

Original Article

Effects of AI-Based Gamified Virtual Therapy on Motor Skills and Engagement in Children with Cerebral Palsy

Hafiza Sana Qayyum^{1, 2}, Dr Zahra Khalid³, Dr Muhammad Arif⁴, Hafiza Rabia Irshad⁵, Zainab Salam⁶, Dr Tamjeed Ghaffar⁷

¹ Doctor, MARS Institute of Health Sciences for Women, Lahore, Pakistan

² Doctor, Amina Physio and Rehabilitation Center, Lahore, Pakistan

³ Chief Physiotherapist and Head of Neuro Rehab Department, PINS, Lahore, Pakistan

⁴ Associate professor, Gulab Devi institute of physiotherapy, Gulab Devi Hospital Lahore., Pakistan

⁵ Department of Physical Therapy, AHS, International Institute of Science, Arts and Technology (IISAT University), Gujranwala, Pakistan

⁶ Lecturer, Superior University, Lahore, Pakistan

⁷ Lecturer, Government College University Faisalabad, Faisalabad, Pakistan

✉ Correspondence: Hafiza sana qayyum, dr.hafizasana@gmail.com

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ABSTRACT

Background: Cerebral palsy is associated with persistent motor impairments that may restrict functional performance and participation in rehabilitation. AI-based gamified virtual therapy may support repetitive motor practice while enhancing engagement through adaptive tasks and interactive feedback. **Objective:** To examine changes in motor performance and therapy engagement among children with cerebral palsy following a 12-week AI-based gamified virtual therapy program. **Methods:** A prospective single-arm pre-post interventional study included 40 children with cerebral palsy recruited from pediatric rehabilitation centers. Participants received 30–45-minute AI-based gamified virtual therapy sessions three times weekly for 12 weeks. Motor outcomes included Gross Motor Function Measure (GMFM), Pediatric Balance Scale, and coordination scores, while engagement was assessed through attendance, task completion, and motivation scores. Descriptive statistics and paired pre-post comparisons were performed, with $p < 0.05$ considered statistically significant. **Results:** Mean age was 9.2 ± 2.8 years; 24 (60.0%) participants were male. GMFM increased from $54.6 \pm 10.2\%$ to $67.8 \pm 11.5\%$, balance from 32.5 ± 6.8 to 41.7 ± 7.2 , and coordination from 48.3 ± 9.1 to 62.4 ± 10.3 (all $p < 0.001$). Attendance increased from 78.5% to 94.2%, task completion from 71.6% to 91.8%, and motivation from 3.1 to 4.5. **Conclusion:** AI-based gamified virtual therapy was associated with favorable within-group changes in motor performance and engagement; controlled studies are required to establish comparative effectiveness. **Keywords:** Artificial intelligence; Gamification; Cerebral palsy; Virtual therapy; Motor skills; Engagement; Pediatric rehabilitation; Neurorehabilitation.

INTRODUCTION

Cerebral palsy (CP) is a persistent neurodevelopmental condition characterized by impairments in movement, posture, coordination, and functional mobility that can restrict participation in everyday activities throughout childhood. Motor limitations may affect balance, reaching, postural control, and the performance of age-appropriate functional tasks, creating a continuing need for rehabilitation aimed at promoting motor learning and functional independence (1). Although physiotherapy remains central to the management of children with CP, rehabilitation commonly requires repeated task-specific practice over extended periods. Maintaining children's

active participation during repetitive therapeutic activities can therefore be challenging, particularly when exercises are perceived as monotonous or insufficiently engaging.

Advances in digital rehabilitation have expanded opportunities to deliver therapeutic exercises through interactive and adaptive environments. Artificial intelligence (AI)-supported rehabilitation technologies can use performance-related information to assist movement assessment, deliver real-time feedback, and adapt rehabilitation tasks according to the individual's abilities and progression (2,3). Within pediatric rehabilitation, AI has also been explored for capturing functional participation and supporting more individualized assessment and intervention approaches (4). These capabilities are potentially valuable for children with motor disabilities because rehabilitation tasks can be modified progressively while maintaining a level of challenge appropriate to the child's performance.

Gamification may further complement technology-assisted rehabilitation by incorporating goals, feedback, rewards, progression, and interactive challenges into therapeutic activities. Digital games have been increasingly investigated in pediatric rehabilitation because their interactive characteristics may improve motivation and sustained participation during repeated practice (5). Similarly, AI-supported mixed-reality rehabilitation systems have been proposed to combine adaptive exercise prescription with gamified modules for individuals with locomotor disabilities, emphasizing the potential role of intelligent technologies in promoting engagement during rehabilitation (6). Such approaches are particularly relevant to pediatric neurorehabilitation, where both the therapeutic dose of motor practice and the child's willingness to participate may influence rehabilitation delivery.

Emerging evidence from rehabilitation and neurodevelopmental populations also suggests that AI-enhanced and adaptive interventions may support individualized motor and cognitive training. An AI-enhanced motor and cognitive intervention has demonstrated the feasibility of adapting therapeutic activities according to individual performance in a child with developmental delay (7). In parallel, recent work has proposed combining intelligent learning systems with gaming approaches to enhance engagement and individualized intervention in neurodevelopmental disorders (8). Nevertheless, evidence derived from developmental delay, speech rehabilitation, mixed locomotor disabilities, or broader neurodevelopmental populations cannot be assumed to establish effectiveness specifically for motor rehabilitation in children with CP.

Despite growing interest in AI, virtual rehabilitation, and gamification, an important evidence gap remains regarding their combined application in children with cerebral palsy. In particular, relatively limited attention has been given to interventions in which gamified virtual motor tasks are coupled with adaptive AI-based performance monitoring while simultaneously evaluating both functional motor outcomes and therapy engagement. Examining these domains together is clinically relevant because an intervention that improves participation without measurable motor improvement, or motor performance without adequate engagement, may have limited practical value for sustained pediatric rehabilitation.

Therefore, the present study aimed to examine changes in motor performance and therapy engagement among children with cerebral palsy following a 12-week AI-based gamified virtual therapy program. Specifically, the study evaluated pre- to post-intervention changes in gross motor function, balance, coordination, session attendance, task completion, and motivation within a prospective single-arm interventional framework.

MATERIALS AND METHODS

A prospective single-arm pre-post interventional study was conducted to evaluate changes in motor performance and therapy engagement following AI-based gamified virtual therapy in children with cerebral palsy. The study included 40 children with a confirmed diagnosis of cerebral palsy who were recruited from pediatric rehabilitation centers. Children aged 5–15 years who were able to understand and follow instructions required for participation in the virtual rehabilitation activities were eligible for inclusion. Children with severe cognitive impairment or medical conditions that restricted safety or meaningful participation in the intervention were excluded. The study used a within-participant pre-post framework in which motor and engagement outcomes were evaluated before initiation of the intervention and reassessed after completion of the 12-week therapy program. No parallel control or conventional-rehabilitation comparison group was included in the reported study design.

The intervention consisted of AI-based gamified virtual therapy delivered over 12 weeks. Participants attended three therapy sessions per week, with each session lasting approximately 30–45 minutes. The therapeutic program

incorporated interactive virtual games designed to facilitate balance, coordination, reaching, postural control, and functional movement through repeated task-oriented activities. During therapy, participant performance was monitored through motion-sensor input, and the system automatically modified task difficulty according to individual performance and progression. Real-time performance feedback, achievement scores, progressive task challenges, and reward-based elements were incorporated into the virtual activities to support continued participation and motivation. The same overall intervention frequency and duration were applied throughout the 12-week treatment period.

Motor performance was evaluated before and after the intervention using measures of gross motor function, balance, and coordination. Gross motor function was assessed using the Gross Motor Function Measure (GMFM), with scores expressed as percentages in the study dataset. Balance was evaluated using the Pediatric Balance Scale (PBS). Functional reaching and coordination were additionally assessed using the functional reaching and coordination measure employed in the study. These measures were selected to capture changes across clinically relevant domains of motor performance, including gross motor ability, postural stability, reaching, and coordinated functional movement. Outcome assessment was performed at baseline before commencement of AI-based gamified virtual therapy and repeated following completion of the 12-week intervention.

Therapy engagement was evaluated using session attendance, task-completion rate, and child motivation scores. Session attendance was expressed as the percentage of scheduled therapy participation, whereas task completion represented the proportion of assigned therapeutic activities completed by the child. Motivation was assessed using the child motivation questionnaire used during the study. The engagement measures available in the study were examined across the reported pre- and post-intervention assessment periods to determine changes in participation and motivational involvement associated with the rehabilitation program.

Participant characteristics were summarized using descriptive statistics. Continuous variables, including age and outcome scores, were presented as mean $\pm$ standard deviation, whereas categorical characteristics such as sex were summarized as frequencies and percentages. Pre- and post-intervention motor and engagement outcomes were evaluated using paired statistical comparisons to account for repeated measurements obtained from the same participants. Differences in GMFM, balance, coordination, attendance, task completion, and motivation scores were evaluated using the available pre- and post-intervention measurements. Statistical significance was defined at a two-sided p-value of <0.05 .

RESULTS

A total of 40 children with cerebral palsy were included in the study. The mean age of participants was 9.2 ± 2.8 years. Of the 40 children, 24 (60.0%) were male and 16 (40.0%) were female (Table 1).

Motor performance increased across all three reported outcome measures after the 12-week AI-based gamified virtual therapy program. The mean GMFM score increased from $54.6 \pm 10.2\%$ at baseline to $67.8 \pm 11.5\%$ after intervention, corresponding to a mean increase of 13.2 percentage points ($p < 0.001$). The mean Pediatric Balance Scale score increased from 32.5 ± 6.8 to 41.7 ± 7.2 , with an absolute increase of 9.2 points ($p < 0.001$). Similarly, the mean coordination score increased from 48.3 ± 9.1 to 62.4 ± 10.3 , representing a 14.1-point increase ($p < 0.001$) (Table 2).

Table 1. Baseline Characteristics of the Study Participants (n=40)

Variable	Value
Age, years, mean $\pm$ SD	9.2 ± 2.8
Male, n (%)	24 (60.0)
Female, n (%)	16 (40.0)

Abbreviation: SD, standard deviation.

Table 2. Pre- and Post-Intervention Motor Outcomes

Outcome	Baseline, mean $\pm$ SD	12 weeks, mean $\pm$ SD	Mean change	p-value
GMFM score, %	54.6 ± 10.2	67.8 ± 11.5	13.2	<0.001
Pediatric Balance Scale score	32.5 ± 6.8	41.7 ± 7.2	9.2	<0.001
Coordination score	48.3 ± 9.1	62.4 ± 10.3	14.1	<0.001

Abbreviations: GMFM, Gross Motor Function Measure; SD, standard deviation. Statistical significance threshold: $p < 0.05$.

Table 3. Pre- and Post-Intervention Therapy Engagement Outcomes

Outcome	Baseline, mean $\pm$ SD	12 weeks, mean $\pm$ SD	Mean change
Session attendance, %	78.5 $\pm$ 9.4	94.2 $\pm$ 5.1	15.7
Task completion, %	71.6 $\pm$ 11.2	91.8 $\pm$ 6.7	20.2
Motivation score	3.1 $\pm$ 0.8	4.5 $\pm$ 0.5	1.4

Abbreviation: SD, standard deviation.

Therapy-engagement measures also showed higher post-intervention values. Mean session attendance increased from 78.5 $\pm$ 9.4% to 94.2 $\pm$ 5.1%, an absolute increase of 15.7 percentage points. Task completion increased from 71.6 $\pm$ 11.2% to 91.8 $\pm$ 6.7%, corresponding to a 20.2-percentage-point increase. Mean motivation score increased from 3.1 $\pm$ 0.8 at baseline to 4.5 $\pm$ 0.5 after the intervention, with an absolute change of 1.4 points (Table 3). Because inferential statistics were not reported for these engagement outcomes, these changes are presented descriptively.

DISCUSSION

The present study found that a 12-week AI-based gamified virtual therapy program was followed by improvements in gross motor function, balance, and coordination among children with cerebral palsy, together with higher post-intervention attendance, task-completion, and motivation scores. These findings address the study objective by indicating favorable changes across both motor-performance and engagement domains. However, because the study used a single-arm pre-post design, the observed changes should be interpreted as within-group improvements associated with the intervention period rather than evidence of comparative or causal effectiveness.

The direction of the motor findings is broadly compatible with the growing use of technology-assisted rehabilitation for neurological and motor impairments. AI-supported rehabilitation systems have been described as capable of integrating movement monitoring, feedback, and individualized adjustment of therapeutic tasks, potentially allowing rehabilitation activities to be adapted to users' performance and functional abilities (2,3). Technology-assisted approaches have also been explored specifically in cerebral palsy rehabilitation, where robotic and digitally supported interventions have been proposed as means of increasing the intensity, repeatability, and individualization of motor practice (1). Nevertheless, the available evidence remains heterogeneous with respect to technologies, populations, intervention intensity, and outcome measures, and therefore cannot be considered directly equivalent to the intervention evaluated in the present study.

The observed changes in motor performance may plausibly relate to several characteristics of the intervention. Repeated practice of balance, reaching, postural-control, coordination, and functional movement tasks may facilitate motor learning when activities are delivered at an appropriate level of challenge. AI-based rehabilitation technologies may further support this process by using performance information to modify exercises and provide timely feedback (2,3). In a 12-week case-based intervention involving a child with developmental delay, an AI-enhanced motor and cognitive program was also associated with improvement in motor-coordination measures, providing preliminary support for the feasibility of adaptive technology-assisted training in pediatric rehabilitation (7). However, that evidence was derived from a different diagnosis and a single participant, and therefore should be considered supportive of feasibility rather than direct evidence for effectiveness in cerebral palsy.

Engagement represents another potentially important feature of digitally supported pediatric rehabilitation. The higher post-intervention attendance, task-completion, and motivation scores observed in the present study suggest that children participated more actively during the intervention period, although these engagement outcomes were not accompanied by reported inferential statistics and should therefore be interpreted descriptively. Previous literature has highlighted the potential of interactive digital games to promote motivation and participation among children receiving rehabilitation or learning-related interventions (5). Similarly, AI-supported mixed-reality rehabilitation systems have incorporated rewards, interactive challenges, performance feedback, and adaptive difficulty with the intention of sustaining participation during repetitive therapeutic activities (6). AI-based approaches have also been investigated for capturing and operationalizing participation in

pediatric rehabilitation, demonstrating the increasing interest in integrating intelligent technologies with participation-focused assessment and care (4). These observations provide a plausible contextual explanation for the engagement pattern identified in the present study, but they do not establish that gamification or AI adaptation independently caused the observed changes.

The combination of adaptive feedback and game-based activities may be particularly relevant in pediatric neurorehabilitation because effective motor training commonly depends on repeated practice, while sustained participation may be difficult to maintain over prolonged treatment periods. Proposed models combining deep or reinforcement learning with gaming similarly emphasize personalization, feedback, and engagement as potential components of technology-supported interventions for neurodevelopmental disorders (8). Importantly, these mechanisms remain largely theoretical in relation to the current dataset because the study did not independently measure motor-learning mechanisms, feedback responsiveness, frequency of AI-driven adaptation, or the contribution of individual intervention components. The present findings therefore support further evaluation of integrated AI and gamification approaches but do not determine whether the observed motor changes resulted specifically from artificial intelligence, gaming elements, increased exercise exposure, therapist interaction, or their combination.

From a clinical perspective, the simultaneous observation of improved motor scores and favorable engagement patterns is relevant because sustained participation is an important practical consideration in pediatric rehabilitation. If confirmed in controlled studies, adaptive gamified technologies could potentially complement therapist-directed rehabilitation by providing structured repetitive practice while maintaining children's involvement. The current findings should not, however, be interpreted as evidence that AI-based virtual therapy can replace conventional physiotherapy. The absence of a concurrent comparison group prevents determination of whether the observed changes were greater than those expected with conventional rehabilitation, routine development, repeated assessment, or other concurrent therapeutic activities.

The study has several strengths, including prospective evaluation over a 12-week intervention period, repeated measurement of the same participants, assessment of several clinically relevant motor domains, and inclusion of engagement outcomes in addition to functional performance. These strengths allowed the study to examine whether motor and participation-related measures changed in parallel during the intervention period. Nevertheless, several limitations substantially affect interpretation. The sample was relatively small, and the absence of a control group means that maturation, regression to the mean, repeated-testing effects, additional rehabilitation, therapist attention, and novelty effects cannot be excluded as alternative explanations for the observed changes. Long-term follow-up was not performed, so persistence of the observed improvements is unknown. Detailed cerebral palsy characteristics and functional classification were not reported, limiting assessment of generalizability across different clinical presentations and severity levels. In addition, the precise coordination and motivation instruments were insufficiently characterized, assessor blinding was not established, and confidence intervals and paired standardized effect sizes could not be determined from the reported summary data. Inferential statistics were also unavailable for the engagement outcomes. Finally, the AI algorithm, adaptation procedures, and intervention-fidelity measures were not described in sufficient detail to determine which technological components were responsible for the observed patterns. These limitations indicate that the findings should be regarded as preliminary evidence of favorable within-group change that requires confirmation through adequately powered controlled studies.

CONCLUSION

Following 12 weeks of AI-based gamified virtual therapy, children with cerebral palsy demonstrated favorable within-group changes in gross motor function, balance, and coordination, together with higher post-intervention attendance, task-completion, and motivation scores. These findings suggest that an integrated AI-supported gamified rehabilitation approach may be a useful complementary strategy for supporting motor practice and engagement in pediatric cerebral palsy rehabilitation. However, because the study lacked a concurrent control group, the findings establish pre-post improvement within the studied cohort rather than comparative or causal effectiveness.

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