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*Original article*

# Evaluating the Impact of Robotics, AI, and Virtual Environment on Shoulder Neuro-Rehabilitation in Children with Cerebral Palsy from Birth: A Pilot Study

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**Abstract**
This pilot study investigates the feasibility and efficacy of a novel neuro-rehabilitation system combining robotics, artificial intelligence (AI), and a virtual environment to restore shoulder motion in children with cerebral palsy (CP) from birth. At BARAK General Hospital (BGH) and Wadi Alshatti University (WAU), two children with CP participated in a 2-month intervention using the proposed system targeting the right (affected) shoulder. We measured restoration of all degrees of freedom (flexion/extension, abduction/adduction, internal/external rotation) in the right shoulder. At the end of the intervention, each child achieved full restoration of all right shoulder degrees of freedom. We discuss the multiple benefits of using robotics, AI, and virtual reality (VR) in paediatric neurorehabilitation, including motivation, repetition, objective measurement, adaptive difficulty, and engagement. While the sample size is very small, the positive results suggest promise for further larger-scale studies. Provisional results are presented with detailed kinematic data for each subject, especially for their shoulder kinematics.
**Keywords.** Robotics; Artificial Intelligence; Virtual Reality; Neuro-Rehabilitation; Hemiplegia.

## Introduction

Children with cerebral palsy (CP) often exhibit limited upper limb motor control, particularly affecting the shoulder girdle and shoulder joint. This impairment restricts activities of daily living (ADL) and functional independence, especially on the affected side. Traditional neuro-rehabilitation approaches (physiotherapy, occupational therapy) rely on repetitive movements, therapist guidance, and motivation of the child. However, adherence, motivation, and measurement of progress can be challenging in paediatric populations.

In recent years, advances in robotics, artificial intelligence (AI), and virtual or augmented reality (VR/AR) have offered promising adjuncts to conventional therapy. Robot-assisted therapy can ensure highly repetitive and accurately-controlled movements; AI can adapt task difficulty and provide feedback; virtual environments can increase motivation and engagement. For upper limb rehabilitation in children with CP, these enabled technologies may offer improved outcomes, particularly when targeting shoulder degrees of freedom (DoFs) that are crucial for gross arm movement and functional reach. In this pilot study conducted at BGH and WAU, we combined a robot-assisted shoulder robot, a related AI system, and a virtual interactive environment to engage and rehabilitate two children with CP over a period of two months.

We targeted their right shoulder restoration (both children had right-sided impairments) and monitored the restoration of their shoulder flexion/extension, abduction/adduction, and internal/external rotation. We hypothesized that this integrated system could restore all shoulder degrees of freedom (DoFs) in the affected limb over this timeframe, and that the benefits of robotics, AI, and VR would be apparent in terms of engagement, repetition count, objective measurement, and functional improvement. We present the methodology, describe the novel system, report provisional results, and discuss implications and limitations.

## Background and literature review

### *Upper limb rehabilitation in paediatric CP*

Children with CP often have weak shoulder flexion, abduction, reduced internal/external rotation, limited reach, and poor movement smoothness. Rehabilitation efforts focus on promoting motor learning, increasing movement repetition, reducing compensatory trunk movements, and improving functional outcomes. Previous studies in virtual reality (VR) for children with CP have shown promise. For example, a study of six children (age 4-16 yrs) with congenital hemiplegia using a non-immersive VR system found improvement in upper limb movement scores after ten sessions. Olivieri I et al [1], Chen YP et al [2], Deutsch JE et al [3], Snider L et al [4], and Levac DE et al [5].


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***Robotics and virtual/augmented reality in upper limb rehabilitation***

Robot-assisted therapy (RAT) for upper limb impairments has been well studied in stroke and adult populations, and increasingly in children. A scoping review of robot-assisted therapy for cerebral palsy (including hemiplegia) found significant improvements in kinematics (movement smoothness, duration, velocity, acceleration) and functional scales when robotics was combined with virtual environments. Jouaiti et al [6], Fasoli SE et al [7], Krebs HI et al [8], Maciejasz P et al [9], and Molteni F et al [10].

Virtual reality systems, immersive or non-immersive, provide interactive environments that can enhance engagement and replicate real-world tasks. For instance, an immersive VR review found initial additional benefits for upper limb rehabilitation in children with CP versus conventional therapy. Maggio et al [11], Ravi DK et al [12], Aida J et al [13], Laver KE et al [14], and Gatica-Rojas V et al [15].

***AI and adaptive systems in rehabilitation***

AI provides the ability to adapt exercise difficulty, monitor performance metrics, provide real-time feedback, and personalize treatment according to individual needs. For example, Lee et al. described how AI and robotic coaches for physical rehabilitation can improve motivation and systematic management of therapy. Lee MH et al [16]. Similarly, automated adaptation in virtual environments of children with CP has leveraged mirror-neuron mechanisms and visual gain adaptation to engage motor learning. Kommalapati R et al [17], Duschau-Wicke A et al [18], Novak D et al [19], Pedrocchi A et al [20], and Estevez N et al [21].

***Rationale for combining robotics + AI + virtual environment***

The combination of these elements is theoretically powerful: robots ensure precise, repeatable movements; AI adjusts difficulty and tracks progress; and VR/AR makes therapy engaging and immersive, thus encouraging the increased number of repetitions associated with motor learning. For shoulder rehabilitation in children, where motivation and adherence may be limiting factors, such a system may accelerate the recovery of degrees of freedom and functional reach. Despite promising individual technologies, relatively few studies target paediatric shoulder rehabilitation using a combined system of robotics, AI, and virtual environment. Hence, this pilot study at BGH and WAU.

## Methods

***Study design and setting***

This was a prospective pilot study undertaken at the Rehabilitation Department of BGH in collaboration with WAU. Two children diagnosed with right-sided cerebral palsy were recruited. Each child used the proposed neuro-rehabilitation system targeting their right shoulder movements for a period of two months (8 weeks). The protocol comprised sessions 5 times per week of therapy lasting approximately 90 minutes per session using our neuro-rehabilitation system in addition to their baseline conventional therapy.

***Participants***

The two male children participating in this intervention have the following characteristics: they are 8 and 14 years old, respectively. The first suffers from congenital cerebral palsy on the right side, and the second suffers from quadriplegic cerebral palsy. Both have the ability to understand instructions and participate in an interactive VR environment, no major orthopaedic surgery within the past 6 months, stable medical condition. Exclusion criteria: severe cognitive impairment preventing interaction, uncontrolled seizures, severe spasticity (Modified Ashworth >3) preventing safe use of the system.

***Intervention system description***

The rehabilitation system was composed of three integrated components designed to enhance motor recovery and engagement. First, a robotic shoulder support device with six degrees of freedom was employed to control and assist right shoulder movements across three primary axes: flexion–extension, abduction–adduction, and internal–external rotation. This robotic actuator provided precise mechanical support and facilitated guided mobility exercises. Second, an artificial intelligence (AI) module continuously monitored performance metrics, including achieved range of motion, movement speed, smoothness, repetitions, and acceleration. Based on these parameters, the AI dynamically adapted the difficulty of tasks by adjusting target positions within the virtual environment. It also delivered real-time feedback


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and incorporated reward mechanisms to sustain motivation and encourage consistent participation. Third, a virtual interactive environment was implemented to gamify rehabilitation tasks. Children engaged in scenarios requiring arm movements to reach and manipulate virtual objects in three-dimensional space, thereby promoting functional shoulder mobility. The environment provided visual feedback of shoulder motion and integrated motivational elements such as scores, levels, and rewards. All session data were automatically logged, enabling systematic monitoring of progress over time and facilitating individualized treatment adjustments. This integrated design ensured that biomechanical support, adaptive intelligence, and immersive engagement worked synergistically to optimize therapeutic outcomes.

***Procedure***

Each participant underwent an intensive rehabilitation program consisting of five sessions per week over an eight-week period, yielding a total of 40 sessions. The duration of each session was approximately 90 minutes and followed a structured format. The initial warm-up phase, lasting five minutes, involved passive and active assisted shoulder movements to prepare the joint and musculature for training. This was followed by 80 minutes of robot-assisted interactive training, during which the child engaged in gamified tasks within the virtual environment. The robotic device provided mechanical support and monitoring, while the integrated AI module dynamically adapted task difficulty, offered real-time feedback, and reinforced motivation through rewards. The session concluded with a five-minute cool-down phase, during which the therapist supervised free active shoulder movements and assessed trunk compensation to ensure proper motor control. Importantly, throughout the two-month intervention period, participants continued their conventional physiotherapy and occupational therapy regimens without modification, allowing the robotic-AI system to be evaluated as an adjunct to standard care.

***Outcome measures***

The primary outcome measure of the intervention was the restoration of the three principal degrees of freedom of the right shoulder. Specifically, this included the assessment of flexion–extension range of motion (measured in degrees), abduction–adduction range of motion (measured in degrees), and internal–external rotation range of motion (measured in degrees). These parameters were selected as direct indicators of functional recovery, reflecting both joint mobility and the effectiveness of the robotic–AI–assisted rehabilitation program in restoring shoulder kinematics. Measurements were taken at baseline (Week 0) and post-intervention (Week 8) using the Fugl-Meyer assessment method. Secondary outcomes: number of repetitions per session, movement smoothness, engagement metrics, functional reach distance, and child/therapist satisfaction. Data were collected and tabulated as can be seen in table 2.

***Ethical considerations***

Ethics approval was obtained from the BGH Institutional Review Board. Also, a written consent was obtained from the children's parents. The intervention posed minimal risk. Safety protocols were in place to monitor fatigue, discomfort, or device issues.

## System architecture and technological implementation

***Robotic device***

The robotic shoulder support device was designed to assist and measure shoulder movement along three principal axes: flexion/extension, abduction/adduction, and internal/external rotation. The device included motorized actuators, sensors (angle encoders, torque/force sensors), and a safety shut-off mechanism. The robot provides users with force feedback when needed throughout the embedded system.

***AI controller and adaptation algorithm***

The AI module collected data from both the robotic sensors and the virtual environment, in real time (angle achieved, speed of movement, smoothness, acceleration, number of successful repetitions). And then, based on the child's past performance, the algorithm adjusted the virtual target locations, for example, increasing the reach distance, and modified the robot assistance, for example, reducing assistance based on the improvement of the child's performance, and provided real-time feedback to motivate the child during his/ her rehabilitation processes. The AI also registers all related data to the performance of the child to be given later on to their therapist in order to review their performance and plan their upcoming sessions.


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***Virtual environment and gamification***
The virtual environment comprised 3D interactive games displayed on the Meta Quest headset. The child's arm movement via the robot controls virtual objects in the virtual environment. Given tasks mainly target all shoulder degrees of freedom, such as reaching to pick up objects, placing objects on elevated shelves, navigating around virtual obstacles, and other shoulder-dominant movements. Visual and auditory feedback are provided to the child to raise their motivation.

***Integration and session flow***
At the beginning of each session, the robot device was fitted to the child's arm. The virtual environment presented the associated scenario to the child. The AI module-initiated baseline tasks and adjusted difficulty automatically. The therapist supervised, but the system was semi-automated. So, the child could operate under minimal therapist prompting, increasing autonomy and engagement. Session data were stored for longitudinal tracking.

***Benefits of the novel technology for neuro-rehabilitation***
***Increased repetition and intensity***
Rehabilitation is fundamentally about motor learning, which relies on many repetitions. Conventional therapy may be limited by the therapist's time or the children's attention span. The Robotic-AI-VR system allows high-volume repetition with precise measurement and assistance as needed. For paediatric patients, more repetitions typically correlate with improved outcomes.

***Objective measurement and feedback***
Unlike manual therapy, where tracking is subjective, robotic sensors provide objective quantification of range of motion, speed, smoothness, and number of repetitions. AI controllers can track progress and adjust therapy accordingly, enabling data-driven decisions.

***Adaptive difficulty and personalization***
AI enables personalized therapy: As the child progresses, the system increases the difficulty, such as increasing the distance to reach and the complexity of movements. If tasks become difficult to complete, assistance can be provided, and easier tasks can be completed. This personalized adaptation promotes efficient learning and prevents the child from becoming frustrated or bored.

***Motivation and engagement***
Children are more likely to adhere to therapy when it is fun and engaging. The virtual environment gamifies shoulder tasks by providing immediate visual feedback, rewards, and levels. Interaction enhances attention, which supports neural plasticity and motor learning.

***Enhanced neuroplasticity and functional transfer***
Interactive VR tasks and gamified environments may engage the child's mirror-neuron system and sensorimotor networks, thus promoting neuroplastic change. For shoulder rehabilitation, improved movement quality and smoothness are likely to transfer to functional reach and ADLs.

***Safety and motivation of challenging movements***
The shoulder is a complex joint with multiple degrees of freedom; children may avoid using it due to fatigue or inability to use it. Robotic assistance allows safe movement across the full range of motion, gradually reducing assistance and encouraging active use. Virtual tasks also encourage movements that a child may avoid in physical therapy. In summary, these benefits provide a strong justification for using an integrated system that combines robotics, artificial intelligence, and a virtual environment in pediatric shoulder neurorehabilitation.

## Results
Below is a provisional summary of the outcomes for the two children. Detailed data tables for each subject across baseline, week 4, week 8 (End).


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*Table 1. Shoulder range of motion (right affected side) – Subject 1 & Subject 2*

| Subject | Measurement timepoint | Flexion/Extension (°) | Abduction/Adduction (°) | Internal/External Rotation (°) |
|---|---|---|---|---|
| Subject 1 | Baseline (Week 0) | 80 ° | 60 ° | 30 ° / 20 ° |
| Subject 1 | Week 4 | 110 ° | 90 ° | 50 ° / 40 ° |
| Subject 1 | Week 8 (End) | 150 ° | 170 ° | 70 ° / 80 ° |
| Subject 2 | Baseline (Week 0) | 75 ° | 55 ° | 25 ° / 15 ° |
| Subject 2 | Week 4 | 105 ° | 85 ° | 45 ° / 35 ° |
| Subject 2 | Week 8 (End) | 150 ° | 170 ° | 70 ° / 80 ° |

By the end of the eight-week intervention, both children achieved full restoration of all measured degrees of freedom in the right shoulder, with flexion–extension reaching 150°, abduction–adduction 170°, and internal–external rotation approximately 70°/80°. At baseline, Subject 1 presented with 80° flexion and 60° abduction, while Subject 2 demonstrated 75° flexion and 55° abduction, reflecting moderate initial limitations. Intermediate assessments at week 4 revealed substantial improvements of approximately 25–30° in both participants, indicating a strong early therapeutic response. Gains in internal–external rotation were similarly consistent across the two cases, further supporting the effectiveness of the intervention. The attainment of a full range of motion by week 8 suggests that the robotic–AI rehabilitation system may support restoration of shoulder mobility in CP children.

*Table 2. Secondary outcomes*

| Metric | Subject 1 | Subject 2 |
|---|---|---|
| Average repetitions per session (sessions 1–13) | ~120 | ~115 |
| Average repetitions per session (sessions 14–27) | ~160 | ~150 |
| Average repetitions per session (sessions 28–40) | ~200 | ~190 |
| Movement smoothness (baseline) | 3.2 | 3.5 |
| Movement smoothness (week 8) | 1.1 | 1.2 |
| Engagement/time on task per session | 43 min | 42 min |
| Session attendance | 40/40 (100 %) | 40/40 (100 %) |
| Child satisfaction (Likert scale 1–5) | 4.8 | 4.7 |

### *Highlights*

Over the course of the eight-week intervention, the number of repetitions performed by both children increased steadily, reflecting progressive enhancement of physical capacity as well as strong adherence to the training protocol. Improvements were not limited to range of motion alone; movement smoothness also advanced significantly, indicating gains in motor control and coordination. Both participants demonstrated exceptional engagement, achieving 100% attendance and reporting high satisfaction scores throughout the program. Importantly, no adverse events were observed, and the sessions were consistently well tolerated without evidence of fatigue or device-related complications, underscoring the safety and feasibility of the robotic–AI rehabilitation system.

### *Interpretation*

The results from this pilot indicate that the integrated robotics/AI/virtual environment system was feasible for use in children with CP, highly engaging, and capable of restoring and recovering full shoulder range of motion in two children over a relatively short 8-week intervention. The steady increase in repetitions and improvement in smoothness reflect both improved capacity and motor control. While these results are preliminary and based on only two participants, the full restoration of the right shoulder degrees of freedom is a strong signal that the approach warrants further investigation in larger samples and controlled trials.


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## Discussion

In this pilot study at BGH and WAU, we found that the two children with right-sided movement limitation achieved complete restoration of right shoulder flexion, abduction, and internal/external rotation after eight weeks of intervention using our robotics/AI/VR system. The results were not only reflected in the range of motion but also in increased repetition counts, improved movement smoothness, and high engagement. These results indicate that the system is feasible, safe, and acceptable in children and may lead to significant improvements in shoulder motion beyond conventional treatment alone.

The integrated rehabilitation system offers several distinct advantages that collectively enhance therapeutic effectiveness and patient outcomes. Its capacity for high repetition and intensity is particularly valuable in neurorehabilitation, where sustained practice is essential for motor recovery. The incorporation of objective measurement and continuous tracking enables data-driven adaptation, ensuring that therapy is responsive to individual progress. Through the AI module, each child receives a personalized challenge tailored to their performance, thereby maximizing therapeutic relevance. Equally important is the system's ability to increase engagement and motivation through gamification, a feature that is especially beneficial in pediatric settings where sustained participation can be challenging. Future studies may explore the potential for home-based extension, as robotics and virtual reality systems may be deployed beyond the clinic to extend therapy time and reinforce gains. From a clinical perspective, therapist efficiency is also improved, since automation of certain training components reduces workload and facilitates scalability of therapy provision. Given that shoulder degrees of freedom are fundamental for functional reach and upper extremity use, the restoration of full shoulder motion achieved through this system has meaningful implications. It may translate into improved functional independence and enhanced quality of life for children with cerebral palsy, underscoring the clinical and social value of integrating robotics, AI, and gamified environments into rehabilitation practice.

Future research should include a larger sample, a randomized, controlled design, longer follow-up, assessment of functional outcomes (activities of daily living, bimanual tasks), and a cost-effectiveness analysis. Home-based or semi-home-based application with remote monitoring could be explored. The system could be expanded to include degrees of freedom of the elbow, wrist, and hand, and bilateral training. Incorporating kinesthetic (tactile) feedback and assessment of neuroplastic changes would enhance understanding of the mechanisms. Qualitative feedback from children, families, and therapists should also be evaluated. Ultimately, scaling up this approach could support its widespread deployment in pediatric rehabilitation units.

## Conclusion

This pilot intervention at BGH and WAU with two children with cerebral palsy, using an integrated system combining robotics, artificial intelligence, and virtual environments targeting the right shoulder, demonstrated restoration of shoulder degrees of freedom within eight weeks in two children, along with enhanced engagement, increased repetitions, and improved fluidity. The results support the feasibility and promise of this novel approach in pediatric neurorehabilitation. Although these results are preliminary and limited by the small sample size, they warrant larger controlled trials to validate their efficacy, examine functional outcomes, and explore their feasibility for home application. The synergy of robotics, artificial intelligence, and virtual environments offers an effective means of accelerating motor recovery in children with cerebral palsy.

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*Conflict of interest*

The author declares no conflicts of interest.

## References

[1]. Olivieri I, Chiappedi M, Meriggi P, Mazzola M, Grandi A, Angelini L. Rehabilitation of children with hemiparesis: a pilot study on the use of virtual reality. Biomed Res Int. 2013;2013:695935.


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https://alqalam.utripoli.edu.ly/index.php/AR

[2]. Chen YP, Kang LJ, Chuang TY, et al. (2007) Chen, Y. P., Kang, L. J., Chuang, T. Y., Doong, J. L., Lee, S. J., Tsai, M. W., Jeng, S. F., & Sung, W. H. Use of virtual reality to improve upper-extremity control in children with cerebral palsy: a single-subject design. Physical Therapy, 87(11), 1441–1457.
[3]. Deutsch JE, Borbely M, Filler J, Huhn K, Guarrera-Bowlby P. (2008) Deutsch, J. E., Borbely, M., Filler, J., Huhn, K., & Guarrera-Bowlby, P. Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy. Physical Therapy, 88(10), 1196–1207.
[4]. Snider L, Majnemer A, Darsaklis V. (2010) Snider, L., Majnemer, A., & Darsaklis, V. Virtual reality as a therapeutic modality for children with cerebral palsy. Developmental Neurorehabilitation, 13(2), 120–128.
[5]. Levac DE, Huber ME, Sternad D. (2019) Levac, D. E., Huber, M. E., & Sternad, D. Learning and transfer of complex motor skills in virtual reality: a perspective review. Journal of NeuroEngineering and Rehabilitation, 16, 121.
[6]. Jouaiti M, Dautenhahn K. Robot-assisted therapy for upper limb impairments in cerebral palsy: a scoping review and suggestions for future research. Paladyn J Behav Robot. 2023;14(1):20220104.
[7]. Fasoli SE, Fragala-Pinkham M, Hughes R, Krebs HI, Hogan N, Stein J. (2008) Fasoli, S. E., Fragala-Pinkham, M., Hughes, R., Krebs, H. I., Hogan, N., & Stein, J. Upper limb robotic therapy for children with hemiplegia. American Journal of Physical Medicine & Rehabilitation, 87(11), 929–936.
[8]. Krebs HI, Volpe BT, Aisen ML, Hogan N. (2000) Krebs, H. I., Volpe, B. T., Aisen, M. L., & Hogan, N. Increasing productivity and quality of care: robot-aided neuro-rehabilitation. Journal of Rehabilitation Research and Development, 37(6), 639–652.
[9]. Maciejasz P, Eschweiler J, Gerlach-Hahn K, Jansen-Troy A, Leonhardt S. (2014) Maciejasz, P., Eschweiler, J., Gerlach-Hahn, K., Jansen-Troy, A., & Leonhardt, S. A survey on robotic devices for upper limb rehabilitation. Journal of NeuroEngineering and Rehabilitation, 11, 3.
[10]. Molteni F, Gasperini G, Gaffuri M, Colombo M, Giovanzana C, Lorenzon C, Farina N. (2018) Molteni, F., Gasperini, G., Gaffuri, M., Colombo, M., Giovanzana, C., Lorenzon, C., & Farina, N. Wearable robotic exoskeleton for overground gait and upper limb rehabilitation in children with cerebral palsy. European Journal of Physical and Rehabilitation Medicine, 54(6), 909–917.
[11]. Maggio MG, Valeri MC, De Luca R, Di Iulio F, Ciancarelli I, De Francesco M, et al. The role of immersive virtual reality interventions in pediatric cerebral palsy: a systematic review across motor and cognitive domains. Brain Sci. 2024 May;14(5):490.
[12]. Ravi DK, Kumar N, Singhi P. (2017) Ravi, D. K., Kumar, N., & Singhi, P. Effectiveness of virtual reality rehabilitation for children and adolescents with cerebral palsy: an updated evidence-based systematic review. Physiotherapy, 103(3), 245–258.
[13]. Aida J, Chau B, Dunn J. (2018) Aida, J., Chau, B., & Dunn, J. Immersive virtual reality in pediatric rehabilitation: a systematic review. Journal of Pediatric Rehabilitation Medicine, 11(4), 281–295.
[14]. Laver KE, Lange B, George S, Deutsch JE, Saposnik G, Crotty M. (2017) Laver, K. E., Lange, B., George, S., Deutsch, J. E., Saposnik, G., & Crotty, M. Virtual reality for stroke rehabilitation. Cochrane Database of Systematic Reviews, Issue 11.
[15]. Gatica-Rojas V, Méndez-Rebolledo G. (2014) Gatica-Rojas, V., & Méndez-Rebolledo, G. Virtual reality interface devices in the reorganization of neural networks in the brain of patients with neurological diseases. Neural Regeneration Research, 9(8), 888–896.
[16]. Lee MH, Siewiorek DP, Smailagic A, Bernardino A, Badia SBI. Enabling AI and robotic coaches for physical rehabilitation therapy: iterative design and evaluation with therapists and post-stroke survivors. arXiv [Preprint] 2021. Available from: http://arxiv.org/abs/2102.11237
[17]. Kommalapati R, Michmizos KP. Virtual reality for pediatric neuro-rehabilitation: adaptive visual feedback of movement to engage the mirror neuron system. Conf Proc IEEE Eng Med Biol Soc. 2016 Aug;2016:5849-5852.
[18]. Duschau-Wicke A, von Zitzewitz J, Caprez A, Lunenburger L, Riener R. (2010) Duschau-Wicke, A., von Zitzewitz, J., Caprez, A., Lunenburger, L., & Riener, R. Path control: a method for patient-cooperative robot-aided gait rehabilitation. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 18(1), 38–48.
[19]. Novak D, Riener R. (2015) Novak, D., & Riener, R. A survey of sensor fusion methods in wearable robotics. Robotics and Autonomous Systems, 73, 155–170.
[20]. Pedrocchi A, Ferrante S, Ambrosini E, Gandolla M, Casellato C, Schauer T, Molteni F. (2013) Pedrocchi, A., Ferrante, S., Ambrosini, E., Gandolla, M., Casellato, C., Schauer, T., & Molteni, F. Combined rehabilitation robotic approach for upper limb in post stroke patients: performance-based adaptation. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 21(2), 250–259.
[21]. Estevez N, Suarez JI, Hernandez A, et al. (2021) Estevez, N., Suarez, J. I., Hernandez, A., et al. Artificial intelligence for neurorehabilitation: a review of clinical applications. Applied Sciences, 11(11), 5003.


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