Effects of an Intelligent Home-based Rehabilitation System on Motor Function and Family Caregiver Burden in Children with Cerebral Palsy

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Abstract

Background Children with cerebral palsy (CP) often have abnormal muscle tone and limitations in balance and walking function, which further affect their activities of daily living; long-term home-based rehabilitation training may also increase caregiver burden. Conventional home-based rehabilitation still has certain limitations in training standardization, continuity, and timeliness of feedback, and more effective intervention approaches urgently need to be explored. Objective To compare the effects of intelligent home-based rehabilitation training and conventional home-based rehabilitation training on functional recovery in children with CP and the burden of family caregivers, providing evidence for optimizing home-based rehabilitation models for children with CP. Methods A total of 48 children with CP who received rehabilitation training at Sichuan Bayi Rehabilitation Center from June to October 2025 were selected and randomly divided using a random number table into an intelligent home-based rehabilitation group (24 cases) and a conventional home-based rehabilitation group (24 cases). Both groups received interventions for 40 min/session, 1 session/d, 6 d/week, for 12 consecutive weeks. Functional recovery in the children was evaluated using the modified Ashworth scale (MAS), Berg Balance Scale (BBS), Gross Motor Function Measure-88 (GMFM-88) dimension D and E scores, 6-min walk test (6MWT), gait parameters, and Pediatric Evaluation of Disability Inventory (PEDI). Family-related outcomes were assessed using home training adherence, the Chinese version of the Short Form Health Survey (SF-36), and the Chinese version of the Zarit Burden Interview (ZBI). Results Before the intervention, there were no statistically significant differences between the two groups in general characteristics, MAS grade distribution, BBS score, GMFM-88 dimension D and E scores, 6MWT distance, gait parameters, PEDI scores, or family caregiver-related indicators ($P>0.05$). After the intervention, compared with the conventional home-based rehabilitation group, children in the intelligent home-based rehabilitation group had lower MAS grades, higher BBS scores, GMFM-88 dimension D and E scores, 6MWT distance, walking speed, step length, and PEDI self-care and mobility scores, and a lower percentage of stance phase ($P<0.05$). The intelligent home-based rehabilitation group also had a higher training completion rate and fewer training interruptions; family caregivers had higher scores in all SF-36 dimensions and lower ZBI total scores, personal burden scores, and role burden scores ($P<0.05$). In both groups, MAS grade, BBS score, GMFM-88 dimension D and E scores, 6MWT distance, gait parameters, and PEDI scores improved after the intervention compared with before the intervention, and family caregivers' SF-36 and ZBI scores also improved compared with before the intervention, with statistically significant differences ($P<0.05$). Conclusion Compared with conventional home-based rehabilitation training, intelligent home-based rehabilitation training has more significant effects on improving functional recovery and reducing family caregiving burden in children with CP aged 6~9 years and classified as Gross Motor Function Classification System levels I~II. This study provides preliminary supporting evidence for the application of intelligent home-based rehabilitation systems in

the rehabilitation of children with CP.

Full Text

Effects of an Intelligent Home-based Rehabilitation System on Motor Function and Family Caregiver Burden in Children with Cerebral Palsy

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【Abstract】 **Background** Children with cerebral palsy (CP) often present with abnormal muscle tone and impairments in balance and walking function, which further affect their ability to perform activities of daily living; long-term home-based rehabilitation training also increases caregiver burden. Conventional home-based rehabilitation still has certain limitations in training standardization, continuity, and timely feedback, making it urgent to explore more effective intervention methods. **Objective** To compare the effects of intelligent home-based rehabilitation training and conventional home-based rehabilitation training on functional recovery in children with CP and on family caregiver burden, and to provide evidence for optimizing the home-based rehabilitation model for children with CP. **Methods** Forty-eight children with CP who received rehabilitation training at Bayi Rehabilitation Center, Sichuan Province, from June to October 2025 were selected and assigned by a random number table method to an intelligent home-based rehabilitation group (24 cases) and a conventional home-based rehabilitation group (24 cases). Both groups underwent training for 40 min/session, 1 session/d, 6 d/week, for 12 consecutive weeks. The Modified Ashworth Scale (MAS), Berg Balance Scale (BBS), Gross Motor Function Measure-88 (GMFM-88) domain D and E scores, 6-minute walk test (6MWT), gait parameters, and Pediatric Evaluation of Disability Inventory (PEDI) were used to evaluate functional recovery in the children; the Family Training Compliance, Chinese version of the 36-item Short Form Health Survey (SF-36), and Chinese version of the Zarit Burden Interview (ZBI) were used to evaluate family-related outcomes. **Results** Before intervention, there were no statistically significant differences between the two groups in general data, MAS grade distribution, BBS score, GMFM-88 domain D and E scores, 6MWT distance, gait parameters, PEDI scores, and family caregiver-related indicators (P>0.05). After intervention, compared with the conventional home-based rehabilitation group, the intelligent home-based rehabilitation group had lower MAS grades; higher BBS scores, GMFM-88 domain D and E scores, 6MWT distance, gait speed, step length, and PEDI self-care and mobility scores; and a lower percentage of support period (P<0.05). The intelligent home-based rehabilitation group also had a higher training completion rate, fewer training interruptions, higher family caregiver SF-36 scores in all dimensions, and lower ZBI total scores, personal burden scores, and role burden scores (P<0.05). After intervention, in both groups, MAS grades, BBS scores, GMFM-88 domain D and E scores, 6MWT distance, gait parameters, and PEDI scores improved compared with before intervention, and family caregivers' SF-36 and ZBI scores also improved compared with before intervention; all differences were statistically significant (P<0.05). **Conclusion** Compared with conventional home-based rehabilitation training, intelligent home-based rehabilitation training has more pronounced effects in improving functional recovery and reducing family caregiver burden in children aged 6–9 years with CP classified as Gross Motor Function Classification System levels – . This study provides preliminary supporting evidence for the application of intelligent home-based rehabilitation systems in the rehabilitation of children with CP.

【Keywords】 cerebral palsy; intelligent home-based rehabilitation; functional recovery; family caregiver burden; pediatric rehabilitation

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【Abstract】 **Background** Children with cerebral palsy (CP) often present with abnormal muscle tone and limitations

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in balance and walking function, which may further impair activities of daily living. Long-term home-based rehabilitation training may also increase caregiver burden. Conventional home-based rehabilitation still has limitations in training standardization, continuity, and timely feedback, indicating the need for more effective intervention approaches. **Objective** To compare the effects of intelligent home-based rehabilitation training and conventional home-based rehabilitation training on functional recovery and caregiver burden in children with CP, and to provide evidence for optimizing home-based rehabilitation programs for children with CP. **Methods** A total of 48 children with CP who received rehabilitation training at the Bayi Rehabilitation Center of Sichuan Province from June to October 2025 were enrolled and randomly assigned, using a random number table, to the intelligent home-based rehabilitation group (n=24) or the conventional home-based rehabilitation group (n=24). Both groups received training for 40 minutes per session, once daily, 6 days per week, for 12 consecutive weeks. Functional recovery was evaluated using the Modified Ashworth Scale (MAS), Berg Balance Scale (BBS), Gross Motor Function Measure–88 (GMFM-88) dimensions D and E scores, 6-minute walking distance measured by the 6-minute walk test (6MWT), gait parameters, and the Pediatric Evaluation of Disability Inventory (PEDI). Family-related outcomes were evaluated using home-based training adherence, the Chinese version of the 36-item Short-Form Health Survey (SF-36), and the Chinese version of the Zarit Caregiver Burden Interview (ZBI). **Results** Before intervention, there were no significant differences between the two groups in general characteristics, MAS grade distribution, BBS scores, GMFM-88 dimensions D and E scores, 6MWT distance, gait parameters, PEDI scores, or caregiver-related outcomes (P>0.05). After intervention, compared with the conventional home-based rehabilitation group, the intelligent home-based rehabilitation group showed lower MAS grades, higher BBS scores, higher GMFM-88 dimensions D and E scores, longer 6MWT distance, higher gait speed and step length, higher PEDI self-care and mobility scores, and a lower percentage of stance phase (P<0.05). The intelligent home-based rehabilitation group also had a higher training completion rate, fewer training interruptions, higher SF-36 dimension scores in family caregivers, and lower ZBI total, personal burden, and role burden scores (P<0.05). In both groups, MAS grades, BBS scores, GMFM-88 dimensions D and E scores, 6MWT distance, gait parameters, and PEDI scores improved after intervention compared with before intervention, and SF-36 and ZBI scores in family caregivers also improved, with statistically significant differences (P<0.05). **Conclusion** Compared with conventional home-based rehabilitation training, intelligent home-based rehabilitation training shows greater effects in improving functional recovery and reducing caregiver burden in children aged 6–9 years with CP classified as Gross Motor Function Classification System (GMFCS) levels – . This study provides preliminary evidence supporting the application of an intelligent home-based rehabilitation system in the rehabilitation of children with CP.

【Key words】 Cerebral palsy; Intelligent home-based rehabilitation; Recovery of function; Family caregiver burden; Pediatric rehabilitation

Cerebral palsy (CP) is a common disabling neurodevelopmental disorder in childhood, mainly manifested as abnormalities in motor and postural development and restricted activity, which can affect children' s independence in daily life, capacity for social participation, and need for family care[^1]. Because functional impairments in children with CP are persistent, complex, and long-term, the rehabilitation process often requires continuous, systematic, and high-frequency training support[^2]. In recent years, artificial intelligence–assisted rehabilitation, rehabilitation robots, virtual reality, and digital interaction technologies have gradually been applied in pediatric rehabilitation, promoting the extension of cerebral palsy rehabilitation from training in a single institution toward intelligence, home-based care, and continuity[^3]. As an important component of the continuous rehabilitation system for children with CP, home-based rehabilitation can embed training into daily routines, reduce the time cost caused by repeated visits to institutions, and help improve children' s motor function and activities of daily living[^4–5]. However, traditional home-based rehabilitation mainly relies on caregiver implementation and supervision, and problems remain, including insufficient standardization of movements, difficulty in ensuring training intensity, lack of process monitoring, and delayed professional feedback. At the same time, the dependence of family training is easily affected by caregivers' rehabilitation knowledge, implementation ability, psychological stress, and support resources, leading to differences in training quality and rehabilitation outcomes[^6]. Existing studies have shown that virtual reality, gamified training, interesting tasks, and higher training intensity help improve children' s rehabilitation participation and promote improvement in motor function[^7–8]; intelligent rehabilitation platforms also have application potential in training monitoring, remote guidance, and closed-loop management[^9]. Artificial intelligence technology is driving the development of medical service models and intelligent evaluation systems[^10-12], and interesting intelligent home-based rehabilitation training has also shown value in improving function and activities of daily living in other populations with neurological dysfunction[^13]. These studies suggest that digital technologies are expected to provide training monitoring, real-time feedback, and remote guidance support for home-based rehabilitation in children with CP, but their intervention effects in real family settings still require further verification. Based on this, the present study adopts an intelligent home-based rehabilitation system independently developed by the team, with children with CP and their family caregivers as the subjects, to explore its intervention effects on motor function, activities of daily living, and caregiver burden in children with CP, in order to provide practical evidence for the application and promotion of intelligent home-based rehabilitation systems in family rehabilitation for children with CP.

1 Objects and Methods

1.1 Study Subjects

This study is a single-center, prospective, assessor-blinded randomized controlled study. Forty-eight children with CP who were recruited from the Bayi Rehabilitation Center of Sichuan Province from June to October 2025 and screened according to the inclusion and exclusion criteria were selected as the study participants. Inclusion criteria: (1) meeting the diagnostic criteria of the *Chinese Guideline for Rehabilitation of Cerebral Palsy (2022)*, with Gross Motor Function Classification System (GMFCS) levels I–II, ability to walk 10 m independently, and ability to complete gait-parameter measurement and the 6-minute walk test (6MWT)[14]; (2) age 6–9 years, with relatively stable condition; (3) Manual Ability Classification System (MACS) levels I–III, and able to cooperate in completing relevant functional assessments and home-training tasks; (4) the guardian had basic smartphone operation ability and could cooperate in completing home training, training records, and completion of related scales. Exclusion criteria: (1) combined severe visual or hearing impairment or severe intellectual disability, making it impossible to cooperate in completing assessment and training; (2) combined severe cardiopulmonary disease, recent joint injury, or other conditions not suitable for participation in home-based rehabilitation training; (3) receipt within the past 3 months of orthopedic surgery, botulinum toxin injection, or other treatment that might significantly affect motor function; (4) currently participating in another clinical trial or intensive rehabilitation program that might affect the outcomes of this study. Withdrawal criteria: (1) adverse events during training or medical reasons making continued participation inappropriate; (2) receipt during the study period of other systematic rehabilitation interventions that might affect the primary outcome indicators; (3) training completion rate $<80\%$ or interruption of training for ( )2 consecutive weeks; (4) active request for withdrawal by the child or guardian. Baseline clinical characteristics were obtained by reviewing clinical diagnostic records at enrollment, rehabilitation assessment records, and previous cranial MRI or CT reports. Clinical classification of CP was categorized according to the *Chinese Guideline for Rehabilitation of Cerebral Palsy (2022)* and clinical diagnostic records[14]; imaging-change classification referred to common abnormal findings on cranial MRI in children with CP and was categorized according to the predominant imaging change[15].

In this study, the family caregiver was defined as the principal family member who assumed the greatest responsibility for the child' s daily care and the organization, supervision, and recording of home-based rehabilitation training. Before and after intervention in the same child, quality-of-life and care-burden scales were completed by the same principal caregiver; if the principal caregiver changed, the relevant indicators were not included in the pre–post comparative analysis.

The sample size was estimated using G*Power 3.1 software[16], with the change in GMFM-88 score as the primary outcome indicator. Referring to the sample-size estimation methods and functional-outcome Cohen' s d results of previous randomized controlled studies of remote home rehabilitation for children with CP, some functional outcomes in those studies reached a large effect size[17]. Considering the exploratory design and implementation feasibility of this study, the expected effect size was set as Cohen' s $d = 0.90$, $\alpha = 0.05$, and test power $(1-\beta) = 0.80$, with an intergroup allocation ratio of 1:1; the calculation showed that at least 21 cases were required in each group. Taking into account an approximately 10% possibility of loss to follow-up or withdrawal, 48 cases were ultimately enrolled, with 24 cases in each group. This sample size also conformed to the design concept for pilot randomized trials[18–19]. A random-number table method was used to allocate children in a 1:1 ratio to the conventional home-rehabilitation group and the intelligent home-rehabilitation group. The random sequence was independently generated by a researcher not involved in recruitment, assessment, or intervention implementation, and allocation concealment was performed using consecutively numbered, opaque, sealed envelopes. Because the home intervention programs differed markedly between the two groups, blinding was not implemented for the children and guardians. Outcomes of child function, including the Modified Ashworth Scale (MAS), Berg Balance Scale (BBS), Gross Motor Function Measure-88 (GMFM-88) D and E area scores, 6MWT, gait parameters, and Pediatric Evaluation of Disability Inventory (PEDI), were all completed by assessors who did not participate in random grouping or intervention implementation. Assessors were unaware of the children' s group allocation during assessment. The study was approved by the Ethics Committee of the Russian State University of Physical Education (ethics approval No.: [2025.05.14] 2), and all guardians signed informed consent forms.

1.2 Methods

1.2.1 Introduction to the intelligent home rehabilitation system

The intelligent home rehabilitation system used in this study was home-rehabilitation assistance software developed by the research group. The software was named "Intelligent Motor Rehabilitation Guidance System Based on Artificial Intelligence Technology V1.0" and was mainly used in home-based rehabilitation training scenarios for children with CP. The system adopts visual-recognition motion-capture technology based on a smartphone camera. Through real-time motion capture and analysis, it provides movement demonstrations, process monitoring, and immediate feedback for home training. The system includes a therapist terminal, physician terminal, patient terminal, institution management terminal, hospital management terminal, and general back-office management terminal. This study mainly used functions of the therapist terminal, physician terminal, and patient terminal (Figure 1). The therapist terminal and physician terminal were mainly used for child management, formulation of individualized training programs, setting of training parameters, viewing of training reports, and health-record management. The system motion library contains commonly used rehabilitation-training movements. Training parameters can be set, including training side, number of sets, number of repetitions per set, inter-set rest time, inter-movement rest time, number of training sessions per day, number of treatment days, and start date of the treatment course. After setup is completed, the training program is pushed to the patient terminal. The patient terminal includes modules such as the training program and training calendar, follow-up practice, and post-training feedback questionnaires. During training, the guardian assists the child in using the system. During training, the interface synchronously displays the child' s real-time image and the standard movement demonstration. The system recognizes key points of the human body in real time and calculates joint angles, and judges movement amplitude, maintenance time, and movement speed. When movement amplitude does not meet preset requirements, exceeds the preset range, maintenance time is insufficient, or movement speed is abnormal, the system immediately issues angle prompts and voice prompts. After training ends, the system automatically records training duration, training-plan completion rate, movement completion rate, movement compliance rate, and post-training feedback results. The research team regularly reviews platform data and dynamically adjusts training content, training intensity, and training difficulty according to the child' s training performance, so as to ensure the standardization, continuity, and traceability of home training.

1.2.2 Intervention program for the conventional home-rehabilitation group

Duration: 40 min/session, 1 session/d, 6 d/week, with continuous intervention for 12 weeks. The training content included joint activity and lower-limb activation training, postural control and balance training, transfer training, walking training, and functional activity training. After the rehabilitation therapist provided offline demonstration and explanation of key points to the guardian, the guardian organized the child to implement training in the home environment. The guardian recorded training completion in accordance with uniform requirements. The research team conducted regular follow-up visits and checked training implementation. The intervention content is shown in Table 1.

Note: A is the therapist-side exercise library interface, used to display the system' s built-in training exercises and related training content; B is the therapist-side training-program detailed parameter-setting interface, used to formulate individualized training programs and set parameters such as training side, number of sets, repetitions, rest time, and treatment course; C is the patient-side training interface, used for children to perform follow-up exercises with the assistance of a guardian, and to receive exercise demonstrations and real-time feedback; D is the patient-side training-report details page, used to display training completion status, exercise attainment, and training result records.

Figure 1 Main functional interfaces of the therapist terminal and patient terminal of the intelligent home-based rehabilitation system

1.2.3 Intelligent Home-Based Rehabilitation Intervention Program

Duration: 40 min/session, 1 session/d, 6 d/week, with continuous intervention for 12 weeks.

On the basis of conventional rehabilitation principles, an intelligent home-based rehabilitation system was applied to carry out home training. Based on the children' s pre-intervention assessment results, the system pushed individualized training programs and assisted caregivers in completing home training through functions such as movement demonstration, training reminders, training records, movement recognition analysis, training-quality feedback, and remote guidance. The research team regularly reviewed platform training data and dynamically adjusted the training content, training intensity, and training difficulty according to the children' s training performance. The intervention contents are shown in Table 2.

1.3 Functional Recovery Assessment Indicators for Children with CP

1.3.1 Muscle Tone

The MAS was used to assess the muscle tone of the major affected muscle groups, reflecting changes in spasticity before and after the intervention. MAS scores include grade 0, grade 1, grade 1+, grade 2, grade 3, and grade 4; higher grades indicate increased muscle tone and more obvious spasticity

1.3.2 Balance Ability

The BBS was used for assessment to reflect changes in postural control and balance ability in children with CP. The scale contains 14 items, with a total score of 56 points; higher scores indicate better balance function

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1.3.3 Walking Ability

(1) GMFM-88: The D and E dimensions of the GMFM-88 were used to evaluate gross motor function related to standing and walking in the children. Dimension D mainly evaluates standing function and contains 13 items, with a full score of 39 points; dimension E mainly evaluates walking, running, and jumping functions and contains 24 items, with a full score of 72 points. Higher scores indicate better gross motor function

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. (2) 6MWT: The 6-min walking distance was recorded to reflect changes in functional walking ability and walking endurance of children with CP in daily activity contexts; larger values indicate better walking ability and endurance

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. (3) Spatiotemporal gait parameters: Gait data were collected using the Vicon three-dimensional motion capture system (Vicon Motion Systems Ltd., Oxford, UK; software version 2.8.1), with a sampling frequency of 100 Hz. Raw data were processed using Vicon Nexus 2.8.1 software, which automatically identified gait events such as heel strike and toe-off, and calculated the percentage of stance phase,

Table 1 Conventional home-based rehabilitation program

Training module	Situation setting	Operating procedure	Goal
Joint activity and lower-limb activation training	A training mat is laid in the family living room or bedroom, and auxiliary items such as small pillows, towel rolls, or elastic bands are prepared. The training environment is kept flat, safe, and well lit.	The caregiver assists the child in assuming supine, sitting, or standing positions and sequentially completes activities for the hip, knee, and ankle joints. Lower-limb activation is carried out in combination with movements such as lower-limb leg lifting, bridging, and half-kneeling with support.	Improve joint range of motion and the preparatory status of lower-limb movement, laying a foundation for subsequent standing, transfer, and walking training.
Postural control and balance training	A training area is set up on a training mat or non-slip floor. Toys and target cards or building blocks are placed in front of the child and on the left and right sides; fixed supports are placed nearby when necessary.	The child assumes sitting, prone, or standing positions and completes static holding, forward–backward and left–right weight shifting, and target-oriented reaching training. The caregiver provides verbal prompts and necessary protection.	Improve postural control and balance ability, and enhance trunk stability and the ability to regulate the center of gravity.

Training module	Situation setting	Operating procedure	Goal
Transfer training	The bedside, beside a chair, or a low stool is selected as the training scenario, ensuring that the surroundings are unobstructed and that protective space is available.	Under caregiver protection, the child completes basic transfer movements such as from lying to sitting, sitting to standing, and standing to sitting; children with better ability add combined transfer training between the bed and chair.	Improve body-position transfer ability and functional-activity coordination, and promote improvement in transfer ability in daily life.
Walking training	A 5–10 m walking passage is designated in a home corridor or living room, with markers or simple obstacles set up.	Under caregiver protection, the child completes straight-line walking, walking around markers, and stepping over small obstacles. During training, emphasis is placed on step length, cadence, foot contact, and gait stability, with the number of round trips gradually increased.	Improve continuous walking ability, walking endurance, and gait stability.

Training module	Situation setting	Operating procedure	Goal
Functional activity training	Based on real-life home scenarios, a table, clothing, tableware, toys, or daily necessities are selected, and training tasks are close to daily activities.	The caregiver guides the child in completing tasks such as placing and retrieving objects, simple dressing and undressing, grasping and releasing, two-handed transfer, using a spoon, organizing the tabletop, and retrieving targets during movement.	Promote transfer of training to daily-life activity ability, and improve self-care ability and mobility.

Table 2 Intelligent home-based rehabilitation program

Training module	Situation setting	Operating procedure	Goal
Personalized training-plan push and movement demonstration	The intelligent home-based rehabilitation system generates a staged training plan based on the baseline assessment results. The caregiver enters the training interface through the mobile terminal, and the system provides a training calendar, video demonstrations, and voice prompts.	After the caregiver logs into the system, the day’ s training tasks are viewed. Under caregiver accompaniment, the child sequentially completes the training content pushed by the system; before training, movement demonstrations are watched, and after training, training records are automatically saved.	Ensure that training content matches the child’ s functional level, and improve the standardization and consistency of training execution.
Postural control and balance training	The system pushes training tasks such as sitting holding, standing balance, and forward–backward and left–right center-of-gravity shifting. The interface prompts the target direction, duration, and completion requirements through animation.	According to system prompts, the child completes static holding and target-oriented center-of-gravity transfer training; the system records completion duration, completion rate, and movement stability, and the research team adjusts the training level according to platform data.	Improve postural control and balance ability, and enhance center-of-gravity regulation ability under target-oriented conditions.

Training module	Situation setting	Operating procedure	Goal
Transfer and walking training	The system pushes training tasks such as sit-to-stand transfers, stepping in place, walking at home, and walking around obstacles, and guides movement execution through voice, images, and rhythmic prompts.	Under caregiver protection, the child completes transfer and walking training according to system prompts; the system records the number of training sessions, duration, and movement completion status; the caregiver completes the training record as required and provides feedback on the training situation.	Improve body-position transfer ability, walking ability, and gait stability.
Functional activity training	The system pushes functional tasks related to daily life, including placing and retrieving objects, tabletop operations, simple dressing and undressing, and retrieving target objects during movement. The training tasks are integrated with the home environment.	Under caregiver guidance, the child completes functional tasks step by step according to the prompts; through completion prompts, phased feedback, and training records, the system helps caregivers grasp training progress; the research team adjusts training content according to task-completion quality.	Promote transfer of motor training to daily-life activity ability, and improve self-care ability and mobility.

Training module	Situation setting	Operating procedure	Goal
Training reminders, records, and remote feedback	The system is configured with training reminders, check-in records, training logs, and data-upload functions. The research team regularly reviews platform data and conducts follow-up visits.	The system reminds caregivers to complete training at preset times; after training ends, it automatically records training duration, task completion, movement completion rate, and movement achievement rate; the research team provides remote feedback and adjusts the training program according to platform data.	Improve adherence to home training and training quality, and achieve continuous management of the training process.

indicators such as swing-phase percentage, step length, step width, and walking speed. Considering the relatively high correlations among gait indicators, this study ultimately selected three representative indicators—walking speed, step length, and support-phase percentage—for statistical analysis, reflecting overall walking ability, gait propulsion ability, and changes in gait stability, respectively.

1.3.4 Activities of daily living The PEDI was used for assessment, mainly reflecting the functional improvement of children with CP in eating, dressing, transfers, mobility, and self-care in daily life from two dimensions: self-care ability and mobility. Higher scores indicate better activities of daily living ability[^24].

1.4 Assessment indicators for family caregivers of children with CP

1.4.1 Family training adherence This included the actual number of sessions completed, the training completion rate, and the number of training interruptions. The planned total number of training sessions in both groups was 72. Training completion rate = actual number of completed sessions / planned total number of training sessions × 100%. The number of training interruptions was counted by training day, referring to the cumulative number of times the planned training for that day was not completed due to non-withdrawal reasons such as the child' s physical discomfort, family affairs, or the caregiver' s inability to organize training; a brief pause on the same day followed by eventual completion of training was not counted as an interruption.

1.4.2 Quality of life of family caregivers The Chinese version of the MOS 36-item Short-Form Health Survey (SF-36) was used for assessment. This scale was developed in Chinese by the Department of Social Medicine, Zhejiang University School of Medicine, and includes 8 dimensions—physical functioning, role-physical, bodily pain, social functioning, vitality, role-emotional, mental health, and general health—with a total of 36 items. The score range is 0–100 points; higher scores indicate a higher level of quality of life[^25]. The Cronbach' s α coefficient of this scale is 0.902, indicating good reliability, and it has been widely used in quality-of-life assessments for different populations.

1.4.3 Burden of family caregivers The Chinese version of the Zarit Caregiver Burden Interview (ZBI) was used for assessment. The scale contains 22 items and includes two dimensions: personal burden and role burden. It mainly evaluates caregiving burden in terms of health status, economic status, mental status, and social life. The scale uses a 5-point Likert scoring method, with each item scored from 0 to 4 points, for a total score of 0–88 points; higher scores indicate heavier caregiving burden[^26]. The Cronbach' s α coefficient of this scale is 0.87, indicating good reliability.

1.5 Statistical methods

SPSS 22.0 software was used for statistical analysis. Measurement data were first tested for normality. Measurement data conforming to a normal distribution were expressed as ($\bar{x} \pm s$); comparisons between groups were performed using the independent-samples t test, and within-group comparisons before and after intervention were performed using the paired t test. Data not conforming to a normal distribution were expressed as M (P_{25}, P_{75}); comparisons between groups were performed using the Mann-Whitney U test, and within-group comparisons before and after intervention were performed using the Wilcoxon signed-rank test. Count data were expressed as number of cases (%); comparisons between groups were performed using the χ^2 test (Fisher' s exact test was used when the theoretical frequency was insufficient). Ranked data were compared using the rank-sum test. To evaluate the clinical significance of improvement in the main functional outcomes, this study compared the change values of GMFM-88 D- and E-area scores and 6MWT distance with previously reported minimal clinically important difference (MCID) reference values, and additionally calculated Cohen' s d effect size. Effect sizes were judged as small, medium, and large according to $0.20 \leq d < 0.50$, $0.50 \leq d < 0.80$, and $d \geq 0.80$, respectively. $P < 0.05$ was considered statistically significant.

2 Results

2.1 General data and clinical characteristics

A total of 48 children with CP were randomly enrolled in this study, including 24 in the conventional home rehabilitation group and 24 in the intelligent home rehabilitation group. During the study period, no adverse events occurred in either group; no child received other systematic rehabilitation interventions that might affect the main outcome indicators, had a training completion rate <80%, or met withdrawal criteria such as continuous interruption of training for ( )2 weeks. All children completed 12 weeks of intervention and post-intervention assessment. Because the randomized participants were identical to the final analysis population, statistical analysis in this study was conducted for all randomized participants.

Comparisons of sex, age, height, and body mass between the two groups of children showed no statistically significant differences ($P > 0.05$), as shown in Table 3. Comparisons of GMFCS level, CP clinical subtype, imaging-change classification, and MACS level between the two groups showed no statistically significant differences ($P > 0.05$), as shown in Table 4.

2.2 Functional recovery assessment indicators in children with CP

2.2.1 MAS and BBS scores Before intervention, there were no statistically significant differences between the two groups in the distribution of MAS grades or BBS scores ($P > 0.05$). After intervention, the MAS grade level in the intelligent home rehabilitation group was lower than that in the conventional home rehabilitation group, and the BBS score was higher than that in the conventional home rehabilitation group; the differences were statistically significant ($P < 0.05$). In both groups, MAS grade levels after intervention were lower than before intervention, and BBS scores were higher than before intervention; the differences were statistically significant ($P < 0.05$), as shown in Table 5.

2.2.2 GMFM-88 D- and E-area scores and 6MWT Before intervention, there were no statistically significant differences between the two groups in GMFM-88 D-area and E-area scores and 6MWT distance ($P > 0.05$). After intervention, the GMFM-88 D-area and E-area scores and 6MWT distance in the intelligent home rehabilitation group were all higher than those in the conventional home rehabilitation group, and the differences were statistically significant ($P < 0.05$). In both groups, GMFM-88 D-area and E-area scores and 6MWT distance after intervention were higher than before intervention; the differences were statistically significant ($P < 0.05$), as shown in Table 6.

2.2.3 Gait parameters Before intervention, there were no statistically significant differences between the two groups in walking speed, step length, or support-phase percentage ($P > 0.05$). After intervention, walking speed and step length in the intelligent home rehabilitation group were higher than those in the conventional home rehabilitation group, and support-phase percentage was lower than that in the conventional home rehabilitation group; the differences were statistically significant ($P < 0.05$). In both groups, walking speed and step length after intervention were higher than before intervention, and support-phase percentage was lower than before intervention; the differences were statistically significant ($P < 0.05$), as shown in Table 7.

2.2.4 PEDI scores Before intervention, there were no statistically significant differences between the two groups in PEDI self-care ability and mobility scores ($P > 0.05$). After intervention, the intelligent

Table 3 Comparison of general characteristics between the two groups

Group	Cases	Male	Female	Age ($\bar{x} \pm s$, years)	Height [M (P_{25}, P_{75}), cm]	Body mass ($\bar{x} \pm s$, kg)
Conventional home rehabilitation group	24	14 (58.3)	10 (41.7)	7.41 ± 0.82	126.05 (121.38, 131.18)	25.42 ± 3.22
Intelligent home rehabilitation group	24	13 (54.2)	11 (45.8)	7.25 ± 0.80	125.10 (123.05, 129.35)	24.87 ± 3.31
Test statistic value		0.000^a	0.000^a	0.692^b	283.500^c	0.583^b
P value		1.000	1.000	0.492	0.934	0.562

Note: ^{a} is the χ^2 value; ^{b} is the t value; ^{c} is the U value.

Table 4 Comparison of clinical characteristics between the two groups

Group	Cases	GMFCS grade I	GMFCS grade II	CP clinical type A	CP clinical type B	CP clinical type C	CP clinical type D
Conventional home rehabilitation group	24	10 (41.7)	14 (58.3)	10 (41.7)	7 (29.2)	4 (16.7)	3 (12.5)
Intelligent home rehabilitation group	24	10 (41.7)	14 (58.3)	11 (45.8)	6 (25.0)	4 (16.7)	3 (12.5)
Z value		0.000	0.000	—	—	—	—
P value		1.000	1.000	1.000	1.000	1.000	1.000

Group	Imaging-change category a	Imaging-change category b	Imaging-change category c	Imaging-change category d	MACS grade I	MACS grade II	MACS grade III
Conventional home rehabilitation group	12 (50.0)	5 (20.8)	3 (12.5)	4 (16.7)	12 (50.0)	10 (41.7)	2 (8.3)
Intelligent home rehabilitation group	13 (54.2)	4 (16.7)	3 (12.5)	4 (16.7)	11 (45.8)	11 (45.8)	2 (8.3)
Z value	—	—	—	—	-0.241	-0.241	-0.241
P value	1.000	1.000	1.000	1.000	0.809	0.809	0.809

Note: GMFCS = Gross Motor Function Classification System; CP = cerebral palsy; MACS = Manual Ability Classification System; —indicates Fisher' s exact probability method was used; CP clinical types (A: spastic diplegia; B: spastic hemiplegia; C: spastic quadriplegia; D: mixed/other types); imaging-change categories (a: periventricular white matter injury/periventricular leukomalacia; b: cerebral atrophy/lateral ventricular enlargement; c: deep gray matter/cerebellar or multifocal softening abnormality; d: other/no obvious abnormality).

Table 5 Comparison of MAS and BBS scores between the two groups of children

Group	Cases	Pre-intervention MAS grade 0	Pre-intervention MAS grade 1	Pre-intervention MAS grade 1+	Pre-intervention MAS grade 2	Pre-intervention MAS grade 3	Pre-intervention MAS grade 4	Post-intervention MAS grade 0	Post-intervention MAS grade 1	Post-intervention MAS grade 1+	Post-intervention MAS grade 2	Post-intervention MAS grade 3	Post-intervention MAS grade 4	Paired Z value	P value	Pre-intervention BBS ($\bar{x} \pm s$, points)	Post-intervention BBS ($\bar{x} \pm s$, points)	Paired t value	P value
Conventional home rehabilitation group	24	0	0	5 (20.8)	14 (58.3)	5 (20.8)	0	0	0	9 (37.5)	13 (54.2)	2 (8.3)	0	-2.428	0.015	42.5 ± 3.6	44.9 ± 4.3	2.993	0.006
Intelligent home rehabilitation group	24	0	0	6 (25.0)	12 (50.0)	6 (25.0)	0	0	8 (33.3)	10 (41.7)	6 (25.0)	0	0	-4.235	<0.001	42.3 ± 3.8	48.8 ± 4.3	4.892	<0.001
U value				288.000	288.000	288.000				138.000	138.000	138.000				0.233	-3.085		
P value				1.000	1.000	1.000				0.001	0.001	0.001				0.817	0.003		

Note: MAS = modified Ashworth scale; BBS = Berg Balance Scale.

The mean scores for PEDI self-care ability and mobility in the intelligent home rehabilitation group were higher than those in the conventional home rehabilitation group, and the differences were statistically significant ($P < 0.05$). After intervention, the mean PEDI self-care ability and mobility scores in both groups of children were higher than before intervention, and the differences were statistically significant ($P < 0.05$), as shown in Table 8.

2.3 Assessment indicators for family caregivers of children with CP

2.3.1 Training compliance In the intelligent home rehabilitation group, the actual number of completions and the training completion rate were both higher than those in the conventional home rehabilitation group, while the number of training interruptions was lower than that in the conventional home rehabilitation group; the differences were statistically significant ($P < 0.05$). In neither group did any child meet the withdrawal criteria of a training completion rate <80% or continuous interruption of training for ( )2 weeks; see Table 9.

2.3.2 Scores of the first four dimensions of SF-36 (physical functioning, role-physical, bodily pain, and social functioning) Before intervention, comparison of the scores of the first four dimensions of SF-36 (physical functioning, role-physical, bodily pain, and social functioning) among family caregivers in the two groups showed no statistically significant differences ($P > 0.05$). After intervention, the scores of the above four dimensions in the intelligent home rehabilitation group were all higher than those in the conventional home rehabilitation group, and the differences were statistically significant ($P < 0.05$). After intervention, the scores of the first four dimensions of SF-36 among family caregivers in both groups were higher than before intervention, and the differences were statistically significant ($P < 0.05$), as shown in Table 10.

Table 6 Comparison of GMFM-88 dimension D and E scores and 6MWT between the two groups of children

Group	Cases	GMFM-88 D dimension (points)	GMFM-88 D dimension (points)	GMFM-88 E dimension (points)	GMFM-88 E dimension (points)	6MWT (m)	6MWT (m)
		Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Conventional home rehabilitation group	24	21.1 ± 4.3	23.0 ± 6.2[a]	22.3 ± 3.7	25.3 ± 4.0[a]	253.0 ± 30.6	279.1 ± 31.8[a]
Intelligent home rehabilitation group	24	21.4 ± 4.1	26.7 ± 5.5[a]	22.3 ± 3.8	28.5 ± 5.8[a]	252.1 ± 33.6	309.0 ± 33.4[a]

Group	Cases	GMFM-88 D dimension (points)	GMFM-88 D dimension (points)	GMFM-88 E dimension (points)	GMFM-88 E dimension (points)	6MWT (m)	6MWT (m)
t value		−0.275	−2.167	0.078	−2.222	0.099	−3.178
P value		0.784	0.035	0.939	0.031	0.922	0.003

Note: [a] indicates comparison with before intervention within this group, P<0.05; GMFM-88 = Gross Motor Function Measure-88; 6MWT = 6 min walk test.

Table 7 Comparison of gait parameters between the two groups of children

Group	Cases	Walking speed (m/s)	Walking speed (m/s)	Step length (m)	Step length (m)	Support phase (%)	Support phase (%)
		Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Conventional home rehabilitation group	24	0.83 ± 0.11	0.88 ± 0.10[a]	0.43 ± 0.05	0.46 ± 0.06[a]	66.00 ± 2.30	65.34 ± 2.43[a]
Intelligent home rehabilitation group	24	0.84 ± 0.13	0.96 ± 0.13[a]	0.42 ± 0.04	0.52 ± 0.07[a]	66.10 ± 2.20	63.46 ± 2.84[a]
t value		−0.346	−2.452	0.607	−2.949	−0.155	2.468
P value		0.731	0.018	0.547	0.005	0.878	0.017

Note: [a] indicates comparison with before intervention within this group, P<0.05.

Table 8 Comparison of PEDI scores between the two groups of children

Group	Cases	PEDI self-care ability	PEDI self-care ability	PEDI mobility ability	PEDI mobility ability
		Before intervention	After intervention	Before intervention	After intervention
Conventional home rehabilitation group	24	41.71 ± 7.57	45.63 ± 8.25[a]	30.13 ± 6.46	33.25 ± 7.75[a]
Intelligent home rehabilitation group	24	41.04 ± 7.92	51.29 ± 10.14[a]	29.63 ± 6.04	38.79 ± 9.22[a]
t value		0.298	−2.124	0.277	−2.253
P value		0.767	0.039	0.783	0.029

Note: [a] indicates comparison with before intervention within this group, P<0.05; PEDI = Pediatric Evaluation of Disability Inventory.

Table 9 Comparison of training dose implementation and home-based training adherence between the two groups

$$*M*(*P*\ 25\ ,*P*\ 75\ )$$

Group	Cases	Actual number completed (times)	Training completion rate (%)	Number of training interruptions (times)
Conventional home rehabilitation group	24	64.50 (63.00, 66.00)	89.59 (87.50, 91.67)	7.50 (6.00, 9.00)
Intelligent home rehabilitation group	24	69.00 (68.00, 70.00)	95.83 (94.44, 97.22)	3.00 (2.00, 4.00)
Z value		−5.473	−5.473	5.473
P value		<0.001	<0.001	<0.001

Note: The total planned number of sessions in both groups was 72; the number of training interruptions refers to the cumulative number of times during the

12-week intervention period when the planned training task for that day was not completed, counted by training day.

2.3.3 Scores of the last four dimensions of the SF-36 (vitality, role-emotional, mental health, and general health)

Before intervention, there were no statistically significant differences between the two groups of family caregivers in the scores of the last four dimensions of the SF-36 (vitality, role-emotional, mental health, and general health) (P>0.05). After intervention, the scores of the above four dimensions in the intelligent home rehabilitation group were higher than those in the conventional home rehabilitation group, and the differences were statistically significant (P<0.05). In both groups, after intervention, the scores of the last four dimensions of the SF-36 were higher than before intervention, and the differences were statistically significant (P<0.05), see Table 11.

2.3.4 ZBI scores

Before intervention, there were no statistically significant differences between the two groups of family caregivers in the ZBI total score, personal strain, and role strain scores (P>0.05). After intervention, the ZBI total score, personal strain, and role strain scores in the intelligent home rehabilitation group were lower than those in the conventional home rehabilitation group, and the differences were statistically significant (P<0.05). In both groups, after intervention, the ZBI total score, personal strain, and role strain scores of family caregivers were lower than before intervention, and the differences were statistically significant (P<0.05), see Table 12.

3 Discussion

Because children with CP have early central nervous system injury, they often have abnormal muscle tone, insufficient postural control, restricted walking ability, and decreased ability in activities of daily living, thereby increasing the pressure on family caregivers[27-28]. This study took children with CP aged 6–9 years and GMFCS levels I–II as the subjects, and compared the interventional effects of 12 weeks of intelligent home rehabilitation training and conventional home rehabilitation training. The results showed that, after intervention, muscle tone, balance ability, gross motor function, walking ability, gait parameters, and ability in activities of daily living improved in both groups of children compared with before intervention, and the improvement was more marked in the intelligent home rehabilitation group. At the same time, in the intelligent home rehabilitation group, home training adherence was higher, the quality of life of family caregivers was better, and caregiving burden was lighter, suggesting that the intelligent home rehabilitation system has certain advantages in promoting functional recovery of children and improving family caregiving outcomes.

Motor dysfunction in children with CP is mainly associated with abnormalities of the motor regulatory network caused by developmental brain injury. When the corticospinal tract, basal ganglia, cerebellum, and related postural-control pathways are affected to varying degrees, children' s abilities to maintain muscle tone, postural stability, and selective motor control decrease, thereby manifesting as spas-

Table 10 Comparison of the first four dimensions of the SF-36 in family caregivers between the two groups ($\bar{x} \pm s$, points)

Group	Cases	Physiological function	Physiological function	Role-physical	Role-physical	Bodily pain	Bodily pain	Social function	Social function
Group	Cases	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Conventional family rehabilitation group	24	65.5 ± 7.6	69.0 ± 10.4	56.1 ± 8.2	62.3 ± 9.8	49.8 ± 7.9	53.8 ± 9.6	52.1 ± 7.4	58.8 ± 9.3
Smart home rehabilitation group	24	66.2 ± 7.8	76.2 ± 10.5	55.8 ± 8.5	69.4 ± 12.9	50.4 ± 7.6	60.1 ± 10.1	52.6 ± 7.1	67.2 ± 11.4
t value		−0.314	−2.401	0.125	−2.166	−0.268	−2.212	−0.239	−2.788
P value		0.755	0.020	0.901	0.036	0.790	0.032	0.812	0.008

Note: indicates comparison with before intervention within this group, P<0.05.

Table 11 Comparison of the last four dimensions of the SF-36 in family caregivers between the two groups ($\bar{x} \pm s$, points)

Group	Cases	Vitality	Vitality	Role-emotional	Role-emotional	Mental health	Mental health	General health status	General health status
Group	Cases	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Conventional family rehabilitation group	24	50.9 ± 7.7	55.5 ± 9.1	47.9 ± 9.4	53.2 ± 10.1	55.0 ± 7.0	60.7 ± 9.4	60.9 ± 6.9	65.6 ± 10.6
Smart home rehabilitation group	24	51.2 ± 8.0	61.8 ± 10.9	47.5 ± 9.1	60.9 ± 11.7	55.4 ± 7.2	66.6 ± 10.5	61.3 ± 6.8	72.5 ± 11.9
t value		−0.132	−2.183	0.150	−2.442	−0.195	−2.074	−0.202	−2.137
P value		0.895	0.034	0.881	0.018	0.846	0.044	0.840	0.038

Note: indicates comparison with before intervention within this group, P<0.05.

Table 12 Comparison of ZBI scores in family caregivers between the two groups ($\bar{x} \pm s$, points)

Group	Cases	Total ZBI score (points)	Total ZBI score (points)	Personal burden (points)	Personal burden (points)	Role burden (points)	Role burden (points)
Group	Cases	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention

Group	Cases	Total ZBI score (points)	Total ZBI score (points)	Personal burden (points)	Personal burden (points)	Role burden (points)	Role burden (points)
Conventional family rehabilitation group	24	39.0 ± 3.3	34.6 ± 4.8	17.1 ± 1.8	15.0 ± 2.6	14.5 ± 1.6	13.0 ± 2.2
Smart home rehabilitation group	24	39.6 ± 3.3	29.9 ± 7.7	17.6 ± 2.0	12.9 ± 4.1	14.9 ± 1.8	11.0 ± 3.7
t value		−0.663	2.514	−0.911	2.131	−0.859	2.277
P value		0.511	0.015	0.367	0.038	0.395	0.028

Note: indicates comparison with before intervention within this group, $P<0.05$.

Insufficient trunk control and restricted functional movements[^29]. Abnormal muscle tone not only interferes with gait patterns[^30–31], but can also further affect balance maintenance, gross motor performance, and walking ability by limiting the range of joint motion, weakening coordinated control of muscle groups, and inducing compensatory postures[^32]. In this study, MAS grade levels decreased in both groups of children after intervention, consistent with previous research findings[^33], suggesting that sustained and standardized rehabilitation training can, to some extent, improve abnormal muscle tone in children with CP. Balance ability is an important basis for completing functional activities such as standing, transferring, and walking. Children with CP are often affected in the quality of movement completion because of insufficient postural control, decreased center-of-gravity adjustment ability, and limited dynamic stability[^34]. In this study, BBS scores increased in both groups after intervention, consistent with relevant research results[^35], which may be related to repeated practice of postural control, center-of-gravity transfer, and functional activities during training.

Gross motor function, walking ability, and gait parameters are important indicators for evaluating the functional recovery level of children with CP. Owing to abnormalities in motor control, children with CP often present with lower-limb coordination limitations, decreased sustained walking ability, and abnormal gait characteristics. The walking process depends on coordinated regulation by cortical and subcortical structures of the brain, among which the cerebral cortex plays an important role in gait control[^36]. In this study, after intervention, the GMFM-88 zone D and zone E scores and 6MWT increased in both groups, walking speed increased, step length increased, and the percentage of support phase decreased, basically consistent with previous research findings[^37-39], suggesting that family rehabilitation training can promote improvements in standing, walking, and gait patterns in children with CP. The reasons may be related to the repeated practice of standing control, lower-limb weight-bearing, walking transitions, and functional mobility during the training process, which helps enhance lower-limb muscle strength and improve joint control and motor coordination, thereby improving gross motor function and sustained walking ability. From a clinical perspective, improvements in the primary functional outcomes in this study were not only statistically significant but also had certain clinical interpretive value. Previous studies have shown that the MCID of GMFM-88 zones D and E and the 6MWT in children with CP can be referenced as 0.8%-5.2%, 0.3%-4.9%, and 6-23 m, respectively, and that the MCID reference range for the 6MWT in children with GMFCS levels I-II is 4-28 m[^40]; research on outcome measures for ambulatory children with CP also suggests that MCID can be used to assist in judging the clinical importance of functional changes[^41]. In this study, calculated using full scores of 39 points for zone D and 72 points for zone E showed that, in the conventional family rehabilitation group, zones D and E increased by approximately 5.0% and 4.1%, respectively, and the 6MWT increased by 26.1 m; in the smart home rehabilitation group, zones D and E increased by approximately 13.6% and 8.6%, respectively, and the 6MWT increased by 56.9 m, suggesting that changes in the primary outcomes in both groups may have reached a clinically perceptible level, and that improvement in the smart home rehabilitation group was more

significant. Similar enhanced or add-on rehabilitation intervention studies have also shown that different degrees of improvement may occur in GMFM-88 domains D and E

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, indicating that the magnitude of improvement in the intelligent home rehabilitation group in this study was within an interpretable range. In terms of effect size, the remote structured family training study by Sel et al.

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showed effect sizes of multiple outcomes in the intervention group of d=0.70-4.64; supplementary estimates in the present study showed that, after intervention, the between-group Cohen's d values for GMFM-88 domains D and E and 6MWT were approximately 0.63, 0.64, and 0.92, respectively, and the between-group Cohen' s d values for change scores were approximately 0.96, 1.04, and 1.94, respectively. These findings suggest that the intelligent home rehabilitation system had moderate to relatively large practical effects on standing function, gross motor function related to walking, and walking endurance.

Activities of daily living reflect the transfer effect of functional recovery in children with CP in real-life situations. Owing to limitations in motor control, postural stability, and mobility, children with CP often show varying degrees of dependence in activities such as dressing, eating, transferring, and moving

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. In this study, PEDI self-care and mobility scores increased in both groups after intervention, and the improvement was more pronounced in the intelligent home rehabilitation group, which is generally consistent with previous findings

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. This suggests that standardized family training can not only improve motor function, but also help promote the transfer of functional recovery to activities of daily living.

Adherence to family training is an important factor influencing the effects of home-based rehabilitation. Pediatric neurorehabilitation usually requires long training cycles and high frequency, and family caregivers bear important responsibilities in training organization, process accompaniment, and implementation supervision. If family training lacks clear guidance and effective feedback, it can easily lead to decreased completion rates and increased interruptions. In this study, the completion rates of family training in both groups were relatively high, but the intelligent home rehabilitation group had a higher actual number of completed sessions and training completion rate, and fewer training interruptions, suggesting that the intelligent system has certain advantages in improving the continuity of family training and the stability of implementation. At the same time, scores on all dimensions of caregiver SF-36 increased after intervention in both groups, while the ZBI total score, personal burden, and role burden scores decreased compared with before intervention, indicating that while family rehabilitation training improved children' s function, it may also have reduced caregiver stress. The more pronounced improvement in quality of life and reduction in burden among caregivers in the intelligent home rehabilitation group may be related to the system' s reduction of caregivers' burden in training organization, movement supervision, and effect judgment

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Taken together, the intelligent home rehabilitation group showed greater improvements than the conventional family rehabilitation group in MAS, BBS, GMFM-88 domains D and E, 6MWT, gait parameters, PEDI, family training adherence, SF-36, and ZBI, indicating that, on the basis that both intervention methods can promote functional recovery in children with CP and improve family caregiving outcomes, the intelligent home rehabilitation system has more obvious comprehensive intervention advantages. The possible reasons are as follows:

(1) The intelligent home rehabilitation system can provide individualized training plans according to the child' s functional level, training goals, and stage-specific rehabilitation needs, making the match between training content and the child' s current ability status higher. Compared with conventional family rehabilitation, which relies more on unified or experiential arrangements, individualized training is more conducive to ensuring that training intensity, movement difficulty, and practice content remain within an appropriate range, thereby improving the specificity and effectiveness of the intervention.

(2) Through video demonstrations, graphic explanations, and voice prompts, the system provides continuous and intuitive guidance for training movements, helping family caregivers and children understand training requirements more accurately and reducing movement errors and training deviation caused by misunderstanding. For CP rehabilitation that requires long-term reliance on family implementation, this clear and standardized guidance can, to a certain extent, compensate for insufficient professional guidance in the home setting.

(3) The intelligent home rehabilitation system has movement-recognition and real-time feedback functions. During training, it can indicate whether movements are in place, whether posture is correct, and whether the training rhythm is reasonable, thereby reducing compensatory movements and ineffective practice. From the perspective of motor learning, the formation of functional movements does not depend solely on the number of repetitions; rather, stable motor patterns are gradually formed in goal-directed task practice through external feedback, error recognition, and movement correction. Knowledge of results (KR), as an important form of external feedback in motor learning, has been emphasized by classical feedback theory

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. The OPTIMAL theory of motor learning proposed by Wulf and Lewthwaite

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further points out that enhancing expectancies for success, supporting autonomy, and directing an external focus of attention help improve motor performance and skill retention. Existing systematic reviews of external feedback and motor learning in children with CP have also suggested that children with CP can benefit from external feedback, but the form, frequency, and timing of feedback should be matched to the child's functional level and task characteristics

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. In this study, through action demonstrations, real-time prompts, process correction, and result recording, the intelligent feedback mechanism helped children and caregivers promptly identify problems such as insufficient movement amplitude, postural compensation, and abnormal rhythm, enabling family training to form a motor-learning pathway of “goal presentation—movement execution—feedback correction—repeated consolidation—functional transfer,” thereby improving the standardization and effectiveness of training. This may be one of the important mechanisms by which the intelligent home rehabilitation group achieved more pronounced recovery of children’ s function and improvement in activities of daily living.

(4) The system automatically records the training process and completion status, so that the training plan, number of completed sessions, training interruptions, and stage-specific changes can all be visualized. This not only improves the continuity and traceability of training management, but also strengthens the external supervisory effect of family training. Compared with conventional family rehabilitation, the intelligent home rehabilitation system no longer leaves training only at the level of “whether it was done,” but further extends it to process management such as “how it was done, to what extent it was completed, and whether adjustment is needed,” thereby being more conducive to improving adherence to family training.

(5) The system supports medical staff in remotely viewing training progress and making dynamic adjustments, helping to achieve effective linkage between the family setting and professional rehabilitation guidance. For children with CP, who require long-term and continuous intervention, the training program is not fixed once formulated, but should be continuously optimized as function changes. The intelligent system enables rehabilitation therapists to revise the program in a timely manner based on training data and stage-specific performance, thereby improving the continuity and precision of rehabilitation intervention.

(6) Improvements in family caregiver outcomes may be jointly related to the child’ s functional recovery, improved quality of training implementation, and intelligent-system support. Through standardized movement guidance, training reminders, process recording, and remote feedback, the intelligent home rehabilitation system reduced the cognitive burden and operational difficulty for caregivers in family training organization, movement supervision, and effect judgment; at the same time, as the child’ s muscu-

strength, balance, walking ability, and activities of daily living improved, the actual pressure on caregivers in daily care, rehabilitation accompaniment, and functional assistance may have lessened accordingly. Therefore, the improvement in caregivers’ quality of life and the reduction in care burden in the intelligent home-based rehabilitation group may be the result of the combined effects of system support, enhanced training adherence, and improvements in children’ s function.

This study suggests that intelligent home-based rehabilitation training has relatively good effects on functional recovery and family caregiving improvement in children with CP aged 6–9 years, GMFCS levels I–II, and with basic independent walking ability, and may provide preliminary reference for home-based rehabilitation of children with mild-to-moderate motor dysfunction due to CP. It should be noted that this study still has certain limitations. The sample size was relatively small, and the sources of study participants were relatively limited; the generalizability of the conclusions still needs further validation in multicenter, large-sample studies. The intervention period was 12 weeks, and the long-term maintenance effect of the intelligent home-based rehabilitation system has not yet been observed. For children with CP at GMFCS levels III–V, who cannot independently complete walking tasks or have severe cognitive, visual, or hearing impairments, the applicability and intervention effect of the intelligent home-based rehabilitation system remain to be further explored. Although this study used assessor blinding, blinding may still have been compromised because children or family members unintentionally mentioned the training method during assessment, thereby producing a certain measurement bias. Meanwhile, because the intelligent group was guided by the system, its "effective training time" may have been longer, and the resulting bias may have had some influence on the results. In addition, this study mainly used scales and behavioral indicators to evaluate intervention effects, and objective indicators such as neuromuscular control mechanisms, effective movement duration, movement compliance rate, and training intensity were insufficiently analyzed. Future studies may further improve the research design by expanding the sample size, extending follow-up, and enriching objective evaluation indicators.

Authors' contributions: Zhan Qianhui was responsible for the study conception and design, study implementation, and manuscript drafting and revision; Zhang Xiaozhen was responsible for data collection and organization; Wang Shuai was responsible for manuscript revision; Zhou Jihe was responsible for feasibility analysis of the study; Rubtsova Nataliya Olegovna was responsible for guidance on study design.

The authors declare no conflicts of interest.

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