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Research Article

VR-Based Rehabilitation Game Design for Children with Cerebral Palsy

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ABSTRACT

In the context of neurological and motor problems, virtual reality has shown great promise as a rehabilitation tool. Virtual Reality(VR)-based rehabilitation presents numerous benefits compared to conventional methods, notably the capacity to develop engaging and interactive settings that can be customized to meet the individual requirements of patients. Additionally, because VR experiences are game-like, they can increase patient motivation and engagement, which will boost results. VR-based rehabilitation game design presents a viable way to enhance therapeutic interventions for kids with Cerebral Palsy (CP).

In this paper, we propose a VR-based rehabilitation game design for children with cerebral palsy. Proposed game design aims to leverage the benefits of VR to address the unique challenges faced by this population, with a focus on improving upper-extremity motor function. By integrating physical movements, feedback mechanisms, and motivational elements, VR games can be designed to encourage active participation, enhance therapy adherence, and deliver personalized treatment protocols. Furthermore, the design considerations for such games—such as accessibility, ease of use, and the ability to monitor progress—are examined. The paper concludes that VR-based rehabilitation games can bridge the gap between clinical needs and therapeutic engagement, offering a novel solution for enhancing pediatric rehabilitation for children with CP

Keywords: Cerebral Palsy, Virtual Reality, Pediatric Rehabilitation.

INTRODUCTION

Cerebral palsy (CP) is a group of neurological disorders that affect movement, posture, and muscle coordination, resulting from brain injury or malformation occurring during early development[1], [2]. Children with CP face a range of motor impairments, including spasticity, muscle weakness, and difficulty with motor control. Rehabilitation plays a crucial role in improving motor function, independence, and overall quality of life for children with CP[2], [3], [4]. However, traditional therapeutic approaches, such as physical therapy, occupational therapy, and speech therapy, often lack the elements of motivation and engagement necessary for sustained participation, especially in younger patients.

Recent advances in Virtual Reality (VR) technology have opened new avenues for rehabilitation, particularly through the development of VR-based games. VR environments offer immersive experiences that can capture the attention of children, making rehabilitation exercises more engaging and enjoyable[5], [6], [7], [8]. VR-based rehabilitation systems have shown promise in various clinical contexts, including paediatric rehabilitation for CP, by providing personalized, adaptable, and motivating therapy sessions[9], [10], [11], [12].

This paper discusses the design of VR-based game to address the specific needs of children with cerebral palsy, focusing on the therapeutic benefits, intellectual challenges, and design strategies.

BACKGROUND

Cerebral palsy is characterized by motor impairments caused by non-progressive brain injury, often affecting muscle tone, movement coordination, and posture[1], [2], [13], [14], [15]. While there is no cure for CP, early intervention

through physical therapy, occupational therapy, and other rehabilitation methods is vital for improving functional outcomes.

Traditional rehabilitation methods for CP, such as manual exercises, assistive devices, and repetitive motion activities, can be monotonous and tiring for children[16], [17], [18]. This lack of engagement may result in poor adherence to therapy regimens. Furthermore, real-time feedback which is essential for skill development and motor learning is absent from many traditional therapies.

VR-based rehabilitation has shown significant potential in overcoming these limitations by integrating interactive and gamified elements into therapy[19], [20], [21]. Virtual reality-based rehabilitation provides a means of enhancing the effectiveness and enjoyment of therapy by immersing kids in a customized virtual environment.

DESIGN CONSIDERATIONS FOR VR BASED REHABILITATION

A. Game Selection

Choosing the familiar objects for rehabilitation therapy is one of the key aspect. So we chose bursting water bubbles in VR based rehabilitation method. As water bubbles are very known to kids. Memory map is ready in the kid's mind[22], [23], [24].

B. Therapeutic Approach

Designing VR-based rehabilitation games for children with CP requires careful attention to therapeutic approach. Children with CP may have varying degrees of physical and cognitive impairments, so it is crucial to design interfaces that are intuitive and adaptable. Involving hand eye coordination, crossing the midline, object manipulation are the fine motor activities considered for developing VR based game[25], [26].

1) Hand Eye Coordination:

In VR based rehabilitation breaking the bubbles are used in hand eye coordination. Breaking bubbles looking by eyes and breaking it on perceived image of it with hand.

2) Crossing Midline:

Midline is the imaginary line of the body from center of body vertically. By choosing Range of Motion in varied ways promote child to cross the hands in both the side and moving hand at opposite side of body towards external rotation are the activities considered for crossing the midline.

3) Object Manipulation:

Opening the lock of a chest prefab using key, focuses on pronation and supination activities. As per the suggestion given by clinician and orthopedic surgeon on adding the pronation and supination activity in VR based rehabilitation, we introduced object manipulation activity, unlock the chest prefab with key.

Design of the game consists of three difficulty levels shown in Fig.1, set to improve the functional ability of a child by focusing on hand elbow movements, generally known as the "Elbow alignment segment".

- Level 0:is targeting movements only of extreme flexion where the child is unable to actively extend past 90º actively. The child is provided with spontaneous movements within the range of 90º. The child is given a target at external rotation, adduction positions of the body. On every movement of external rotation, the child is awarded six badges. For the adduction, the movement child is awarded five points. For extreme flexion, where the child shows hand movement between 140º-90º is awarded three points. If the child shows the least trajectory movement, then the child is rewarded with 2 points per the movement.
- Level 1: is targeting movements only of flexion where the child cannot actively extend past 30º.The child is provided with spontaneous movements within the range 30º. The child is given a target at external rotation, adduction positions of the body. On every movement of External, Rotation child is awarded with six badges, for Adduction movement child is awarded with five points, for flexion where child shows hand movement between 140º-30º is awarded with three points and if the child show least trajectory movement is awarded with one or two points per the movement.
- Level 2: is targeting movements only of the extension where the child is able to actively extend hand between 30º and 0º. The child is provided with spontaneous movements between 30º and 0º. The child is given a

target at external rotation, adduction positions of the body. On every movement of external rotation, the child is awarded 5 points.

- For adduction movement child is awarded five marks. For extreme flexion, where the child can show hand movement between 140°-0° is awarded three points and if the child shows the least trajectory movement is awarded one or two points as per movement.

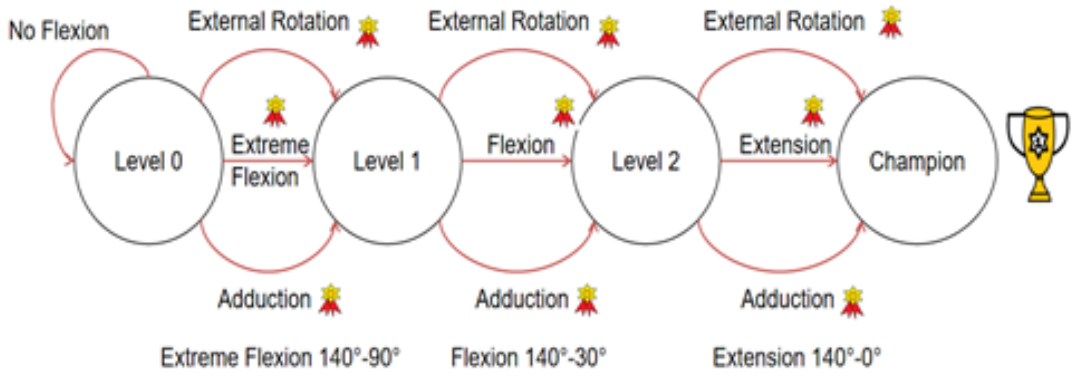

Fig. 1: Therapeutic Game Design for children with CP, with different difficulty levels.

C. Customization and Personalization

Every child with CP has a unique set of abilities and challenges. Therefore, VR rehabilitation games must offer a high degree of customization to cater to individual needs. This includes adjusting difficulty levels, modifying the range of motion required for physical exercises, and providing personalized feedback based on performance. Personalization enhances the child's sense of achievement and fosters a greater sense of motivation and engagement.

D. Feedback and Motivation

Immediate feedback is essential for motor learning, as it helps children understand their progress and correct mistakes. VR-based rehabilitation games can provide real-time visual, auditory, and haptic feedback that motivates children to keep improving their performance. Positive reinforcement, such as rewarding progress with points, and providing new level, can increase the child's desire to continue therapy. Integrating progress tracking features that allow caregivers and therapists to monitor performance over time is another valuable aspect of the game design[22], [25].

E. Gamification and Engagement

One of the main challenges in paediatric rehabilitation is maintaining long-term engagement. Games offer a powerful tool for overcoming this barrier, as they incorporate elements of fun, challenge, and competition. VR-based rehabilitation games should integrate gamification techniques, such as small achievable goals, progressive levels, and challenges, that encourage children to complete therapeutic tasks. By framing rehabilitation exercises as part of a larger narrative or adventure, children are more likely to stay engaged and motivated. Constraints used in VR game environment development are:

- *Total Number of Bubbles spawn on screen at a time:5 nos.*

As per the Miller's Law of Short-Term Memory Load most people can only hold approximately seven pieces of information in their short-term memory at once[27], [28].

Memory Load can directly affect the ability of person to complete the task. Keeping a smaller number of bubbles in visible spawn are reduces memory load, which ultimately reduces the frustration and gives the satisfaction. Achievable target gives satisfaction in game.

- *Repetition:150 nos.*

Repetition is an important aspect of practice, and repetition of a task has been shown to improve performance in people. Iterative achievable repetitions help in improving functional ability of children with CP[29], [30]. Here repetitions are varying in each phase of game with increasing level of difficulty which inversely affects the frustration and directly affects the joy.

- *Range Of Motion (ROM)*

Horizontal Angle (HA) 30-90-140 degrees (Extreme Flexion, Flexion, Extension the metrics are given in SHUEE[30], Vertical Angle (VA) 30- 60- 90 degrees. Small achievable tasks with increasing levels of difficulty directly affects the motivation, satisfaction and indirectly affects the joy.

- *Speed*

Total 50 reaches in minimum 2 minutes and maximum 6 minutes gives time to focus on bubbles and break it accordingly. The time span was suggested by the clinician.

Promoting hand eye coordination in game play improves the fine motor skill. Achievable target, extended time for focusing bubbles increases the satisfaction and indirectly affects joy and reduces the frustration.

- *Size of the game objects:0.1*

Size of the water bubble as a game prefab is set to 0.1-unit for development of the game. Bubbles same as soap water bubbles in specified spawn area reduces the frustration.

F. Safety and Comfort

Safety is paramount when designing VR games for children with CP. VR environments should be designed to avoid inducing discomfort, disorientation, or motion sickness. Game mechanics should be straightforward, with clear instructions to avoid frustration. Moreover, physical safety measures, such as ensuring that children are in a secure and comfortable space while interacting with the VR system, are taken into account. Avoiding triggers such as flickering lights or introducing silent music in between the gameplay along with blank screen or involvement of clinician in between gameplay. Motion sickness can occur when the camera moves while the user is seated and enjoying virtual reality. The child is encouraged to play while seated, camera movement is kept only based on head movement of the child to avoid motion sickness.

SYSTEM DESIGN

Diagrammatical representation of the system and interaction with the system is shown below with various Unified Modeling Diagrams (UML).

- *Use case diagram:*

It shows the possible ways with which clinician can interact with the VR based rehabilitation system. Fig. 2 shows the use case diagram for VR based rehabilitation system.

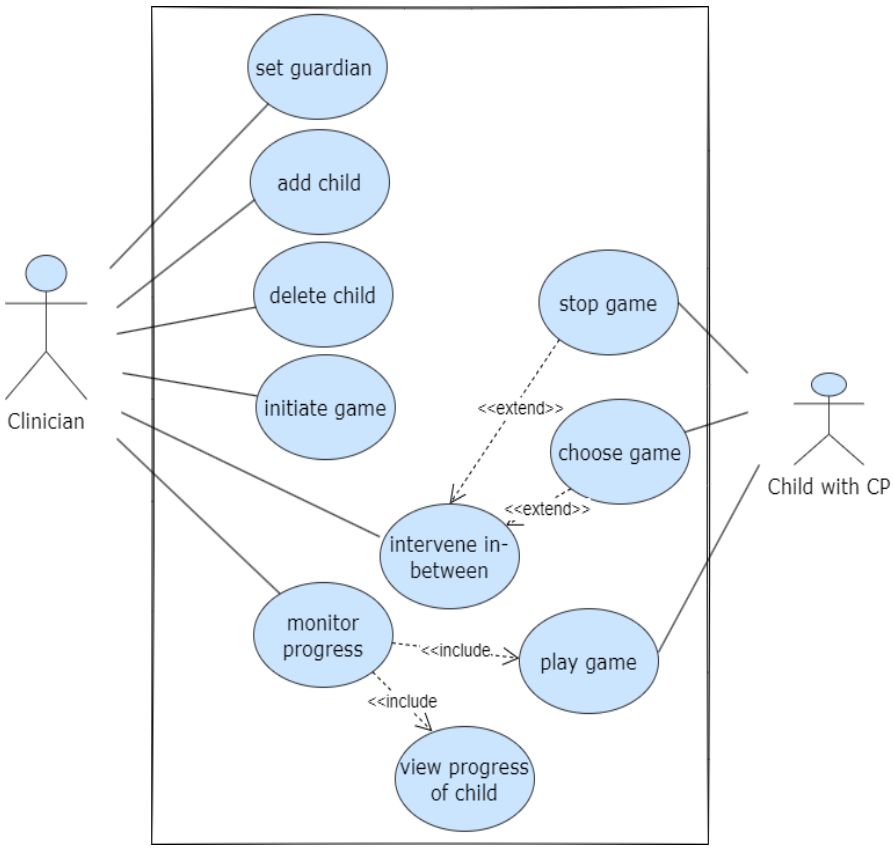

Fig. 2: Use case diagram for VR based rehabilitation

- *Flow diagram*

Flow diagram shows the overall flow of the system. Here system flow is divided into overall game for a child and the levels with progressive levels of difficulties. Fig. 3 shows overall game play flow for child.

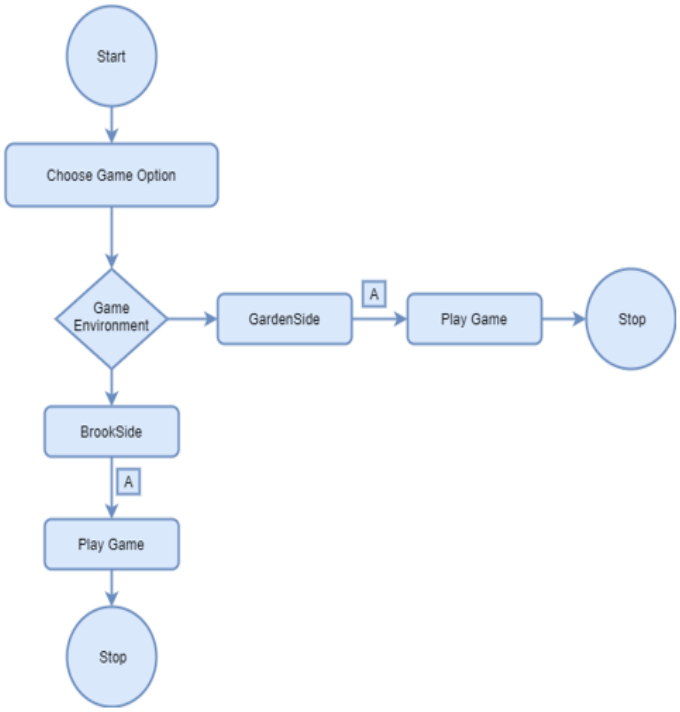

Fig. 3: Overall Game Flow for child's game environment

Fig. 4 shows the flow of level in game and their progressive level of difficulties.

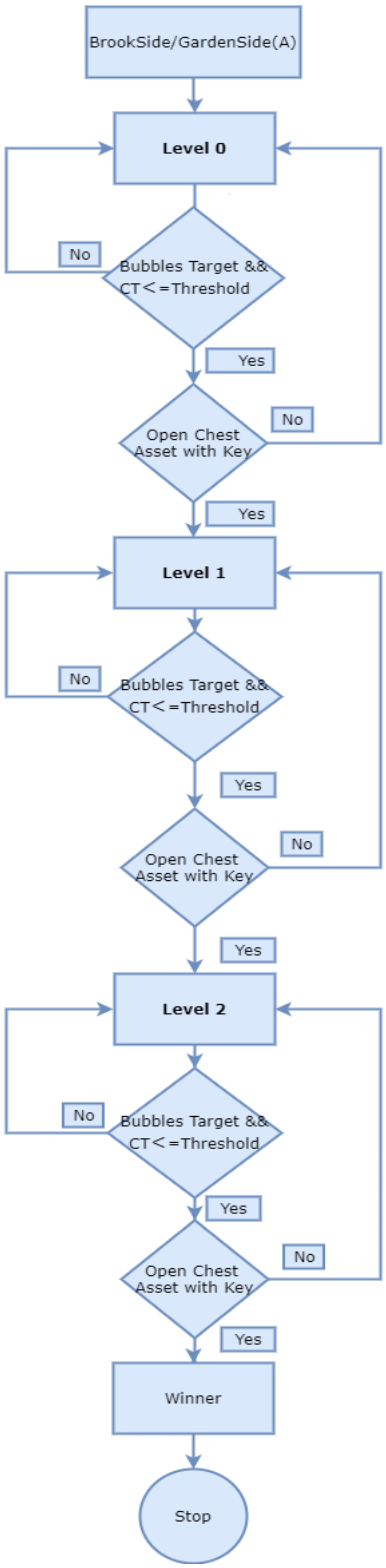

Fig. 4: difficulty levels in game in child's game environment

- *Sequence diagram*

Sequence diagram shows the interaction of objects in time sequence. Fig. 5 shows the sequence diagram of VR based Rehabilitation system.

Fig. 5: Sequence diagram for VR based rehabilitation

CONCLUSION

In conclusion, a major development in the care of kids with cerebral palsy is the use of VR-based rehabilitation games. By leveraging immersive virtual environments, these games provide a more engaging, interactive, and motivating approach to therapy, addressing the common challenge of patient adherence to traditional treatment methods. VR games can improve the rehabilitation process by integrating both motor and cognitive tasks, personalizing workouts, and providing real-time feedback. This makes the process more fun and efficient.

However, challenges such as accessibility and cost must be addressed to ensure broader adoption. As technology continues to evolve, VR holds great potential for transforming pediatric rehabilitation, offering a promising tool to improve the quality of life and functional independence of children with CP.

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REFERENCES

[1] S. Paul, A. Nahar, M. Bhagawati, and A. J. Kunwar, "A Review on Recent Advances of Cerebral Palsy," Oxid. Med. Cell. Longev., vol. 2022, pp. 1–20, Jul. 2022, doi: 10.1155/2022/2622310

[2] Sheffali Gulati & Vishal Sondhi, "Cerebral Palsy: An Overview," vol. 85, pp. 1006–1016, 2018.

[3] M. Kerem, D. Turker, C. Ozal, and O. Kaya Kar, "Physical Management of Children with Cerebral Palsy," in *Cerebral Palsy - Challenges for the Future*, E. Vraka, Ed., InTech, 2014. doi: 10.5772/57505.

[4] M. D. Sewell, D. M. Eastwood, and N. Wimalasundera, "Managing common symptoms of cerebral palsy in children," *BMJ*, vol. 349, no. sep25 7, pp. g5474–g5474, Sep. 2014, doi: 10.1136/bmj.g5474.

[5] A. Bashiri, M. Ghazisaeedi, and L. Shahmoradi, "The opportunities of virtual reality in the rehabilitation of children with attention deficit hyperactivity disorder: a literature review," *Korean J. Pediatr.*, vol. 60, no. 11, p. 337, 2017, doi: 10.3345/kjp.2017.60.11.337.

[6] I. Bortone *et al.*, "Wearable Haptics and Immersive Virtual Reality Rehabilitation Training in Children with Neuromotor Impairments," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 26, no. 7, pp. 1469–1478, Jul. 2018, doi: 10.1109/TNSRE.2018.2846814.

[7] I. Phelan et al., "Immersive virtual reality in children with upper limb injuries: Findings from a feasibility study," J. Pediatr. Rehabil. Med., vol. 14, no. 3, pp. 401–414, Sep. 2021, doi: 10.3233/PRM-190635.

[8] A. Won, J. Bailey, J. Bailenson, C. Tataru, I. Yoon, and B. Golianu, "Immersive Virtual Reality for Pediatric Pain," Children, vol. 4, no. 7, p. 52, Jun. 2017, doi: 10.3390/children4070052.

[9] Changho Kim, "Comprehensive Physiotherapy Approaches for Children With Cerebral Palsy: Overview and Contemporary Trends," vol. 30, no. 4, pp. 253–260, 2023.

[10] Glegg and D. E. Levac, "Barriers, Facilitators and Interventions to Support Virtual Reality Implementation in Rehabilitation: A Scoping Review," *PM&R*, vol. 10, no. 11, p. 1237, Nov. 2018, doi: 10.1016/j.pmrj.2018.07.004.

[11] Michelle Wang; Denise Reid, "Virtual Reality in Pediatric Neurorehabilitation: Attention Deficit Hyperactivity Disorder, Autism and Cerebral Palsy," vol. 36, no. 1, p. 2011.

[12] Nicholas Aderinto, "The Effectiveness of Virtual Reality Therapy in Improving Motor Function and Quality of Life among Children with Cerebral Palsy," vol. 11, 2024.

[13] V. K. Gowda, "Recent advances in cerebral palsy," *Karnataka Pediatr. J.*, vol. 35, pp. 4–18, Sep. 2020, doi: 10.25259/KPJ_1_2020.

[14] A. Kumari and S. Yadav, "CEREBRAL PALSY: A MINI REVIEW," Int. J. Ther. Appl., vol. 3, 2012.

[15] Mr. Faisal Saadoon Alenzy at al., AN OVERVIEW ON CEREBRAL PALSY.

[16] Anuprita Kanitkar et al., "The Effectiveness of a Computer Game-Based Rehabilitation Platform for Children With Cerebral Palsy: Protocol for a Randomized Clinical Trial," vol. 6, no. 5, 2017.

[17] A. Deep and R. Jaswal, "Role of management & virtual space for the rehabilitation of children affected with cerebral palsy: A review," in *2017 4th International Conference on Signal Processing, Computing and Control (ISPCC)*, Solan: IEEE, Sep. 2017, pp. 293–299. doi: 10.1109/ISPCC.2017.8269692.

[18] A. Kanitkar, "Computer Game-assisted Rehabilitation Platform".

[19] M. F. Pereira, C. Prahm, J. Kolbenschlag, E. Oliveira, and N. F. Rodrigues, "Application of AR and VR in hand rehabilitation: A systematic review," *J. Biomed. Inform.*, vol. 111, p. 103584, Nov. 2020, doi: 10.1016/j.jbi.2020.103584.

[20] "Virtual Reality-Based Rehabilitation Gaming System," vol. 229, pp. 135–180, 2022.

[21] Waqar M Naqvi at al., "The Dual Importance of Virtual Reality Usability in Rehabilitation: A Focus on Therapists and Patients," vol. 16, no. 3, 2024.

[22] "Finnie ' s Handling the Young Child with Cerebral Palsy at".

[23] Jiabin Shen et al., "Virtual Reality–Based Executive Function Rehabilitation System for Children With Traumatic Brain Injury: Design and Usability Study," vol. 8, no. 3, 2020.

[24] N. H. Sulaiman and M. Ghazali, "LEARNING THROUGH PLAYING FOR CHILDREN WITH CEREBRAL PALSY," *J. Teknol.*, vol. 78, no. 2–2, Dec. 2015, doi: 10.11113/jt.v78.6930.
[25] S. Alfadhli and A. Alsumait, "Game-based learning guidelines: Designing for learning and fun," *Proc. - 2015 Int. Conf. Comput. Sci. Comput. Intell. CSCI 2015*, no. 2014, pp. 595–600, 2016, doi: 10.1109/CSCI.2015.37.
[26] S. Suggate, H. Stoeger, and E. Pufke, "Relations between playing activities and fine motor development," Early Child Dev. Care, vol. 187, no. 8, pp. 1297–1310, Aug. 2017, doi: 10.1080/03004430.2016.1167047.
[27] N. Cowan, "George Miller's magical number of immediate memory in retrospect: Observations on the faltering progression of science.," Psychol. Rev., vol. 122, no. 3, pp. 536–541, Jul. 2015, doi: 10.1037/a0039035.
[28] Stuart K. Card, The Psychology of Human-Computer Interaction, vol. 2017.
[29] Y.-P. Chen *et al.*, "Use of Virtual Reality to Improve Upper-Extremity Control in Children With Cerebral Palsy: A Single-Subject Design," *Phys. Ther.*, vol. 87, no. 11, pp. 1441–1457, Nov. 2007, doi: 10.2522/ptj.20060062.
[30] J. R. Davids, L. C. Peace, L. V. Wagner, M. A. Gidewall, D. W. Blackhurst, and W. M. Roberson, "Validation of the Shriners Hospital for Children Upper Extremity Evaluation (SHUEE) for children with hemiplegic cerebral palsy," *J. Bone Jt. Surg. - Ser. A*, vol. 88, no. 2, pp. 326–333, 2006, doi: 10.2106/JBJS.E.00298.