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ЦЕРЕБРАЛДЫҚ САЛ АУРУ ҮШІН ЖАҢА ТЕХНОЛОГИЯЛАРДЫ ПАЙДАЛАНҒАН РЕАБЛИТАЦИЯНЫҢ ТИІМДІЛІГІ: САЛЫСТЫРМАЛЫ ШОЛУ

Белокопытов М.

Штаттан тыс профессор, Бен-Гурион Негев университеті, Бир Шева, Израиль

Түйіндеме

Церебральды сал ауруына шалдыққан балаларда қозғалысты қалпына келтіруде қолданылатын әртүрлі технологиялардың экономикалық тиімділігін бағалау, тиімді технологияларды, тиісті инвестициялық шешімдерді анықтау және терапевтік нәтижелерді жақсарту.

Материалдар мен әдістер: Қолданыстағы әдебиеттерді жан-жақты қарастыру арқылы церебральды сал ауруын қалпына келтіруде қолданылатын қазіргі технологияларды анықтау. Құрылғылар бес топқа бөлінді: 1) үлкен, қымбат құрылғылар, 2) орташа өлшемді құрылғылар, 3) шағын, арзан құрылғылар, 4) модульдік үй роботтық жүйелері және 5) бағдарламалық өнімдер. Құрылғының құны, клиникалық тиімділігі және ықтимал үнемділігі туралы деректер рецензияланған жарияланымдар мен онлайн ресурстардан жиналды.

Нәтижелер: Технологиялық оңалту церебральды сал ауруы бар балалардың моторлық функциясын және өмір сүру сапасын жақсартудың жоспарланған жолдарын ұсынады. Роботтық экзоскелеттер және виртуалды шындық (VR) жүйелері сияқты үлкен, қымбат құрылғылар тиімді болғанымен, жоғары құнымен шектеледі. Орташа өлшемді құрылғылар, соның ішінде тағуға болатын сенсорлар және функционалды электрлік ынталандыру, құны мен тиімділігін теңестіреді, мотор функциясын жақсартады және үйде оңалтуға мүмкіндік береді. Мобильді қолданбалар мен ойын жүйелері сияқты шағын, арзан құрылғылар дәстүрлі емдеу әдістерімен жиі салыстырылатын қолжетімді және тиімді шешімдерді ұсынады. Модульдік үй роботтық жүйелері ұзақ мерзімді прогрессивті оңалту мүмкіндігін ұсынады, бірақ олардың құны мен техникалық қызмет көрсету талаптары қолжетімділікті шектеуі мүмкін. Мобильді және компьютерлік қосымшалар сияқты бағдарламалық шешімдер үйдегі терапияның үнемді нұсқаларын ұсынады. Әртүрлі технологиялардың экономикалық тиімділігін мұқият қарастыру маңызды. Жетілдірілген технологиялар айтарлықтай әлеуетті ұсынса да, неғұрлым қолжетімді және арзан шешімдер салыстырмалы нәтижелерді қамтамасыз ете алады.

Қорытынды: Технологияның көмегімен оңалту церебральды сал ауруы бар балалар үшін көптеген нұсқаларды ұсынады. Жетілдірілген құрылғылардың әлеуеті болғанымен, олардың жоғары құны қолжетімділікті шектейді. Тағатын сенсорлар, VR және мобильді қолданбалар сияқты кішірек, қол жетімді технологиялар үйдегі терапия үшін тиімді және үнемді шешімдерді ұсынады. Бұл технологияларды оңтайландыру және олардың емделушілерге әсерін барынша арттыру үшін үздіксіз зерттеулер өте маңызды.

Түйін сөздер: церебральды сал ауруы, оңалту, сауықтыру құралдары, экономикалық тиімділікті талдау.

ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ РЕАБИЛИТАЦИИ С ИСПОЛЬЗОВАНИЕМ НОВЫХ ТЕХНОЛОГИЙ ПРИ ДЕТСКОМ ЦЕРЕБРАЛЬНОМ ПАРАЛИЧЕ: СРАВНИТЕЛЬНЫЙ ОБЗОР

Белокопытов М.

Внештатный профессор, Университет имени Бен-Гуриона в Негеве, Беер-Шева, Израиль

Резюме.

Оценка экономической эффективности различных технологий, используемых в реабилитации локомоции у детей с церебральным параличом (ДЦП) для определения эффективных технологий, соответствующих инвестиционных решений и улучшения терапевтических результатов.

Материалы и методы: Идентификация современных технологий, используемых в реабилитации ДЦП, в результате всестороннего обзора существующей литературы. Устройства были разделены на пять групп: 1) большие, дорогостоящие устройства, 2) средние устройства, 3) небольшие, недорогие устройства, 4) модульные домашние роботизированные системы и 5) программные продукты. Данные о стоимости устройств, клинической эффективности и потенциальной экономической эффективности были собраны из рецензируемых публикаций и сетевых ресурсов.

Результаты: Технологическая реабилитация предлагает многообещающие пути для улучшения двигательной функции и качества жизни у детей с ДЦП. Большие, дорогостоящие устройства, такие как роботизированные экзоскелеты и системы виртуальной реальности (VR), хотя и эффективны, ограничены высокой стоимостью. Устройства среднего размера, включая надеваемые датчики и функциональную электростимуляцию, обеспечивают баланс между стоимостью и эффективностью, улучшая двигательную функцию и позволяя проводить домашнюю реабилитацию. Небольшие, недорогие устройства, такие как мобильные приложения и игровые системы, обеспечивают доступные и эффективные решения, часто сопоставимые с традиционными методами лечения. Модульные домашние роботизированные системы предлагают потенциал для долгосрочной последовательной реабилитации, но их стоимость и требования к обслуживанию могут ограничивать доступность. Программные решения, такие как мобильные и компьютерные приложения, предоставляют экономичные варианты для домашней терапии. Тщательное рассмотрение экономической эффективности различных технологий имеет важное значение. В то время как передовые технологии предлагают значительный потенциал, более доступные и недорогие решения могут обеспечить сопоставимые результаты.

Выводы: Реабилитация с использованием технологий предлагает спектр методов для детей с церебральным параличом. В то время как передовые устройства обладают потенциалом, их высокая стоимость ограничивает доступность. Небольшие, более доступные технологии, такие как носимые датчики, VR и мобильные приложения, предоставляют эффективные и экономически эффективные решения для домашней терапии. Продолжение исследований имеет важное значение для оптимизации этих технологий и максимального увеличения их влияния на результаты лечения пациентов.

Ключевые слова: детский церебральный паралич, реабилитация, реабилитационное оборудование, анализ экономической эффективности.

COST-EFFECTIVENESS OF TECHNOLOGY-ASSISTED REHABILITATION FOR CEREBRAL PALSY: A COMPARATIVE REVIEW

Mark Belokopytov

Adjunct Professor, Ben-Gurion University of the Negev, Beer Sheva, Israel

Abstract.

This study aims to evaluate the cost-effectiveness of various technologies used in locomotion rehabilitation for children with cerebral palsy (CP), to identify the best-value technologies, guide investment decisions, and enhance therapeutic outcomes.

Materials and methods: A comprehensive review of existing literature was conducted to identify current technologies used in CP rehabilitation. Devices were categorized into five groups: 1) large, high-cost devices, 2) medium-sized devices, 3) small, lower-cost devices, 4) modular, home-based robotic systems, and

5) software solutions. Data on device costs, clinical effectiveness, and potential cost-effectiveness were gathered from peer-reviewed publications and digital resources.

Results: Technology-assisted rehabilitation offers promising avenues for improving motor function and quality of life in children with CP. Large, high-cost devices like robotic exoskeletons and virtual reality (VR) systems, while effective, are limited by high costs. Medium-sized devices, including wearable sensors and functional electrical stimulation (FES), offer a balance between cost and effectiveness, enhancing motor function and enabling home-based rehabilitation. Small, lower-cost devices like mobile apps and game-based systems provide affordable and effective solutions, often comparable to traditional therapies. Modular, home-based robotic systems offer potential for long-term, consistent rehabilitation, but their cost and maintenance requirements may limit accessibility. Software solutions, such as mobile and computer applications, provide cost-effective options for home-based therapy. A careful consideration of the cost-effectiveness of various technologies is essential. While advanced technologies offer significant potential, more affordable and accessible solutions may provide comparable outcomes.

Conclusion: Technology-assisted rehabilitation offers a range of modalities for children with cerebral palsy. While advanced devices hold potential, their high-cost limits accessibility. Smaller, more affordable technologies like wearable sensors, VR, and mobile apps provide effective and cost-efficient solutions for home-based therapy. Continued research is essential to optimize these technologies and maximize their impact on patient outcomes.

Key words: Cerebral Palsy, Rehabilitation, Rehabilitation Facilities, Cost-Benefit Analysis

Corresponding author: Mark Belokopytov**,** Adjunct Professor, Ben-Gurion University of the Negev, Beer Sheva, Israel
Address: 72 Klei Shir, Karnei Shomron, Israel 5585500
Phone: +972-544455342
E-mail: markb120@gmail.com

Introduction

Cerebral palsy (CP) is the most common cause of childhood-onset physical disability, affecting approximately 2-3 per 1000 live births [1, 2]. The condition is characterized by permanent disorders of movement and posture due to non-progressive disturbances in the developing fetal or infant brain. CP is highly heterogeneous, with varying degrees of motor impairment, often accompanied by comorbidities such as epilepsy, intellectual disabilities, and sensory impairments [3].

Locomotion rehabilitation is crucial for improving motor function, enhancing quality of life, and promoting overall physical health in children with CP. Regular physical activity, including walking, can prevent the loss of motor skills, reduce sedentary behavior, and mitigate associated health risks such as increased body fat and muscle stiffness [4].

Gait training, whether through traditional methods or advanced technologies, has been shown to significantly improve gait speed, endurance, and gross motor function in children with CP [5]. The ability to walk contributes considerably to physical health and overall well-being, making it a prioritized rehabilitation goal [6]. Moreover, locomotion rehabilitation can induce plastic changes in the corticospinal tract, leading to long-term improvements in gait function. This is particularly important for children, as early intervention can result in more substantial and lasting benefits [7].

Conventional methods for locomotion rehabilitation in children with CP are crucial for improving motor function and quality of life. Gait Training is the most effective intervention for improving gait speed and overall walking ability in children with CP. It involves practicing walking tasks and can be enhanced with tools like treadmills and body-weight support systems [8, 9]. Aerobic activities, such as cycling and swimming, improve gross motor function, mobility, and balance. These exercises are more effective than usual care in enhancing aerobic capacity and participation [10]. Gross Motor Activity Training includes exercises that focus on improving gross motor skills through variable practice opportunities. It has strong positive evidence for improving gross motor function in ambulant and semi-ambulant children with CP [11]. Although isolated strength training has shown limited effectiveness in improving gait parameters, it can be beneficial when combined with other interventions like gross motor activity training [11].

A wide range of new technologies have been introduced in the past decade to advance locomotion rehabilitation for individuals with CP [12]. These innovations focus on improving gait, motor function, and overall mobility through more precise, adaptable, and engaging rehabilitation strategies. Key advancements include robotic exoskeletons, wearable sensors, virtual and augmented reality (VR and AR), and mobile applications. Collectively, these technologies provide increasingly individualized and data-driven rehabilitation for cerebral palsy, supporting improvements in gait, endurance, and quality of life through more dynamic, accessible, and effective therapy solutions. This paper is an attempt of a cost-effectiveness comparative review of some current technologies for locomotion rehabilitation in CP to identify the best-value technologies for CP rehabilitation, guiding investment decisions, supporting equitable access, and ultimately enhancing therapeutic outcomes across diverse patient populations.

Materials and Methods

We reviewed the most known and common devices that are currently available on the market and are in clinical use not sporadically and experimentally, but in a certain number of modern rehabilitation and physiotherapy clinics in countries with advanced healthcare infrastructure. To enable the generalization of cost-effectiveness description and to illustrate the range of practical and financial considerations for implementing these technologies in clinical or home settings, we grouped the technologies by size, cost, and ease of setup and use. Large, high-cost devices include robotic exoskeletons, treadmill-based gait trainers, and immersive VR systems. While these systems offer robust, intensive therapeutic interventions tailored to correct gait patterns and improve muscle strength, they remain largely confined to clinical use due to their expense, size, and complexity. The second category encompasses medium-sized devices with moderate costs and setup requirements, including wearable biofeedback sensors, FES devices, and AR systems. With initial training provided to caregivers or therapists, they can be safely operated in less controlled environments, providing flexibility and tailored intervention through muscle activation and real-time biofeedback.

The third group consists of small, lower-cost devices that are particularly user-friendly and easy to set up, such as mobile apps for remote monitoring, balance and coordination training platforms, and cognitive-motor training tools. Due to their portability, ease of setup, and minimal training requirements, these devices are effective for at-home supplemental training. They serve to reinforce balance, motor planning, and adherence to daily therapeutic routines, providing families with flexible, cost-effective options to support ongoing rehabilitation. The fourth group includes modular, home-based robotic systems with variable costs and a straightforward setup process. These systems are intended for regular, long-term use in home settings and are specifically designed for ease of installation and operation by non-professionals. Modular devices in this category allow families to maintain consistent, low-intensity therapeutic engagement over extended periods, complementing clinical therapy with the potential for significant functional gains. Finally, a subset of devices falls under software solutions, such as mobile and computer applications. They reveal notable advantages in terms of affordability and scalability. By eliminating the need for specialized hardware, these software-based approaches present a lower entry cost while still delivering meaningful rehabilitative benefits. The data were sourced from a range of peer-reviewed publications, conference proceedings, and publicly accessible digital resources.

Results

Large, high-cost devices

Large, high-cost devices such as robotic exoskeletons, treadmill-based gait trainers, and immersive VR systems have shown promising results in improving locomotion in children with CP and other locomotion issues, often outperforming traditional rehabilitation methods.

Studies have demonstrated that robotic exoskeletons can significantly improve gait parameters in children with CP. For instance, a systematic review found that these devices enhance walking speed, knee and hip extension, and reduce the metabolic cost of walking. Another randomized clinical trial showed that overground robot-assisted gait training (RAGT) using a wearable exoskeleton significantly improved gross motor function and gait patterns compared to standard physical therapy [11, 12].

Treadmill training, especially when combined with partial body weight support, has been shown to be effective in improving walking speed and gross motor function in children with CP. A systematic review highlighted that treadmill training is safe and feasible, with significant improvements in walking speed and gross motor performance. Additionally, combining treadmill training with VR has been shown to further enhance walking endurance and speed, as well as balance and functional independence [13, 14].

VR-assisted exergaming and VR-coupled treadmill training have demonstrated significant improvements in gait parameters, including gait velocity, stride length, and cadence. A meta-analysis found that VR training significantly enhances gait performance in children with CP. Another systematic review and meta-analysis reported that VR-assisted exergaming was more effective than conventional physiotherapy in improving gross motor function and participation outcomes in children with CP [15, 16]. Immersive VR systems have been particularly effective in increasing motivation and engagement during rehabilitation sessions, which can enhance therapy outcomes. VR-based interventions provide an entertaining and interactive environment that can make repetitive exercises more enjoyable for children, thereby improving adherence to rehabilitation programs [16-18].

The economic aspects of technology-assisted rehabilitation for CP using large, high-cost devices such as robotic exoskeletons, treadmill-based gait trainers, and immersive virtual reality (VR) systems are significant. These devices, including the Ekso Bionics exoskeleton, the Lokomat robotic gait trainer, and the Computer Assisted Rehabilitation Environment (CAREN) VR system, typically require substantial financial investment and are usually situated in specialized rehabilitation centers. The cost of these advanced rehabilitation devices ranges from tens of thousands to several hundred thousand dollars. For example, the Lokomat system can cost upwards of $300,000, while the Ekso Bionics exoskeleton is priced around $100,000 to $150,000. The CAREN VR system, which offers a highly immersive rehabilitation experience, can also be in the range of several hundred thousand dollars [19-21]. The cost per treatment session varies based on multiple factors, including the type of device, session duration, and the need for specialized personnel. For instance, robotic exoskeleton training sessions can cost between $100 to $200 per session, depending on the facility and the specific requirements of the therapy. The cost-effectiveness of these interventions is still a subject of ongoing research, with some studies indicating potential cost savings in the long term due to improved rehabilitation outcomes and reduced need for long-term care [19-21]. While robotic devices and treadmill-based trainers are expensive, their ability to reduce the need for intensive therapist support and improve functional outcomes may justify the cost in certain cases. VR systems, particularly those using commercial gaming consoles, are relatively low-cost and have shown potential for cost savings, especially when used in home-based settings [18, 19, 22].

Medium-sized devices. Technology-assisted rehabilitation methods for cerebral palsy, such as wearable biofeedback sensors, FES devices, and AR systems, have shown promising results compared to traditional rehabilitation methods for children. These technologies offer engaging, personalized, and effective alternatives to conventional therapies. A randomized controlled trial demonstrated that FES cycling combined with goal-directed training and adapted cycling, significantly improved gross motor function and goal performance/satisfaction in children with CP compared to usual care. Another study found that FES during walking improved ankle dorsiflexion and range of motion, although patient selection and thorough follow-up are critical for success [23, 24]. A feasibility study on a biofeedback-enhanced therapeutic exercise video game intervention showed moderate effects on body function measures and small-to-moderate effects on activities and participation measures in children with cerebral palsy. This suggests that biofeedback systems can effectively engage children in home rehabilitation, complementing traditional therapy [25]. AR interventions have been effective in improving upper extremity function and balance in children with spastic hemiplegic cerebral palsy. A randomized clinical trial found significant improvements in the Disability of Arm, Shoulder, and Hand (DASH) scores and Pediatric Balance Scale (PBS) scores post-intervention. Another meta-analysis indicated that nonimmersive VR interventions significantly improved lower extremity function, balance, and social participation compared to traditional rehabilitation [26, 27]. Medium-sized devices like the ReWalk exoskeleton and WalkAide FES system typically range from $30,000 to $100,000. AR-based rehab solutions using systems like the Microsoft HoloLens are generally less expensive, with costs around $3,500 to $5,000 for the hardware, plus additional costs for software development and customization [28-30]. The cost per treatment session varies based on the type of device and the setting. For instance, sessions using wearable biofeedback sensors or FES devices can range from $100 to $200 per session, depending on the complexity of the therapy and the need for specialized personnel. AR-based rehabilitation sessions may be more cost-effective, especially if conducted at home, reducing the need for frequent clinic visits [29, 31, 32]. These technologies enhance engagement, improve motor function, and offer accessible rehabilitation options, potentially reducing long-term healthcare costs by improving functional outcomes and decreasing the need for more intensive interventions. For example, AR systems like the Microsoft HoloLens have shown excellent feasibility and user experience in pediatric populations, making them a cost-effective option for home-based rehabilitation [29, 32].

Small, lower-cost devices

A systematic review and meta-analysis found that Nintendo Wii Balance Board Therapy significantly improved functional and dynamic balance in children with cerebral palsy, especially when combined with conventional physical therapy (CPT) in sessions lasting longer than 3 weeks. Another study demonstrated that NWT was more effective than standard physiotherapy (SPT) in improving standing balance, although the effects waned 2-4 weeks post-intervention [33, 34]. While specific studies on FitMi Therapy were not identified in the provided references, similar interactive computer play (ICP) interventions have been shown to be more effective than conventional therapy in improving postural control and balance in children with mild to moderate CP [35]. Although direct evidence for PT Pal Pro was not found in the provided references, the general trend in the literature supports the efficacy of home-based, interactive rehabilitation technologies. For instance, a study on home-based VR therapy using the Nintendo Wii Fit found it to be feasible, safe, and potentially cost-effective, with improvements in gross motor function and balance [18]. Computer-assisted arm rehabilitation gaming technology has been evaluated for its potential benefits on arm function in children with spastic cerebral palsy. While initial studies did not show significant improvements, feedback indicated that more engaging games could potentially yield better functional benefits [36].

Mobile applications and touch screen tablets are generally more affordable compared to other advanced rehabilitation technologies. Tablets used for fine motor exercises can be relatively inexpensive, with costs ranging from $200 to $500. VR-assisted exergaming systems, while more costly, have become increasingly accessible. Low-cost VR systems can range from $300 to $1,000, making them a viable option for home-based rehabilitation. Game-based rehabilitation systems using motion-sensing devices like the Kinect are also relatively affordable, with initial costs around $100 to $200 for the hardware [37, 38].

A systematic review in the Journal of Clinical Medicine highlighted that semi-immersive VR devices, such as those using commercial video game consoles like the Nintendo Wii and Kinect, could involve significant cost savings. These savings are mainly derived from the low prices of the systems and reduced transportation costs when applied through telerehabilitation programs, compared to in-clinic interventions [19].

A randomized controlled trial demonstrated that the Nintendo Wii Balance Board significantly improved standing balance in children with cerebral palsy, with effects comparable to standard physiotherapy, although the benefits waned after 2-4 weeks [34]. This suggests that while initial costs are low, ongoing engagement may be necessary to maintain benefits. The study found that this low-cost VR approach could improve postural control and was likely to be as effective as face-to-face modalities, making it a cost-effective alternative. Additionally, a qualitative study in the International Journal of Environmental Research and Public Health explored the benefits of a low-cost walking device in children with cerebral palsy. The study found that such devices improved emotional welfare, physical well-being, and social enjoyment, indicating that they are not only cost-effective but also beneficial for overall quality of life [39]. For example, the Mitii training system, a web-based multimodal therapy for unilateral cerebral palsy, has been shown to be cost-effective. The cost per responder for the Mitii program ranged from AU$3078 to AU$4191 depending on the outcome measures used, which is modest relative to the improvements in function observed [40].

Additionally, the cost of assistive devices for children with mobility limitations varies widely, with an average cost of $539 per device. This includes a range of devices from low-cost items to more expensive high-technology devices [41].

The cost per treatment session using these technologies can vary. For instance, VR-assisted exergaming has been shown to be cost-effective by reducing the need for in-person therapy sessions. A systematic review and meta-analysis indicated that VR exergaming could be more effective than conventional physiotherapy, potentially reducing overall rehabilitation costs. Game-based systems and mobile applications can also lower costs by enabling home-based therapy, reducing the frequency of clinic visits, and allowing for continuous monitoring and adjustments by therapists remotely [16].

In the context of telerehabilitation, the American Physical Therapy Association notes that costs per session are generally lower with telerehabilitation compared to in-person care, especially for patients living more than 30 km from the healthcare center [42]. This cost-effectiveness is due to reduced travel and associated costs, making telerehabilitation a viable and economical option for pediatric locomotion rehabilitation.

A study demonstrated that an intervention using devices like the Nintendo Wii Fit could be implemented at a low cost of £20 per child, making them a highly cost-effective option for enhancing traditional rehabilitation methods [18]. The use of these technologies can lead to significant long-term economic benefits. By improving motor function and engagement, they can reduce the need for more intensive and costly interventions later. Additionally, the ability to perform rehabilitation at home can decrease transportation costs and time burdens for families [43].

Modular, home-based robotic systems

Technology-assisted rehabilitation for CP using modular, home-based robotic systems with variable costs and a straightforward setup process shows comparable success rates to traditional rehabilitation methods for children. Trexo Plus exemplifies this category, offering a modular and adaptable robotic solution designed for home use [44]. A systematic review and meta-analysis found that robot-assisted gait therapy (RAGT) demonstrated superior outcomes in gait speed, walking distance, and walking, running, and jumping ability compared to conventional therapy (CT) [45]. This suggests that RAGT can be more effective in improving specific gait parameters in children with cerebral palsy. A pilot randomized comparative trial comparing home-based and laboratory-based robotic ankle training found significant improvements in both groups across various biomechanical and clinical outcome measures, with no significant differences between the two settings [46]. This indicates that home-based robotic systems can be as effective as laboratory-based systems, offering the advantage of convenience and potentially lower costs.

Another study on the Walkbot, a robotic gait trainer, combined with physiotherapy, showed significant improvements in standing, muscle strength, and knee range of motion compared to isolated physiotherapy [47]. This further supports the efficacy of robotic-assisted rehabilitation in enhancing functional outcomes.

Studies have shown that home-based robotic systems are generally safe for use in children with cerebral palsy. For instance, the AiWalker-K system was found to be safe under the guidance of experienced medical personnel, with adverse events being manageable and within safe ranges [48]. The Trexo Plus, a pediatric lower limb exoskeleton designed for home use, exemplifies a modular and adaptable robotic solution. The initial investment for such devices can be substantial, and the costs range from $10,000 to $30,000 depending on the customization and components selected. This high cost is justified by the potential for improved rehabilitation outcomes and reduced long-term healthcare costs [44, 49]. The cost per treatment session with these robotic devices varies based on factors such as the type of device, session duration, and the need for specialized personnel. While specific session costs for Trexo Plus are not detailed in the literature, the general trend indicates that robotic-assisted rehabilitation can be more expensive than conventional therapy. However, these costs are often offset by enhanced engagement and improved motor function outcomes, making rehabilitation more accessible and effective for children with CP [28, 44, 49].

Software solutions

Computer game-assisted rehabilitation programs have shown significant improvements in manual dexterity and visual-motor integration in children with cerebral palsy, with moderate to large effect sizes [16, 50]. Technology-assisted methods often enhance user engagement through interactive and enjoyable experiences. VR and computer games provide a fun and motivating environment, which can lead to higher compliance and sustained participation in rehabilitation programs. For example, children reported enjoying the training with ICP, and there were no adverse events, indicating high levels of engagement and safety [51].
The prices of software solutions like mobile and computer applications used in locomotion rehabilitation for children can vary widely, but some general trends and specific examples can be highlighted.

A study on Digital Therapeutic Care (DTC) apps for unsupervised treatment of low back pain provides some insight into pricing models that could be relevant for pediatric locomotion rehabilitation apps. The study found that the price for a 3-month prescription of a DTC app was approximately €239.96. Reducing this price to €164.61 could make the app a dominant strategy over traditional treatment methods in terms of cost-effectiveness [52]. While this study focused on low back pain, the economic principles can be extrapolated to pediatric locomotion rehabilitation, indicating that DTC apps can be a cost-effective option. According to the American Physical Therapy Association, telerehabilitation services can be cost-effective, especially for patients living far from healthcare centers. The cost per session for telerehabilitation can be lower than in-person care, particularly when considering travel and associated costs. However, the study did not include specific technology costs to patients and therapists, which can vary based on the complexity and features of the software used [42]. Studies have shown that telerehabilitation can result in similar or lower costs compared to in-person rehabilitation. For example, a systematic review found that telerehabilitation may reduce barriers to care and result in cost savings, particularly for patients living far from healthcare centers. Another study highlighted significant cost savings and improved clinical outcomes in patients using a clinician-controlled telerehabilitation system following total knee arthroplasty, with a cost-saving advantage of $2,460 per patient. These findings suggest that telerehabilitation can be a cost-effective alternative to traditional rehabilitation, especially when considering travel and associated costs [53, 54].

In comparison, traditional rehabilitation methods often involve higher costs due to the need for specialized equipment, frequent in-person sessions, and associated travel expenses. For instance, the cost of delivering intensive physiotherapy alone can be substantial, as seen in studies evaluating the cost-effectiveness of botulinum toxin injections combined with intensive physiotherapy, which reported significantly higher treatment costs [55]. Moreover, digital therapeutic care apps for conditions like low back pain have shown that reducing the app's cost to €99 per 3 months can make it a dominant strategy over "traditional treatment as usual" by being less costly and generating more quality-adjusted life years (QALYs) [56]. This indicates that similar cost reductions in digital therapeutic apps for CP could enhance their cost-effectiveness.

Discussion

Advanced technologies for walking rehabilitation face several key challenges, primarily due to the complexity of human movement, differences in patient needs, and the need to smoothly integrate new tools into clinical and home settings. One of the main issues is the cost and accessibility of high-tech gait rehabilitation devices. These devices are often expensive, which limits access for many patients, especially in low-resource settings or home environments where ongoing, effective rehabilitation is needed. The high costs often raise questions about cost-effectiveness and accessibility [19]. Reducing the cost while keeping the devices highly functional is a major priority to make these technologies more widely available. Another challenge involves integrating these technologies into clinical practice. For the best results, these devices need to work well within existing healthcare systems. This means being compatible with electronic health record systems, working seamlessly with other rehabilitation equipment, and being easy for clinicians to use and monitor patient progress [57]. If setup and use are too complex or time-consuming, clinicians may be less likely to adopt these technologies, limiting their potential benefits to patients [58]. Overcoming these challenges is crucial for making walking rehabilitation technologies accessible to a wider range of patients. Progress in creating affordable, accessible, and easy-to-integrate solutions will help ensure that these innovations are used effectively in both clinical and home rehabilitation.

One primary reason for this review is the need for informed decision-making among healthcare providers, families, and policymakers. With the rising costs of healthcare and the limited budgets of many rehabilitation centers, stakeholders require a clear understanding of which technologies deliver the best value relative to their clinical benefits. Cost-effectiveness reviews allow for more transparent evaluations, offering data on whether a particular technology provides meaningful functional improvements, such as enhanced gait and mobility, in proportion to its financial demands. This is particularly relevant given that many advanced rehabilitation devices, such as robotic exoskeletons, are often prohibitively expensive for routine clinical or home-based use, potentially limiting access to those who could benefit the most. Furthermore, children with CP often require long-term, repetitive therapy, making the cumulative cost of interventions a significant factor in treatment planning [59]. Comparative cost-effectiveness analyses can highlight which technologies sustain benefits over time, making them more financially viable options for long-term rehabilitation. This type of review would also help identify low-cost, high-impact solutions, such as wearable sensors or mobile-based applications, which may provide effective therapy at a fraction of the cost of more complex systems.

Finally, a cost-effectiveness review addresses the broader issue of healthcare equity. Families and rehabilitation centers in lower-resource settings are often unable to invest in high-cost devices, leading to disparities in access to effective rehabilitation for children with CP. By identifying and promoting the most cost-effective options, these reviews can support a more equitable distribution of resources, ensuring that effective rehabilitation strategies reach a broader population.

Limitations

The paper analyses the cost-effectiveness of various technologies, focusing on factors like initial investment, maintenance costs, and potential long-term savings. However, a quantitative cost-effectiveness analysis, such as a cost-utility analysis or a cost-benefit analysis, is not explicitly conducted. This limitation prevents a precise comparison of the economic efficiency of different technologies. This study has several other limitations that should be considered when interpreting its findings. One notable limitation is the limited availability of data on the long-term costs and benefits associated with technology-assisted rehabilitation for cerebral palsy. While this research highlights the potential for cost savings over time due to improved functional outcomes and reduced healthcare utilization, empirical evidence on the sustained economic impact remains sparse. Further longitudinal studies are necessary to assess whether these initial investments yield substantial cost savings in both direct and indirect healthcare costs over the long term. Another limitation is the variability inherent in clinical practice, which could influence both the effectiveness and cost-effectiveness of these technologies. The outcomes of technology-assisted rehabilitation are likely to differ based on a range of factors, including the severity of the patient's condition, therapist's expertise, and the specific rehabilitation protocols employed. Such variability can lead to differences in both clinical results and economic outcomes, making it challenging to generalize findings across diverse patient populations and clinical settings. Finally, this study does not deeply explore ethical considerations associated with technology use in rehabilitation. Issues such as data privacy, especially in home-based or telehealth rehabilitation models, require attention to ensure that patient information remains secure. Additionally, the development and application of these technologies may inadvertently introduce biases, potentially affecting access and outcomes for specific patient groups [21, 57]. Addressing these ethical dimensions is essential for equitable implementation and for fostering trust in these evolving rehabilitation approaches. Further research should consider these ethical concerns to guide the responsible integration of technology in clinical practice.

Possible implications

The findings of this study have significant clinical implications for healthcare providers and policymakers working with individuals with cerebral palsy. Technology-assisted rehabilitation offers the potential for highly personalized and tailored interventions, enabling clinicians to address the unique motor impairments of each patient more effectively. This individualized approach is associated with improved therapeutic outcomes, as rehabilitation devices can adapt to the patient's specific movement patterns, facilitating targeted improvements in gait and functional mobility. Additionally, interactive technologies embedded within these devices have been shown to enhance patient engagement and motivation, factors critical to successful rehabilitation. Increased engagement is particularly important for children with cerebral palsy, as adherence to therapy regimens often poses challenges. The incorporation of gamified elements and real-time feedback not only sustains interest but also reinforces progress, ultimately supporting long-term gains in motor skills and functional independence.

A notable advantage of technology-assisted rehabilitation is the facilitation of remote rehabilitation. Telehealth platforms and home-based devices expand access to high-quality care for individuals residing in rural or underserved regions, who otherwise might face significant barriers to in-person therapy. This model allows for continuous monitoring and interaction with therapists, ensuring that patients can benefit from consistent, supervised rehabilitation, even outside of traditional clinical settings. While initial costs for implementing these technologies are considerable, the potential for long-term cost-effectiveness supports their adoption. The reduction in required in-clinic visits, coupled with the ability to achieve similar or even superior outcomes remotely, may alleviate some of the economic burdens on healthcare systems and families. Improved functional outcomes associated with technology-assisted interventions can reduce the need for subsequent interventions and decrease the overall cost of care, creating a sustainable model for the long-term management of cerebral palsy. These findings suggest that policymakers should prioritize investments in technology-assisted rehabilitation to enhance care accessibility and quality. Policy support could include funding initiatives for telehealth infrastructure, subsidies for home-based devices, and reimbursement models that support these innovative interventions. By fostering such advancements, policymakers can play a critical role in improving the health outcomes and quality of life for individuals with cerebral palsy, promoting equitable and effective rehabilitation options for all. In summary, a cost-effectiveness comparative review is vital for identifying the best-value technologies for CP rehabilitation, guiding investment decisions, supporting equitable access, and ultimately enhancing therapeutic outcomes across diverse patient populations.

Conclusion

Technology-assisted rehabilitation for CP offers a promising avenue for improving functional outcomes and quality of life. While advanced robotic systems hold significant potential, their high cost necessitates the exploration of more affordable alternatives. Medium-sized devices like wearable biofeedback and AR systems offer a balance between cost and effectiveness, improving motor function and potentially reducing long-term healthcare costs. Small devices and digital therapeutics, such as mobile apps and VR, provide accessible and cost-effective solutions for home-based rehabilitation. Ongoing research is crucial to optimize the design, implementation, and long-term efficacy of these technologies, ensuring their widespread adoption and maximizing their impact on patient outcomes.

Conflict of Interest disclaimer

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author's contribution

The author (MB) solely contributed to this publication, including the concept, methodology, drafting, and writing.

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БАЛАЛАРДАҒЫ ЗЕЙІН ТАПШЫЛЫҒЫ СИНДРОМЫНДАҒЫ ҰЙҚЫ АПНОЭЫНЫҢ ЖИІЛІГІ

Малиопулос Антуан-Хавьер[1], Так Сабине[2], Дарибаев Ж.Р.[3]

[1] «Одиссей» бөлімшесінің басшысы (неврологиядық күндізгі оңалту бөлімшесі), Кало Институты, Берк-сюр-Мер, Франция, antoine-xavier.malliopoulos@fondation-hopale.org
[2] Ұйқы бөлімшесінің басшысы, Кало Институты, Берк-сюр-Мер, Франция
[3] КеАҚ «Астана медициналық университеті» неврология кафедрасының доценті, Астана, Қазақстан, daribayev.zh@amu.kz

Түйіндеме

Бұл жұмыстың мақсаты зейін тапшылығы бұзылған (ЗТБ) балалар популяциясындағы ұйқы апноэ синдромының (ҰАС) жиілігін анықтау болды. *Материалдар мен тәсілдер*. Зерттеу екі жыл бойына ретроспективті болып табылады және бөлімшеде ЗТБ диагнозы қойылған барлық балалардың жазбаларына бағытталған. 156 файл талданды. Орташа жас 10,7 жас, стандартты ауытқу 2,45 жас. Жынысы бойынша бөлу: 40 қыз және 116 ұл. *Нәтижелер.* Ұйқының бұзылуы 38 жағдайда (24,3%) анықталды, бұл негізінен ЗТБ балалардың 17,3% -ында болатын ҰАС (71%) болды. *Талқылау, қорытындылау.* Басқа зерттеулермен салыстырғанда, біздің зерттеуіміз ЗТБ балалардағы ұйқының бұзылуын анықтау үшін сауалнаманың сезімталдығының жоқтығын және ЗТБ кезінде ҰАС анықтау ақауын көрсетеді. Сауалнамалардың сезімталдығы мен спецификасының жоғарылауымен ЗТБ кез келген балаға жүйелі полисомнографияны жүргізген жөн.

Түйінді сөздер: зейін тапшылығының бұзылуы, ұйқы апноэ синдромы, балалар.

ЧАСТОТА СИНДРОМОВ АПНОЭ ВО СНЕ ПРИ СИНДРОМЕ ДЕФИЦИТА ВНИМАНИЯ У ДЕТЕЙ

Малиопулос Антуан-Хавьер[1], Так Сабине[2], Дарибаев Ж.Р.[3]

[1] Руководитель отдела «Одиссей» (отделение дневной неврологической реабилитации), Институт Кало, Берк-сюр-Мер, Франция, antoine-xavier.malliopoulos@fondation-hopale.org
[2] Руководитель отделения сна, Институт Кало, Берк-сюр-Мер, Франция
[3] Ассоциированный профессор кафедры неврологии НАО «Медицинский Университет Астана», Астана, Казахстан, daribayev.zh@amu.kz

Резюме

Целью данной работы было определение частоты синдрома апноэ во сне (САС) в популяции детей с синдромом дефицита внимания (СДВ). *Материалы и методы*. Исследование является ретроспективным в течение двух лет и фокусируется на записях всех детей, у которых был диагностирован СДВ в отделении. Было проанализировано 156 файлов. Средний возраст составляет 10,7 лет со стандартным отклонением 2,45 года. Распределение по полу: 40 девочек и 116 мальчиков. *Результаты*. Нарушения сна были выявлены в 38 случаях (24,3%), в основном состоящие из САС (71%), который присутствует у 17,3% детей с СДВ. *Обсуждение, заключение*. По сравнению с другими исследованиями наше исследование показывает недостаточную чувствительность опроса для