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Application of virtual reality-based sensorimotor intervention in motor skills for children with cerebral palsy

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ABSTRACT

This study explores virtual reality media's influence on improving children's walking ability with CP diplegia. Children with this condition often face challenges in daily mobility, which significantly impacts their quality of life. This study used a quantitative approach with a single-subject research method on one subject, selected from a population of 50 CP children using purposive random sampling. The research instruments included action tests and observations to measure gait ability and response to interventions. The results showed a significant improvement in walkability after the virtual reality intervention, compared to the pre- and post-intervention phases. Data analysis indicated that the technology effectively provided additional stimulus for developing motor skills and balance, significantly improving the Gross Motor Function Measure (GMFM) score. While the results are promising, the study highlights the need for further studies to measure the long-term impacts and address the challenges of accessibility, cost, and training in using these technologies. This research makes an essential contribution to the development of more effective and innovative rehabilitation interventions, offering great potential to improve the quality of life of children with CP diplegia.

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ABSTRAK

Penelitian ini mengeksplorasi pengaruh penggunaan media virtual reality dalam meningkatkan kemampuan berjalan anak-anak dengan CP diplegia. Anak-anak dengan kondisi ini sering menghadapi tantangan dalam mobilitas sehari-hari, yang berdampak signifikan pada kualitas hidup mereka. Studi ini menggunakan pendekatan kuantitatif dengan metode single subject research pada satu subjek, dipilih dari populasi 50 anak CP menggunakan purposive random sampling. Instrumen penelitian meliputi tes perbuatan dan observasi untuk mengukur kemampuan berjalan dan respons terhadap intervensi. Hasil penelitian menunjukkan peningkatan signifikan dalam kemampuan berjalan setelah intervensi virtual reality, dibandingkan fase sebelum dan sesudah intervensi. Analisis data mengindikasikan bahwa teknologi ini efektif dalam memberikan stimulus tambahan bagi perkembangan keterampilan motorik dan keseimbangan, dengan peningkatan signifikan pada skor Gross Motor Function Measure (GMFM). Meskipun hasilnya menjanjikan, penelitian ini menyoroti perlunya studi lanjutan untuk mengukur dampak jangka panjang dan mengatasi tantangan aksesibilitas, biaya, serta pelatihan dalam penggunaan teknologi ini. Penelitian ini memberikan kontribusi penting dalam pengembangan intervensi rehabilitasi yang lebih efektif dan inovatif, menawarkan potensi besar untuk meningkatkan kualitas hidup anak-anak dengan CP diplegia.

Kata Kunci: *bina gerak; cerebral palsy; intervensi sensorimotorik; virtual reality*

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INTRODUCTION

Motor development in children is one of the important aspects that must be considered by teachers and parents. Motor development refers to physical skills and the ability to control movements (Ng et al., 2025). Children who have good motor skills will be more flexible in interacting with their peers. This will certainly affect the child's confidence when socializing with their friends. However, this will take on a different meaning when associated with Cerebral Palsy (CP), which is one type of motor impairment that can be experienced by children. Muscle weakness and motor barriers in CP are caused by longer sarcomeres that do not function optimally (Romero et al., 2024). This CP condition is caused by many factors, whether abnormalities in the prenatal, perinatal, or postnatal periods. CP impacts the ability to perform physical activities (Brien et al., 2024). Like children with special needs in general, children with CP experience barriers, particularly in the motor aspect, although it is also possible for them to face challenges in other areas. One of the components in CP children that experiences delays is gross motor function (Oskoui et al., 2013). Gross motor function is defined as the child's ability to resist gravity, manifested in movements such as stabilizing the head and body position, rolling over, sitting, crawling, standing, and walking (Kobesova & Kolar, 2014).

Awareness to reduce motor barriers experienced by children with CP does not arise spontaneously or fully in the child. It is necessary to instill awareness and understanding in children with CP to overcome or minimize the obstacles they have and to maximize their potential to achieve independence. Children who show symptoms of CP need intensive mobility training to improve their motor skills. Training related to motor aspects for children with CP is commonly referred to as *bina gerak*. Due to the varying conditions of CP children, assistance from others is sometimes required for them to perform *bina gerak*. The importance of *bina gerak* lies in monitoring motor development, as delays in movement can be indicators of delays in other developmental areas (Airaksinen et al., 2023). The training methods used vary, and one of them is the drill method (Salma & Fatmawati, 2019).

Although the understanding of the importance of movement training for children with CP is widespread, there are still several gaps and problems that need to be addressed. Structured training programs may not significantly improve physical fitness or activity levels compared to traditional physiotherapy, highlighting individual variability in response and the modest clinical significance of observed improvements (Narayanan, 2015). One issue is the lack of practical media for training their walking ability at home. The high cost of physical therapy is also an obstacle for many parents. Additionally, limited parental knowledge in training their children is another barrier. Parents often face high costs associated with physical therapy, which can be a significant barrier to accessing necessary care (Beveridge et al., 2015).

Although virtual reality technology already exists, its use in training the walking ability of children with CP has not been optimal, especially due to limitations in the use of devices such as smartphones. Previous research has investigated the use of virtual reality (VR) training systems to improve gross motor function and balance in children with CP and found significant improvements in motor skills and balance when using the Nintendo Wii Balance Board alongside conventional physiotherapy (Kolezoi et al., 2025). However, further research is needed to refine the intervention parameters, indicating that current findings may not yet be fully optimized and could benefit from adjustments to improve effectiveness in enhancing gross motor function and balance in children with cerebral palsy (Mirzoev et al., 2022). To address this gap, this study aims to explore the influence of virtual reality media in improving walking ability in children with diplegic CP. This study hypothesizes that the use of virtual reality media as a therapeutic tool will provide the necessary stimulus for the development of their motor skills and balance.

https://doi.org/10.17509/jik.v22i2.76329

LITERATURE REVIEW

Virtual Reality (VR)

The advancement of the times has provided opportunities for the education sector to improve its quality and continuously develop innovations to meet the needs of students, teachers, and stakeholders. Technology is the result of the development of science, thus, it is natural for education to utilize technology to support the implementation of learning (Lestari, 2018; Ulya et al., 2021). One of the rapidly advancing technologies being tested for its effectiveness is Virtual Reality (VR) (Anthes et al., 2016).

Fundamentally, VR technology is closely related to the metaverse, which is generally known as a virtual space ecosystem. The metaverse itself is an online, 3D, immersive environment that offers real-like experiences even in virtual settings (Diaz, 2020). Virtual Reality then becomes one of the core technologies enabling users to experience immersive virtual environments. Virtual Reality refers to a visual simulation or environment generated by a computer and accessed through special equipment, allowing users to interact with the virtual environment itself (Flavián et al., 2019).

Virtual Reality (VR) technology has been proven to support student learning processes in various previous studies. VR is often used in education to increase student motivation, provide new learning experiences, foster enjoyable learning atmospheres, such as through collaboration and gamification, and enhance constructivist pedagogical diversity, among others (Kavanagh et al., 2017; Lampropoulos & Kinshuk, 2024; Monahan et al., 2008). VR can provide realistic experiences for students, allowing them to engage in interactive and immersive learning, thereby enhancing the quality of education and student motivation.

Cerebral Palsy

Cerebral Palsy (CP) is a condition that affects the control of the motor system as a result of brain lesions (Dabney & Miller, 2012; Gupta, 2001). CP is a neuromuscular disorder caused by developmental impairments or partial brain damage related to motor function control (Sandran et al., 2024). A major cause of CP is genetic factors. Gene identification has found 55 genes consistently linked to CP, including PLP1, ARG1, and CTNNB1 (Janzing et al., 2024). CP has significant impacts on daily life, such as motor disorders, difficulty performing activities, sensory disturbances, cognitive development problems, and even social skill challenges (Buonocore et al., 2022). CP is classified by muscle tone into spastic, dyskinetic, ataxic, and mixed types (**Al-Sowi et al., 2023**). In terms of motor limitations, classification is based on the GMFCS level — the higher the level, the greater the motor limitation (McGrath & Palmer, 2024). Based on the above, CP is a condition caused by brain tissue damage that disrupts development and posture. Additionally, CP can be caused by a combination of other factors, such as premature birth and postnatal risk factors (Vilhelmsson et al., 2023).

Bina Gerak (Motor Therapy)

Bina gerak refers to development and training activities aimed at building knowledge, skills, and attitudes for learners with motor disorders to manage their movements in daily life activities. It involves a series of exercises in muscle strengthening, stretching, and skill training to improve motor coordination and physical fitness in children with CP (Sharova et al., 2021). According to the National Education Standards Agency, *bina gerak* is an educational effort in the form of activities, development, and training designed to enhance knowledge, skills, values, and attitudes in children with motor

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impairments to guide their movements in daily activities. *Bina gerak*, often referred to as physical therapy, is any effort or rehabilitation carried out to alter, correct, and form movement patterns that approximate normal movement (Wahyu, 2013; Yosafat, 2024). *Bina gerak* helps improve motor function related to posture and movement control (Degerstedt et al., 2025). Children with CP need early and intensive motor rehabilitation or *bina gerak* to improve their movement function (Todrani, 2022). Therefore, *bina gerak* is said to significantly influence motor function improvement and the quality of life for those with CP. CP individuals have limited motor capacity and require more structured *bina gerak* activities to enhance endurance and motor functionality (Wijnhoud et al., 2024).

Sensorimotor Intervention

Sensorimotor intervention is a therapeutic approach aimed at improving motor and sensory abilities through nervous system stimulation. In the context of children with CP, this intervention focuses on developing fine and gross motor skills as well as movement coordination. It can enhance motor function by optimizing neuroplasticity and reducing spasticity (Sharma et al., 2023). Sensorimotor interventions that include interactive movement exercises can support sensorimotor development in CP cases (Lucas et al., 2024). Studies have shown that integrating technology like Virtual Reality (VR) into sensorimotor therapy can provide interactive experiences and more effective multisensory stimulation. VR technology offers interactive learning experiences that stimulate both sensory and motor engagement and has been proven to improve practical skills when facing tasks (Ladjar & Susanti, 2024). Through VR, children can participate in engaging game-based activities, increasing their motivation and involvement in therapy. VR-based interventions not only improve motor function in terms of balance and posture control but also provide multisensory stimulation that contributes to better sensory integration (Iqbal et al., 2024). The use of technology-based media can also affect interest, which is a foundation for developing sensory stimulation in children (Idris et al., 2025). Sensorimotor interventions can enhance muscle strength and motor performance, supporting functional improvement in CP cases (Busboom et al., 2022). This approach has the potential to accelerate motor therapy skill development in innovative and adaptive ways tailored to individual needs. VR technology delivers curricular innovation that is responsive to learning needs by encouraging active engagement through the learning process (Ardini & Safran, 2024).

METHODS

This study used a single-subject research design, which was employed to evaluate the effectiveness of Virtual Reality (VR) media in improving the walking ability of children with diplegic Cerebral Palsy (CP). The population studied consisted of 50 children with CP, from which 3 subjects were selected using purposive random sampling. This approach allows for in-depth focus on each subject, enabling detailed observation of changes that occur in response to the intervention.

The instruments used in this research were performance tests and observation techniques. The performance test was used to measure the subjects' walking ability, while observation was used to obtain information on the subjects' behavior and responses to the intervention. This allowed the researcher to gather comprehensive data on the subjects' progress throughout the study period.

The data analysis procedure was conducted by using within-condition and between-condition analyses based on each subject. This involved comparing the results across the baseline 1 phase (before intervention), the intervention phase, and the baseline 2 phase (after intervention). The GMFM (Gross Motor Function Measure) test results were used as indicators to evaluate the subjects' walking ability.

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Through this approach, a deeper understanding can be obtained regarding the role of VR media in enhancing the walking skills of children with diplegic CP.

RESULTS AND DISCUSSION

After undergoing the intervention period using virtual reality media, a significant improvement in walking ability was observed in all subjects studied. The data collected through performance test techniques and observation showed consistent improvements in the subjects' walking abilities throughout the research period. The use of virtual reality as a therapeutic tool effectively provided additional stimulus for the development of motor skills and balance in children with diplegic CP. Subjects showed improvements in muscle strength, movement coordination, and postural control during the intervention period.

Within-condition and between-condition analysis based on each subject revealed that the changes observed during the intervention phase were statistically significant compared to baseline phase 1 and baseline phase 2. The results of the GMFM (Gross Motor Function Measure) walking ability test also showed a significant increase in walking ability scores across all subjects. The following presents the within-condition analysis results of the average walking ability of the three subjects.

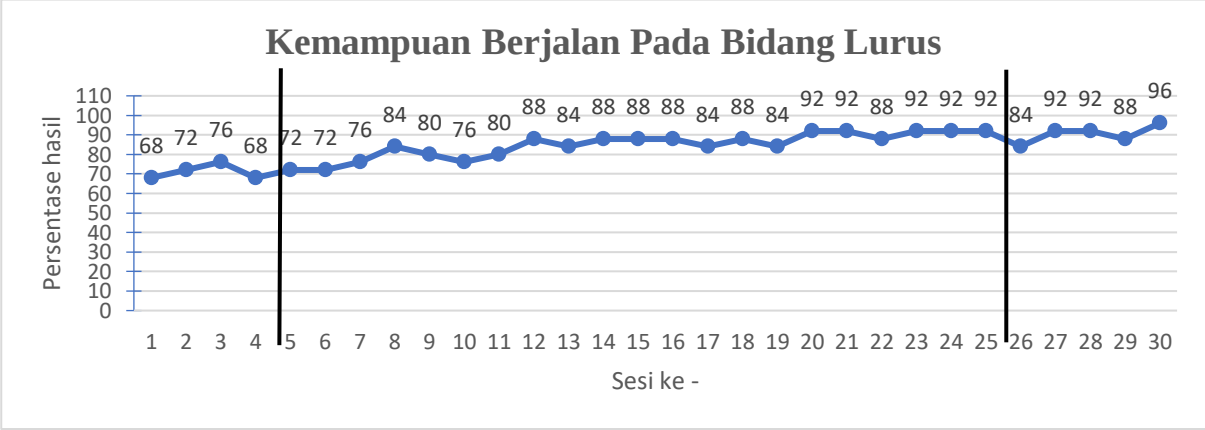

Figure 1. Average Walking Ability on a Straight Path
Source: 2024 Research

Data analysis was carried out to evaluate changes in walking ability in children with diplegic cerebral palsy before, during, and after the intervention using Virtual Reality (VR) media. The within-condition analysis showed that in baseline phase 1 (pre-intervention), the condition lasted for five observation sessions. The estimated trend direction in this phase was flat (=), with a stability rate of 100%. The range of recorded walking ability levels was between 68% and 72%, with a level change of 4 points. This reflects that the children's walking ability was relatively stagnant before intervention and did not show meaningful improvement naturally without specialized treatment.

During the intervention phase, which lasted for 20 sessions, there was a significant change. The estimated trend direction showed an upward trend (+), with a stability trend of 85%. The walking ability level increased from 72% to 92%, with a total level change of 20 points. This data indicates that the use of VR media provided a positive stimulus for walking ability improvements, particularly in muscle strength, coordination, and postural control. This medium also proved effective in maintaining children's interest and participation throughout the training process.

After the intervention, baseline phase 2 showed that the progress achieved during the intervention was not merely temporary, but tended to persist. The condition duration in this phase was five sessions,

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with the estimated trend direction continuing to rise (+), and the stability rate returning to 100%. The walking level increased from 84% to 96%, resulting in a level change of 12 points. This indicates that the effects of the intervention continued even after the training was discontinued, which is an important indicator of the medium-term effectiveness of this technology-based therapy.

Further between-condition analysis strengthened these findings. Comparisons between baseline 1 and the intervention phase (B/A1), as well as between the intervention phase and baseline 2 (A2/B), showed consistent and positive changes in walking ability trends across all three subjects. The change in trend direction from flat (=) to upward (+) indicated a direct effect of the intervention. Walking ability stability was also maintained during and after the intervention. Although there were differences in percentage overlap between conditions (20% in B/A1 and 40% in A2/B), these results still support that VR media contributed significantly to walking ability improvement.

Overall, the data obtained suggest that VR media is a promising intervention approach and can be used to complement conventional physical therapy. This technology not only enhances the effectiveness of motor training but also expands access for children with cerebral palsy to quality rehabilitation, especially in home and community settings. This study offers important implications for the development of more adaptive and individually-oriented interventions. A summary of the between-condition analysis of gross motor development is presented in **Table 1** below.

Table 1. Between-Condition Analysis of Walking Ability

Walking Ability on a Straight Path		
Condition	$^{B}/_{A1}$	$^{A2}/_{B}$
Number of Variables Changed	1	1
Changed in the Variable and Effect		
	(=) (+)	(+) (+)
Changed in Trend Stability	Stable To Stable	Stable To Stable
Changed in Level	72-72 (0)	84-92 (-8)
Persentase Overlap	20	40

Source: 2024 Research

The results of this study demonstrate that the use of virtual reality media has significant potential in improving the walking ability of children with diplegic CP. These findings are consistent with previous studies showing the benefits of technology in rehabilitation contexts. However, several aspects must be considered when interpreting these results. It is important to acknowledge that although there was a significant improvement in walking ability, the change may not yet reach the clinical threshold considered as meaningful functional improvement in daily life. In this context, further research is needed to measure the long-term impact of this intervention on the independence and participation of children with CP in their everyday activities. The implementation of this technology in clinical practice must consider factors such as accessibility, cost, and support from parents and healthcare professionals. Although virtual reality technology offers the potential for home-based training, there are still challenges

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related to device accessibility and the training required for effective use. Moreover, further research is necessary to explore which types of VR interventions are most effective and appropriate for children with diplegic CP. This includes studies on optimal game design, duration, and frequency of interventions, and integration with other physical and cognitive therapies. Finally, this research highlights the importance of an individualized approach in the rehabilitation of children with CP. Each child has unique needs and responses to interventions, thus, a personalized and integrated approach is key to achieving optimal outcomes. Overall, these findings provide a strong foundation for continuing research and development in the use of virtual reality media in the rehabilitation of children with diplegic CP. With collaboration among researchers, clinicians, and parents, this technology has the potential to transform care paradigms and improve the quality of life for children living with this condition.

Discussion

The research findings indicate that virtual reality media holds great potential in improving the walking ability of children with diplegic CP. Virtual reality (VR) has shown significant results in enhancing the walking ability of children with diplegic CP, as demonstrated by several previous studies. VR provides an interactive and motivating environment that can improve balance, motor function, and daily life activities in children with CP (Komariah et al., 2024). Specifically, VR-assisted exergaming has been proven to be more effective than conventional physiotherapy in enhancing gross motor function, including walking and standing dimensions, overall mobility, and cognitive domains (Tobaiqi et al., 2023). Moreover, VR training has been found to significantly improve gait parameters such as speed, stride length, and rhythm, with optimal results achieved through sessions lasting 20–30 minutes, conducted up to four times a week over a period of at least eight weeks (Ghai & Ghai, 2019).

Virtual Reality (VR), as an immersive technology, can assist the training or rehabilitation process. In this regard, VR training can improve balance and gross motor function, although its impact on daily living abilities remains somewhat debated (Liu et al., 2022). The immersive nature of VR also helps enhance visuospatial skills and navigation, which are crucial for effective movement and orientation in children with CP (Nossa et al., 2022). Collectively, these findings suggest that VR media, through its engaging and adaptable platform, can play a significant role in the rehabilitation of children with diplegic CP, especially in improving walking ability and overall motor function. Furthermore, VR has proven effective in significantly improving motor function, including arm function and postural control, with moderate effects on ambulation, indicating its potential in enhancing walking ability (Chen et al., 2018). The results of this study provide a strong empirical foundation for the development of more effective and innovative rehabilitation interventions to improve the quality of life of children with diplegic CP. By continuing to explore and develop this technology, it is hoped that greater benefits can be delivered to those in need. Virtual Reality (VR) has emerged as a promising tool in the rehabilitation of children with Cerebral Palsy (CP), especially in improving motor function and walking ability. When integrated with conventional therapy, VR has shown significant short-term benefits in improving upper limb function, although long-term effects on balance and gross motor function remain inconclusive due to limited studies (Kilcioglu et al., 2023).

The importance of VR in improving upper extremity function and motor performance suggests a minimum of 360 minutes of VR intervention over more than three weeks for meaningful improvements (Bell et al., 2024). Regarding VR system design, it is noted that abstract representations in VR can result in smoother and more energy-efficient movements, which can be beneficial in rehabilitation settings (Garcia-Hernandez et al., 2021). The feasibility of multi-component VR programs in improving motor skills and functional postural control has been recognized, although further research is recommended to establish long-term benefits (Roostaei et al., 2023). However, the current evidence supporting the efficacy of VR in upper limb rehabilitation is weak and inconclusive, mainly due to the

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reliance on non-immersive commercial VR games, highlighting the need for high-quality research to explore the potential of immersive VR (Alrashidi et al., 2023). Collectively, these findings suggest that VR, with its engaging and adaptable platform, holds significant promise in the rehabilitation of children with CP, especially in improving motor function and potentially enhancing walking ability, although further research is needed to optimize its application and confirm its long-term benefits.

CONCLUSION

The research findings directly address the challenges faced in the rehabilitation of children with complex neurological conditions. The integration of virtual reality media into rehabilitation programs has a significant impact on clinical practice, as this technology enhances access to therapy, increases children's motivation and participation, and optimizes overall rehabilitation outcomes. In the context of rehabilitation theory, these findings provide a strong empirical foundation to enrich understanding of rehabilitation interventions for children with diplegic CP. By demonstrating the effectiveness of virtual reality media in improving walking ability, this study makes an important contribution to the development of more holistic and integrated therapeutic approaches. These findings also highlight the importance of individualized approaches in rehabilitation, reinforcing the principle that each child has unique needs and responses to intervention. Looking ahead, the practical implications of these findings are highly significant. The development of integrated and personalized rehabilitation programs is essential to ensure that each child with diplegic CP receives care tailored to their specific needs. Moreover, increasing accessibility and the utilization of technology in daily clinical practice is key to maximizing the benefits of this intervention. Thus, these findings offer an optimistic outlook for the future of rehabilitation in children with diplegic CP, with the potential to improve their quality of life and bring positive impacts to the broader community.

AUTHOR'S NOTE

The author declares that there is no conflict of interest related to the publication of this article. The author affirms that the data and content of the article are free from plagiarism.

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