancements in verbal memory can be attributed to the intricate relationship between memory and executive functions, particularly working memory.[71,72] Working memory and immediate memory are two different cognitive functions that are often erroneously used interchangeably. While working memory is a cognitive system that temporarily holds and manipulates information for cognitive tasks, immediate memory refers to the ability to store and retrieve information within seconds.[73] The fact that both cognitive functions are closely interrelated leads

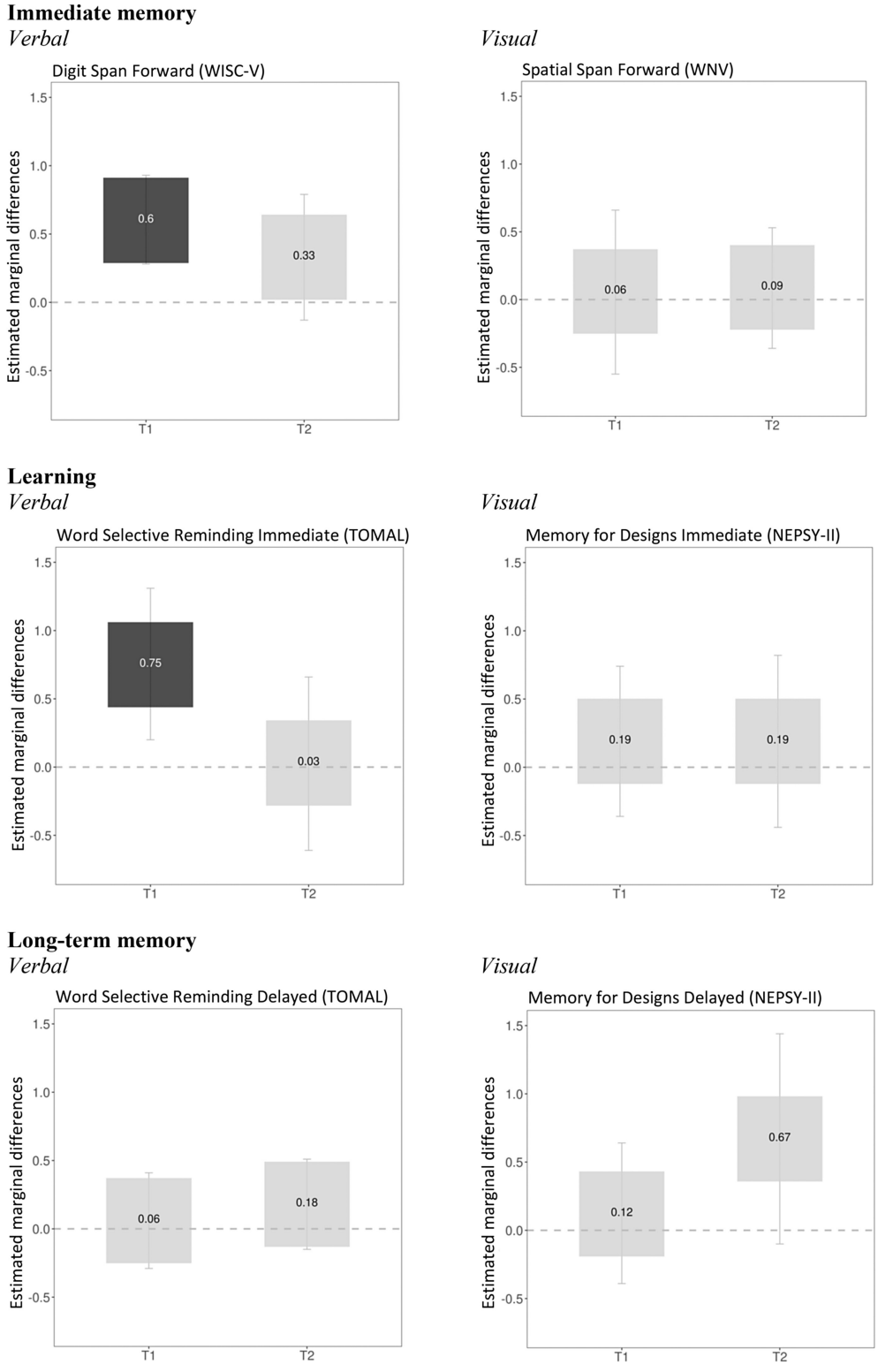

FIGURE 3 Differences between intervention and waitlist groups in learning and memory. Estimated marginal differences are the intervention group estimated marginal mean minus the waitlist group estimated marginal mean; dark grey-coloured box, significant differences; grey-coloured box, non-significant differences. Estimated marginal differences above zero indicate better performance in the intervention group than in the waitlist group. Abbreviations: NEPSY-II, Developmental NEuroPSYchological Assessment, Second Edition; TOMAL, Test of Memory and Learning; WISC-V, Wechsler Intelligence Scale for Children, Fifth Edition; WNV, Wechsler Non-Verbal Scale of Ability.

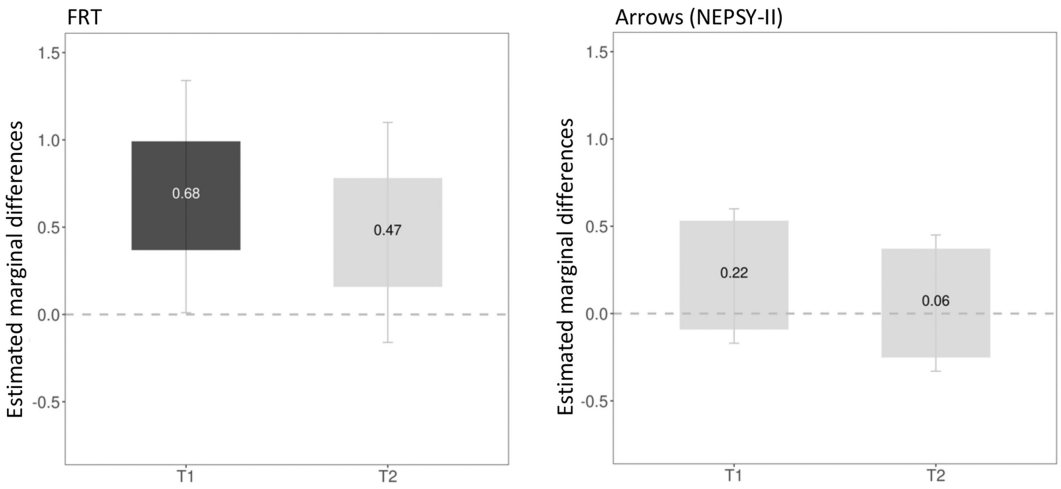

FIGURE 4 Differences between intervention and waitlist groups in visual perception. Estimated marginal differences are the intervention group estimated marginal mean minus the waitlist group estimated marginal mean; dark grey-coloured box, significant differences; grey-coloured box, non-significant differences. Estimated marginal differences above zero indicate better performance in the intervention group than in the waitlist group. Abbreviations: FRT, Facial Recognition Test; NEPSY-II, Developmental NEuroPSYchological Assessment, Second Edition.

us to believe that the effects obtained are between the near-transfer and far-transfer effects. Hence, the improvements observed in immediate memory may represent intermediate-transfer effects, as described by others.[74]

Nevertheless, some authors consider the Digit Span Forward (Wechsler Intelligence Scale for Children, Fifth Edition) as a measure of working memory; the improvements observed in this measure could be interpreted as near-transfer effects.[75]

However, no changes in long-term memory were observed. Long-term memory is a complex and gradual process that requires considerable time to produce improvements.[76] Previous research established that working memory has a crucial role in the formation of long-term memories, despite involving distinct cognitive functions.[76,77] Further research should investigate whether longer interventions with higher doses can lead to better long-term memory performance. Likewise, no improvements in visual memory were evident. Consistent with our findings, previous research in CP did not report improvements in learning and long-term visual memory, as assessed using the Memory for Designs subtest of the NEPSY-II.[25,26] Furthermore, the lack of significant changes in visual memory observed in our study and by others may stem from limitations in the assessment tools used, which may not be sufficiently sensitive to detect subtle improvements in visual memory after an intervention. Additional research using more comprehensive and sensitive measures of visual memory may be necessary to better understand the impact of interventions targeting executive functions in this cognitive domain.

The improvements found in visual perception are consistent with previous studies reporting far-transfer effects in this cognitive function after cognitive and multimodal computerized interventions in children with CP.[22,23] The findings of this study indicate that interventions, including cognitive tasks delivered via a computerized programme, improve some components of object and picture recognition, such as face processing, in children with CP. Previous research associated facial recognition with a specific domain of QoL in children with CP.[29] This fact, together with the high prevalence of visual perception impairments in CP,[78] highlights the importance of targeting visual perception in interventions for individuals with CP.

Our research did not find any enhancements in the visuospatial perception domain. These results align with the findings by Di Lieto et al.,[26] who showed that an executive function intervention with a lower intervention dose did not lead to changes in the Arrows subtest either (NEPSY-II).

Research in the field of CP suggests that a weekly computerized intervention programme is necessary to achieve far-transfer effects in specific domains of visual perception, such as object and picture recognition. Although there is a wide variety of visuoperceptual functioning in children,[49] assessment in intervention research has been mainly limited to specific domains (e.g. the object and picture recognition or visuospatial perception domains).[22,26] This could hinder the identification of a global perspective of improvement based on children's visual perception profiles. Consequently, further studies should include an extensive visual perception battery to determine which specific dimensions are improved by interventions for children with CP.

Visual perception and verbal memory improvements were not maintained 9 months after the intervention finished. A previous study on near-transfer effects showed long-term effects on executive functions 9 months after the intervention.[35] This reinforces the notion that near-transfer effects occur frequently, but that far-transfer effects are modest.[79] It would be interesting to explore whether a booster intervention could help maintain far transfer effects in these specific cognitive functions. Booster interventions in cognitive programmes have scarcely been investigated, but some studies

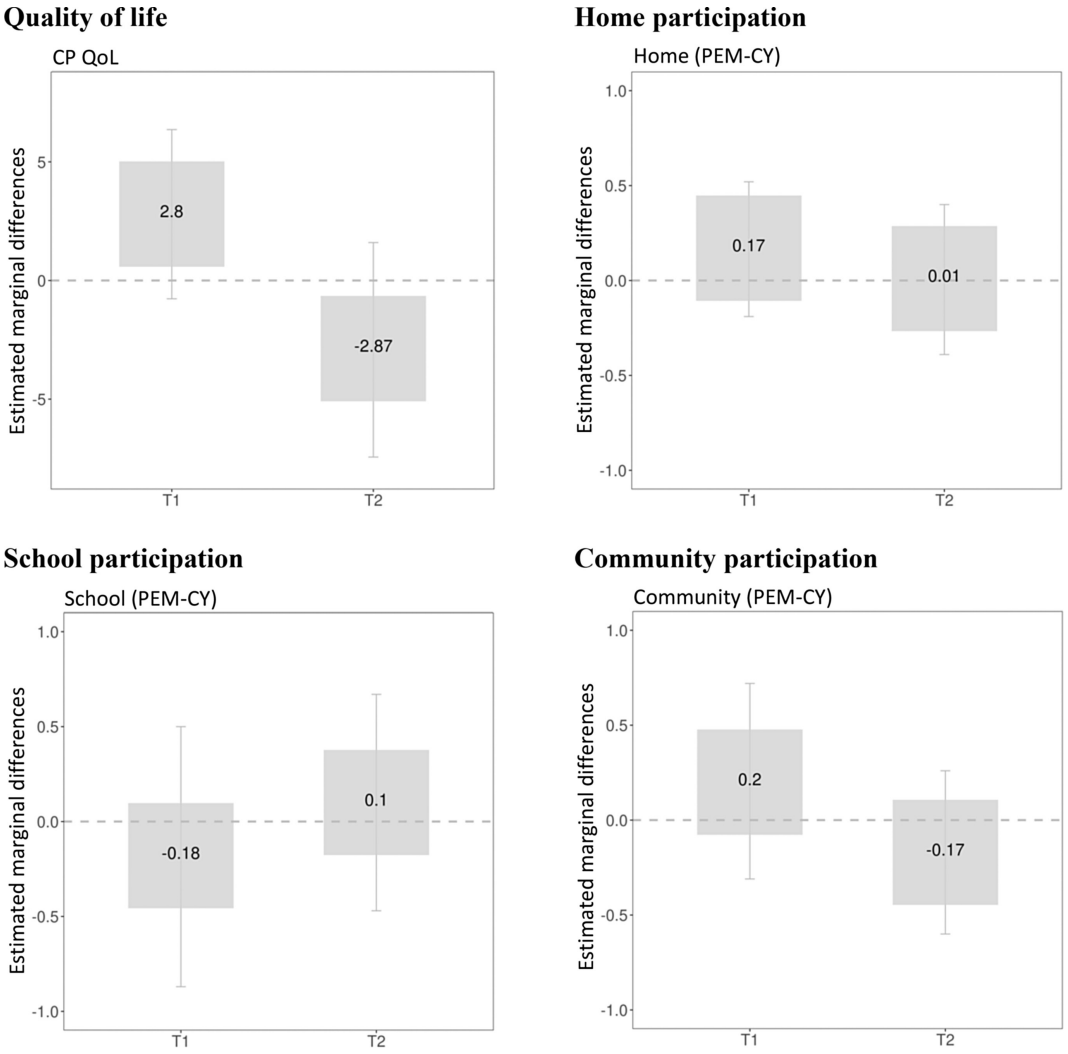

FIGURE 5 Differences between intervention and waitlist groups in quality of life (QoL) and participation. Estimated marginal differences are the intervention group estimated marginal mean minus the waitlist group estimated marginal mean; dark grey-coloured box, significant differences; grey-coloured box, non-significant differences. Estimated marginal differences above zero indicate better performance in the intervention group than in the waitlist group. Abbreviation: CP, cerebral palsy; PEM-CY, Participation and Environment Measure for Children and Youth.

in other populations indicated that they promote long-term effects.[79] Another point of interest could be to include computerized assessments to test whether the beneficial effects could be higher or maintained at follow-up.

Our study is the first to investigate the effects of cognitive intervention on the QoL and participation of individuals with CP. However, our results showed no significant transfer effects in QoL and participation; no delayed effects appeared 9 months later. These findings are in line with previous studies in CP about multimodal and physical interventions, where no changes in QoL were reported.[20,80] However, our results for participation differ from those found in a previous study whose participants underwent a physical intervention, where improvements were found after 12 weeks of a dance intervention.[19] Recent research reported that executive function interventions can enhance QoL in paediatric populations, with effects maintained over time.[30] The nature of the training tasks used in our intervention, with few resembling aspects of daily life, may have hindered the transfer of intervention effects to daily life. Therefore, further research is needed to clarify the effectiveness of executive function interventions, including ecologically valid tasks, to improve QoL and participation in this population.

Despite the strengths of this study, some questions need to be raised for future research. First, the children in our study were classified in MACS levels I to III. The sample was limited to children with mild motor impairment to homogenize the sample characteristics and minimize the influence of motor effort on proving the effect of the intervention. Future studies should include participants in the entire spectrum of pattern and motor severity as cognitive impairments probably vary across different types and severity of CP.[3] Second, our study did not include an active control group. Although it would be interesting to include an active control group, it is difficult to find computerized intervention tasks that do not include executive function components or domains. In

addition, the COVID-19 pandemic may have affected the children's responses to treatment. Recent studies indicated that children with CP discontinued their daily routines and their activities in special education and rehabilitation centres during the pandemic.[81] This decreased general health status and functional ability during the pandemic may have affected their performance in the assessment and intervention of our study. Another aspect to consider is the possible impact of practice effects, particularly on memory assessment. Despite this limitation, the inclusion of the control group had an important role in ensuring that the observed changes in the intervention group could be attributed to the effects of the intervention itself. Moreover, QoL and participation were assessed using proxy-reported questionnaires. Research indicates that parents may perceive their child's QoL differently than children with CP themselves.[82] Therefore, whether changes in self-reported measures of QoL and participation occur after a cognitive intervention should be investigated. Finally, QoL and participation were evaluated to assess the impact of interventions on daily activities. However, both are complex constructs influenced by multiple factors, making it challenging to translate intervention efficacy into changes in these outcomes. Therefore, it is important to incorporate additional measures, such as social well-being, for a comprehensive assessment of the broader impacts of interventions. In summary, a home-based computerized executive function intervention can be effective in obtaining transfer effects on memory and visual perception. However, improvements are not maintained in the long term, and QoL and participation were not enhanced after the intervention. Further research across the whole spectrum of CP severity is needed to identify strategies that allow these improvements to be maintained over time and the possibility of transferring these to daily life.

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DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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SUPPORTING INFORMATION

The following additional material may be found online:

Figure S1: CONSORT flow chart. Abbreviation: MACS, Manual Ability Classification System; IQ, intelligence quotient.

Table S1: Outcomes descriptive data on the neuropsychological assessment tasks of intervention and waitlist groups at baseline, after the intervention, and at the follow-up.

Table S2: Intention-to-treat analysis of covariance comparing intervention and waitlist control groups after the intervention.

Table S3: Intention-to-treat analysis of covariance comparing intervention and waitlist control groups at the follow-up.

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