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Original Article

Effect of a Rehabilitation Program Including Home-Based Vibration-Assisted Therapy on Gait Parameters in Children with Cerebral Palsy

Stefanie Steven[1], Karoline Spiess[1], Bruno Lentzen[1], Nina Reinhart[1], Eckhard Schoenau[1,2], Ibrahim Duran[1,2]

[1]Center of Prevention and Rehabilitation, Medical Faculty and University Hospital, University of Cologne, Cologne, Germany;
[2]Department of Pediatrics, Medical Faculty and University Hospital, University of Cologne, Cologne, Germany

Abstract

Objectives: The aim of the present study was to examine the effects of a rehabilitation program combined with a home-based vibration-assisted therapy on gait parameters in children with cerebral palsy (CP). **Methods**: In a retrospective study, 180 children, 101 boys and 79 girls, (mean age 7.2 ± 3.3 years) with CP at Gross Motor Function Classification System (GMFCS) Level I and Level II were examined using gait analyses with the Leonardo Mechanograph® Gangway at three measurement points. The measurements were conducted before (M0) and after a six-month rehabilitation period (M6), as well as 12 months after the commencement of rehabilitation (M12). The difference between measurement points M6-M0 (treatment interval) and M12-M6 (follow-up interval) were compared, and significance was determined using the Wilcoxon test. **Results**: Children with CP at GMFCS Level I and II demonstrated a significant improvement in gait efficiency (pathlength/distance M6-M0: -0.053 (SD 0.25) vs M12-M6: -0.008 (0.36), p=0.038). There were no significant difference in change of mean velocity and average step length between M6-M0 and M12-M6 (p=0.964 and p=0.611). **Conclusions**: The rehabilitation program seems to enhance gait efficiency in children with CP. German Clinical Trial Registry: DRKS00011131 at www.germanctr.de

Keywords: Cerebral Palsy, Children, Gait Parameter, Whole-Body Vibration, Mechanography

Introduction

Cerebral Palsy (CP) refers to a set of symptoms involving sensorimotor movement issues, affecting posture and movement. It includes various motor impairments that result in permanent but modifiable dysfunctions. Early therapeutic interventions can be effective during childhood development. CP affects approximately 2-3 out of every 1,000 live births, making it the primary cause of physical disabilities in children globally[1].

When considering a child's activities of daily living (ADL), it becomes evident that walking holds significant importance and is among the most common everyday movement for a child. In the presence of a central nervous system disorder like CP in children, acquiring walking skills or the act of walking itself can present a daily challenge. Because of brain damage, developmental disorders ensue, with adverse effects on daily activities and overall quality of life[2].

To therapeutically support this challenge, it is crucial to closely examine the walking ability of children with CP to assess and modify therapeutic interventions as necessary. The side-alternating vibration therapy (sVT) is employed as a therapeutic approach to enhance motor skills in children with CP. Serveral studies have consistently reported that sVT has a positive impact on these skills and demonstrates long-term improvements[3]. Additionally, it has also been shown to have a positive effect with home-based sVT on GMFM-66

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Corresponding author: Ibrahim Duran, MD, University of Cologne, Medical Faculty and University Hospital, Center of Prevention and Rehabilitation, UniReha, Lindenburger Allee 44, 50931 Cologne, Germany
E-mail: Ibrahim.duran@unireha-koeln.de
ORCID ID 0000-0003-4044-8822

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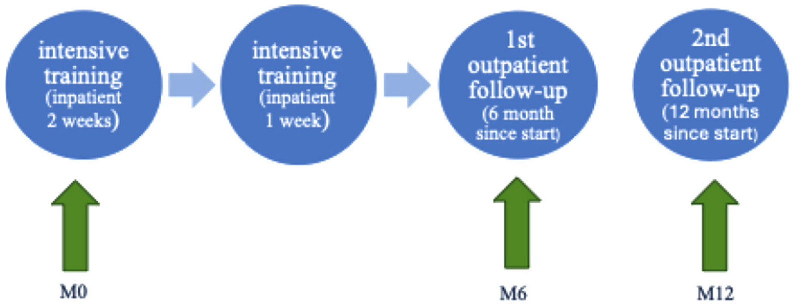

Figure 1. Rehabilitation program "On your feet". (*Interval rehabilitation with home-based vibration therapy. MO: Begin of rehabilitation program; M6: six months since beginning of rehabilitation program; M12: 12 months since beginning of rehabilitation program. The active is between MO and M6, the follow-up between M6 and M12).*

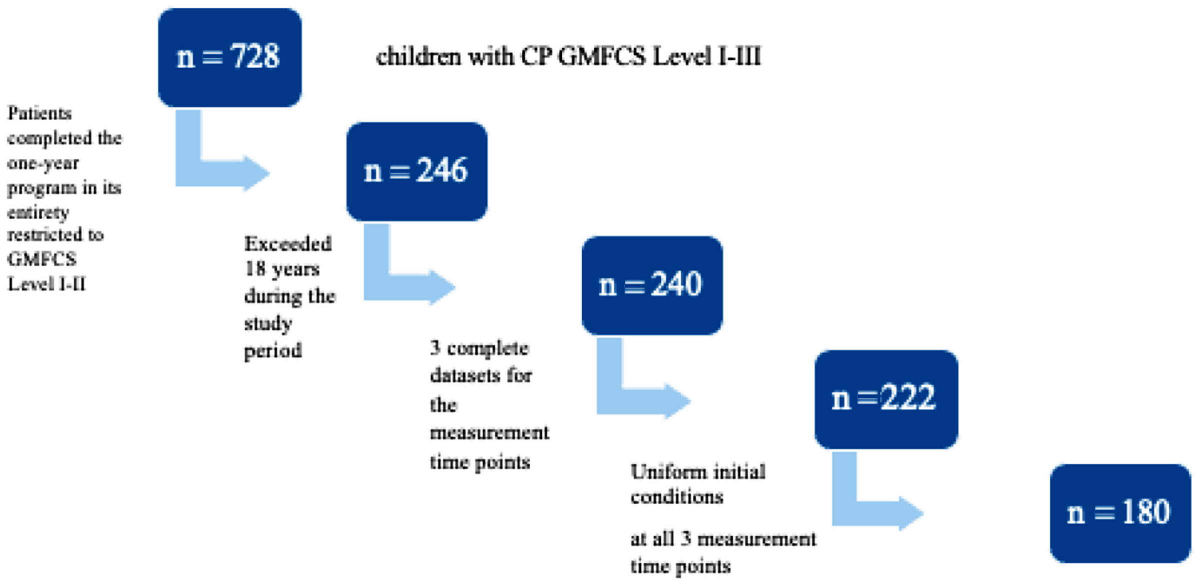

Figure 2. Consort diagram.

Scores, which is a standardized measurement instrument for assessing motor abilities in children with CP[4].

The aim of this study is to examine the effects of a rehabilitation program "On your feet" with home-based vibration-assisted therapy on gait parameters in children with CP. This study aimed to investigate whether vibration-assisted therapy leads to improvements in individual gait parameters in children with CP.

Materials and Methods

Study Population

In this study, we investigated changes in gait parameters among children and adolescents with CP GMFCS-Level 1 and GMFCS-Level 2 following an intensive training program, which included home-based training with vibration support as part of the rehabilitation program "On your feet" at the Center for Prevention and rehabilitation of the University Hospital of Cologne from January 2006 to March 2021. The rehabilitation program "On your feet" has been comprehensively described in previous studies and will be further elaborated upon in the subsequent text[5].

The basis for this study is a retrospective and exploratory single-center data analysis. The data were recorded in the German Clinical Trial Registry and can be accessed at www.germanctr.de (DRKS00001131) as of December 16, 2022. A pre-post examination was conducted to determine changes in the performance of individual gait parameters.

The analyzed data were derived from a patient cohort consisting of children and adolescents aged 2 to 17 years with a confirmed diagnosis of cerebral palsy. This cohort comprised a total of 753 children with cerebral palsy who participated in the rehabilitation program “On your feet”.

The overall cohort was narrowed down to include only the children who were classified as GMFCS Level I and Level II. Children with CP classified as GMFCS Level I and Level II are capable of walking independently during the examination. To enhance the internal validity of the study, the sample was homogenized based on different criteria. Specifically, the dataset was assessed for completeness with respect to three distinct measurement time points. The first measurement time point (M0) was taken at the begin of the rehabilitation program, the second measurement time point occurred after six months, marking the end of the active phase of intensive training within the rehabilitation program (M6), the third measurement was conducted 12 months from the commencement of the rehabilitation program (M12, the follow-up phase) (Figure 1). Incomplete datasets were excluded from the analysis.

Therefore, the sample comprised 220 children who met the inclusion criteria. Additional homogenization was achieved by examining the consistency of footwear within each individual study participant during the measurement time points, as well as ensuring a consistent GMFCS level throughout the study.

Furthermore, both free walking and walking with assistance, such as guidance by holding a hand, were considered. All children were capable of walking without aids such as walkers or crutches.

In the end, the examined sample consisted of a total of 180 children and adolescents aged 2-16 years, without any gender-specific distinctions. The recruitment process of the study population is illustrated in a Consort diagram (Figure 2).

Intervention

The intensive training was conducted as part of the 12-month interval-based rehabilitation program called “On your feet”. This concept is an integral part of healthcare provision in Germany and integrates intensive, goal-oriented training during the inpatient stay with six months of home-based whole-body vibration training. During a two-week inpatient stay, participants received four to five hours of daily physiotherapy[6].

In addition to physiotherapeutic interventions such as Bobath or Vojta therapy, treadmill training, and muscular training therapy, an individualized training plan was devised in collaboration between therapists and parents. This plan incorporated the use of a vibration platform. A side-alternating vibration platform (System Galileo©, Novotec Pforzheim, Germany) was provided by the center. Furthermore, accompanying parents received individual guidance from a physiotherapist to prepare them for the home-based vibration platform training with an individually compiled set of exercises based on the child’s motor skills and therapeutic goals[7]. The home vibration training is conducted ten times a week for three sessions of three minutes each[8]. The primary goals of these therapeutic measures were to enhance mobility, improve walking performance and increase the participation of the patients. During the first and second inpatient stays, as well as during the outpatient examination after a six-month training break, gait analysis using the Gangway system (see Investigation) was conducted for all participating children in the rehabilitation program.

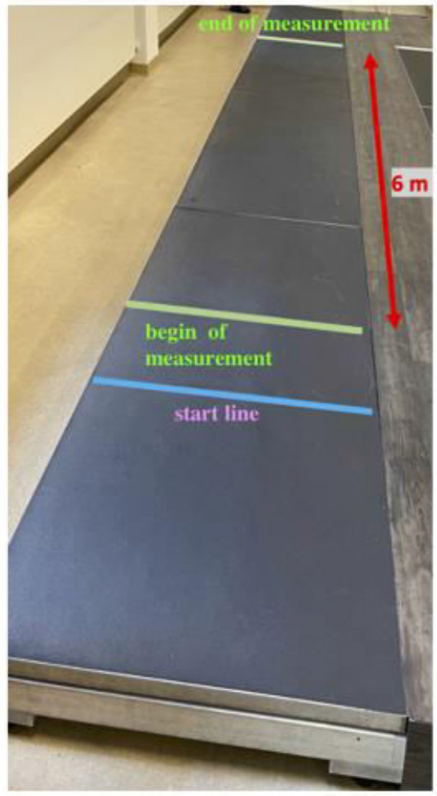

Figure 3. Leonardo Mechanograph® Gangway.

Gait analysis

To assess the gait parameters, including velocity (in meters per second), average step length (in meters), and pathlength/distance, measurements were conducted using a 6-meter-long Leonardo Mechanography® system walkway (Figure 3). All patients walked in their orthoses, shoes or barefoot. The use of other walking aids was not permitted. The employed assistive tools were customized for each patient.

This measuring instrument can be used for assessing motor performance in the form of walking ability. Mechanography, through the use of software, enables an objective motion analysis for assessing the development of gait parameters such as velocity, average step length, and coordination,

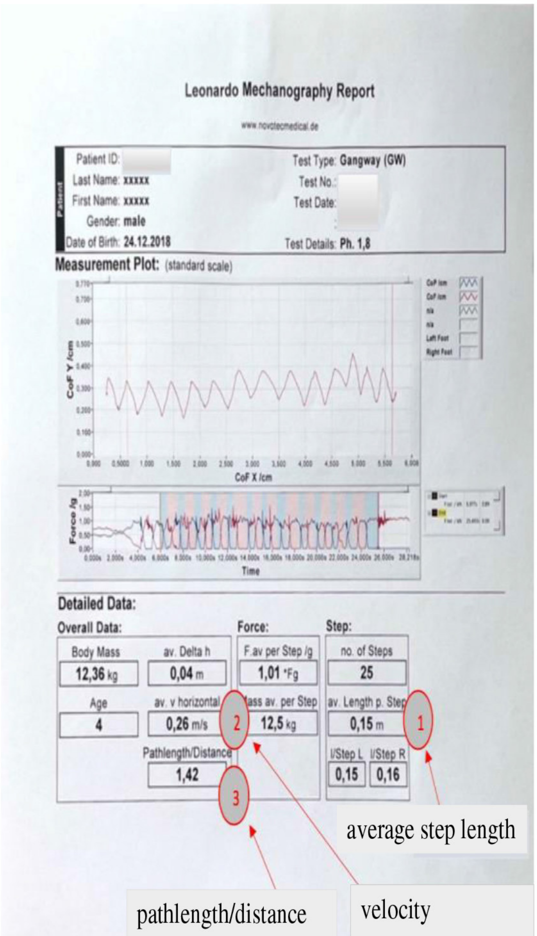

Figure 4. Example of a software output of Leonardo Gangway Mechanograph®.

Table 1. Definition of gait parameters used in the present study.

Parameter	Unit	Definition
Velocity	m/s	Distance between first and last step divided by time
Average step length	m	Distance between left and right food by one step
Pathlength/ distance	no unit	Expresses the extent of deviation in the COF curve from a linear path. A perfectly straight COF curve would result in a relative path length of 1. The relative path length increases e.g. with the growing lateral translation of the COF curve during locomotion or with shorter step length

m: meter, s: second, m/s: meter per second.

Table 2. Demographics of the study population.

Participants:	n= 180
GMFCS level I	n= 60
GMFCS level II	n= 120
Age	7.2 ± 3.4 years
Sex	girls: n= 79
	boys: n= 101
Height, cm	121.7 (20.9)
BMI	16.0 (2.8)

The numbers listed in the table represent the mean ± the standard deviation (SD).

measured using the pathlength/distance[9].

The reliability of the device has been demonstrated[10]. Another research team has provided evidence of its validity for balance measurements[11]. Additionally, it has been demonstrated that the Leonardo Mechanograph® Gangway has a repeatability in healthy children[12]. These findings provide substantial support for the validity of the data collected in this study. To ensure data comparability, all datasets were configured to the latest software version (v4.4b03.58) before analysis due to software updates over time.

This study examined changes in gait parameters, specifically velocity, average step length and pathlength/ distance, before (M0), after the rehabilitation program (M6), and following a six-month resting period (M12) of intensive training using the vibration plate. In general, the gait analysis procedure involved recording walking with or without orthoses three times. Data collection followed the protocol outlined in the Novotec company's operator manual.

The three-time execution on the gangway is as follows:

Data is recorded in the patient's file under "New Measurement." Recording starts with the button "Start this test now." The possibility "Measurement Details" contains specific individual information and "Measurement Comments" documents details such as walking with or without orthotic support. The examination begins with a verbal prompt and a start signal.

Measurement occurs at the starting point on the plateau before the line, with weight recorded.

The end of the measurement is also acoustically signaled and verbally supported.

Prior to measurements, we ensured that the measurement platform was properly calibrated.

Participants were asked to stand at the starting point of a marked pathway with their feet shoulder-width apart. After the initial audible signal, they were instructed to stand still for weight measurement. Following a second signal, they were verbally prompted to walk at their chosen pace along

Table 3. Differences between the timepoints of measurements.

Parameter	M6-M0 (treatment)	M12-M6 (follow up)	P value	Cohen`s d
Velocity (m/s)	0.027 (0.21)	0.026 (0.20)	0.964	NA
Average step length (m)	0.013 (0.11)	0.010 (0.36)	0.611	NA
Pathlength/ distance (m/m)	-0.053 (0.25)	-0.008 (0.36)	0.038	0.2

NA not applicable; Data are given as mean (standard deviation).

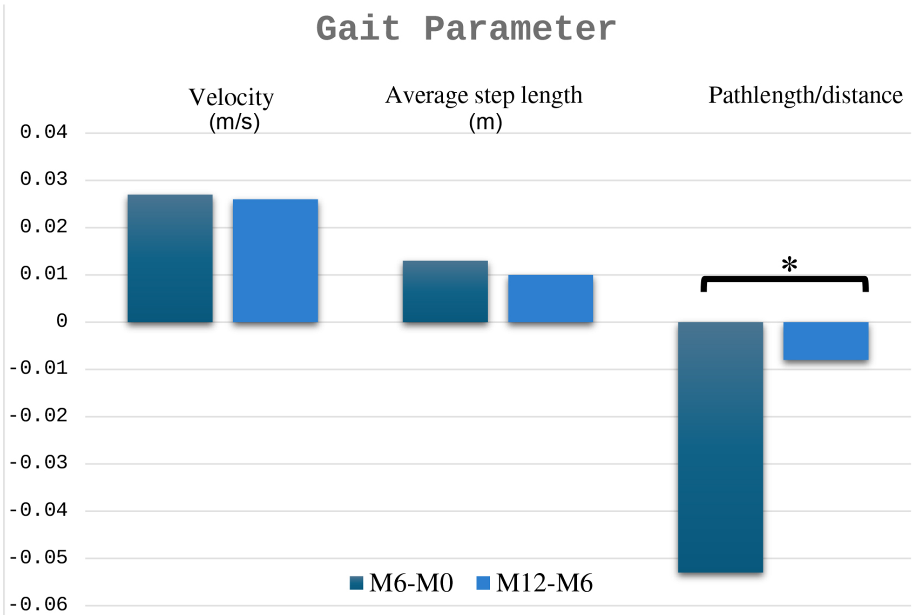

Figure 5. Graphical presentation of the results. (**: significant (p= 0.038).*

the pathway while keeping their feet on the platform. At the end of the pathway, a "Stop" command was given to cease movement, followed by a second weight measurement and subsequent calculations.

After software processing and analysis, a third auditory signal indicated the end of data recording. To ensure measurement reliability, the measurements were repeated three times under the same conditions, with the initial setup carefully documented (Figure 4). The measurement with the lowest pathlength/distance was used for further statistical analysis.

Evaluated parameters

Velocity, as a product of stride length and stride frequency, assesses walking ability and enables comparison with age-specific normative values[13]. It provides insights into performance and improvements in walking ability. Average step length, as the distance between the contact points of both feet, directly influences gait speed[14].

Pathlength/distance assesses gait coordination and efficiency by measuring the ratio of the total pathlength of the center of force to the actual distance. In non-physically impaired individuals, the ratio of path length to distance typically falls around 1.0-1.1. This parameter is associated with coordination tests and represents the ability to control movements and maintain body stability during motion (Table 1)[15].

The Gross Motor Function Classification System (GMFCS) is a widely accepted five-level scale to assess functional limitations in children with CP. While useful, it provides limited insight into movement precision. Children at GMFCS Levels I and II can walk, albeit less smoothly than their healthy peers. GMFCS Levels III and IV use mobility aids, and GMFCS Level V individuals depend on wheelchairs and may face head and trunk control challenges[16].

Statistical analysis

In the present study, a change analysis was conducted, retrospectively examining changes between the measurement time points M6 and M0, as well as M12 and M6, in a longitudinal study for the gait parameters, including velocity, average step length and pathlength/ distance. Based on these analyses, the mean values for M6-M0 and M12-M6, along with their respective standard deviations, were determined.

Following this, a Shapiro-Wilk test was employed to examine normal distribution, and due to the lack of normal distribution, the Wilcoxon test was utilized to evaluate the significance of the differences. To quantify the effect size, the Cohen's d value was determined.

Results

Study population

The sample for this study included a total of 180 children, comprising 101 boys and 79 girls. The average age of the participants was 7.2 (±3.4) years. Participants were classified based on the GMFCS. Of the 180 children, 60 were classified as Level 1, and 120 were classified as Level 2 (Table 2).

Gait parameter

The walking speed and step length improved on average in all children. However, no statistically significant difference was observed.

Of particular significance is the alteration in pathlength/ distance (p= 0.038), which exhibited a statistically significant improvement over the period from M0 to M6. The distance covered has decreased. The effect size, as measured by Cohen's d, was small (d=0.2) (Table 3), indicating a measurable improvement (Figure 5).

Discussion

The present study shows that the performance of the gait parameter pathlength/distance improved significantly in 180 children after the six-month rehabilitation concept. The individually adapted concept "On your feet" including home-based vibration-assisted therapy seems to be particularly suitable for improving motor skills, especially walking, in children with GMFCS Level I and Level II.

Enhancing gait parameters can directly impact the improvement of walking, which in turn has a positive influence on increasing the child's participation[17]. Additionally, the results are intended to contribute to reducing mechanical stress on the hip joint while walking, alleviating pain, and thus influencing the improvement of the quality of life[18].

Previous studies have already shown that Whole Body Vibration Therapy (WBV) can positively influence various aspects of gait parameters.

Dickin et al. (2013) observing increased walking speed and stride length following vibration therapy in adults, the present study did not identify a significant difference in these two parameters in our study population[19].

The review by Pulay et al. (2023) also demonstrates an enhancement in gait performance and improvement in gait parameters among children with CP. In addition to the improvement in muscle strength and reduction of muscle spasticity, WBV has a positive effect on gait stability and performance in this population[20].

The observed significant improvement in performance during the therapy phase provides valuable insights into the positive effects of vibration-assisted therapy. Possible reasons for the improvement in pathlength/distance performance could include the increase in muscle strength, reduction of spasticity and improvement of motor control resulting from vibration-assisted therapy.

According to Kirkwood et al. (2012), limited stability of the hip abductors and increased spasticity of the hip adductors can result in an unstable gait with heightened balance problems. The increase in muscle strength and reduction of spasticity through vibration-assisted therapy could thus be a potential cause for the improvement in coordination performance, as reflected in the pathlength/ distance[21]. Similarly, an increase in muscle mass was observed in home-based vibration training, suggesting that muscle strength has increased through home-based vibration therapy[22].

The application of WBV may exhibit spasticity-reducing effects, leading to improved movement control and facilitating progress in movement coordination[23]. El-Shamy (2014) also observed a positive effect on muscle strength and balance following intensive training with vibration-assisted therapy in diplegic children. Vibration-assisted therapy enhances the coordination abilities in children with CP[24].

Krause et al. (2017) demonstrated a reduction in reflex activity, which positively impacts the mitigation of spasticity-induced movements and improved muscle activation following whole-body vibration therapy. Consequently, this leads to an enhancement in motor control, which may also be reflected in the gait parameters[25].

Furthermore, increased muscle strength can positively impact the increased energy expenditure during walking in children with CP. Improved strength can lead to an enhanced gait pattern that requires less energy, allowing children to cover longer distances and improve their participation[26]. The energy efficiency during walking can be illustrated by the representation of pathlength/ distance, allowing the child to enhance participation in activity of daily living (ADL).

This is of particular significance when considering gait, as Chakraborty, Nandy and Kesar (2020) highlighted in their meta-analysis the correlation between unstable postural control and alterations in gait patterns[27].

Reduced stability may result in gait imbalance, reflected in altered pathlength/distance as a coordination gait parameter[28].

Cai et al.'s (2023) meta-analysis confirms that vibration-assisted therapy can enhance motor function more effectively than conventional therapy. This includes improvements in muscle strength, reduction of spasticity, promotion of postural stability, and balance capacity. Gross motor functions, as well as walking speed, are positively influenced. Vibration-assisted therapy demonstrates high efficacy with minimal physical strain for the child[29].

Pulay et al. (2023) meta-analysis reveals a significant difference in walking speed and stride length, supporting the understanding that whole body vibration is one of the key objectives to prepare inactive muscles responsible for weakened walking ability. Improving balance skills helps to normalize muscle tone before functional therapy and enhance gait functions and mobility in children with CP[20].

A similar conclusion was clearly evident in the study where the positive impact of the same home-based vibration therapy on the improvement of the GMFCS score was determined[7].

The walking distance, measured through the 6-minute walk test (6MWT), also increased in children undergoing home-based vibration therapy, considering the anticipated growth over the six-month period of development[30].

In another study of the same therapeutic concept as the present one, a statistically significant improvement in walking capacity, assessed through the 1-minute walk test (1MWT) in children with CP, GMFCS levels I and II, was observed under treatment with an intensive neuromuscular rehabilitation program, including home-based vibration training[31].

Limitations

The present study has limitations due to its retrospective dataset, including potential incompleteness and inaccuracies. A prospective approach would have allowed for more targeted data collection and better control over data quality. The lack of timeliness in the GMFM66 score in retrospective data could impact interpretation. Nevertheless, the large sample size mitigated some of these limitations.

Another significant limitation in this study is the extended data collection period involving different examiners, which may introduce potential biases due to variations in assessment methods. A shorter, more standardized data collection period with a consistent team of examiners could reduce this potential bias.

Additionally, it can be assumed that the children's motor skills may have naturally improved over the course of the study period. However, it is crucial to note that future studies could benefit from randomization to examine and eliminate this effect more precisely. By randomizing participant groups, the influence of growth on motor skills can be better controlled and accounted for.

Partially, children were guided while walking along the gangway. This support is not measurable and therefore cannot be included in the assessment of the improvement of gait parameters, serving as a limitation.

Further studies are needed to confirm the effectiveness of vibration-assisted therapy on gait parameters.

Conclusion

In this study, gait parameters (Velocity, Average Step Length, and Pathlength/Distance) were assessed during a home-based vibration therapy to improve motor skills in 180 children with CP Level I and Level II. The Leonardo Mechanograph® Gangway ensured reliable measurements. The aim of the study was to investigate the impact of a rehabilitation program on the gait parameters of children with CP. The program consisted of a six-month home-based intervention, which commenced with a two-week intensive phase during the rehabilitation stay. After three months of home training, another one-week intensive phase occurred. At the conclusion of the six months, a final assessment was conducted. Statistical analysis in R Studio determined mean values, standard deviations, and change over time. Improvement was observed in all parameters, with significant enhancement noted in pathlength/distance. Home-based vibration therapy over six month seems to have a positive effect on gait efficiency in children with CP and may lead to improved daily activities and participation.

Ethics approval

Data collection and utilization received approval from the Ethics Committee of the University of Cologne (16-269). The conducted study was carried out in accordance with the principles of the Helsinki Declaration.

Consent to participate

The study participants provided consent to participate in the study and for the collection of their data.

Authors' contributions

Research design, data improvement, analysis and manuscript writing were conducted by Stefanie Steven and Ibrahim Duran. We thank Bruno Lentzen, Nina Reinhart, Karolin Spieß und Eckhard Schönau for editing the manuscript. All authors provided suggestions, revisions, and edits to the manuscript and approved the final version.

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References

1. Strassburg HM. Behandlungskonzept bei Kindern mit infantiler Zerebralparese. In: Leitlinien Kinder- und Jugendmedizin. Elsevier; 2015:R5.1-R5.6.
2. Zai W, Xu N, Wu W, Wang Y, Wang R. Effect of task-oriented training on gross motor function, balance and activities of daily living in children with cerebral palsy: A systematic review and meta-analysis. Medicine 2022;101(44):e31565.
3. Duquette SA, Guiliano AM, Starmer DJ. Whole body

vibration and cerebral palsy: a systematic review. J Can Chiropr Assoc 2015;59(3):245-252.
4. Duran I, Stark C, Martakis K, Hamacher S, Semler O, Schoenau E. Reference centiles for the gross motor function measure and identification of therapeutic effects in children with cerebral palsy. J Eval Clin Pract 2019;25(1):78-87.
5. Stark C, Herkenrath P, Hollmann H, et al. Early vibration assisted physiotherapy in toddlers with cerebral palsy – a randomized controlled pilot trial. JMNI 2016;16(3):183-192.
6. Stark C, Nikopoulou-Smyrni P, Stabrey A, Semler O, Schoenau E. Effect of a new physiotherapy concept on bone mineral density, muscle force and gross motor function in children with bilateral cerebral palsy. J Musculoskelet Neuronal Interact 2010;10(2):151-158.
7. Stark C, Semler O, Duran I, et al. Intervallrehabilitation mit häuslichem Training bei Kindern mit Zerebralparese. Monatsschr Kinderheilkd 2013;161(7):625-632.
8. Duran I, Stark C, Schönau E. Vibrationsunterstütze Physiotherapie im Kindes- und Jugendalter. Published online 2019. https://www.kinder-undjugendarzt.de/uploads/SKpDm8m6/KJA_8-2019_Web.pdf Accessed on 17 March 2024.
9. Taani MH, Kovach CR, Buehring B. Muscle Mechanography: A Novel Method to Measure Muscle Function in Older Adults. Research in Gerontological Nursing 2017;10(1):17-24.
10. Veilleux LN, Robert M, Ballaz L, Lemay M, Rauch F. Gait analysis using a force-measuring gangway: Intrasession repeatability in healthy adults. J Musculoskelet Neuronal Interact 2011;1(11):27-33.
11. Wiegmann S, Felsenberg D, Gast U, Börst H, Armbrecht G, Dietzel R. Balance Performance across the Lifespan Assessed by the Leonardo Mechanograph®: A Cross Sectional Study. JFMK 2019;5(1):1.
12. Veilleux LN, Ballaz L, Robert M, Lemay M, Rauch F. Analysing gait using a force-measuring walkway: intrasession repeatability in healthy children and adolescents. Computer Methods in Biomechanics and Biomedical Engineering 2014;17(13):1447-1451.
13. Kramers-de Quervain I, Stüssi E, Stacoff A. Ganganalyse beim Gehen und Laufen. 2008;56(2):35-42.
14. Götz-Neumann K. Gehen Verstehen; Ganganalyse in der Physiotherapie. 4. Auflage. Georg Thieme Verlag; 2015.
15. Wank V. Gehen, Laufen, Sprint und Hürdenlauf. In: Biomechanik der Sportarten. Springer Berlin Heidelberg; 2021:125-165.
16. Russel DJ, Rosenbaum PL, Avery LM, Lane M. GMFM und GMFCS - Messung und Klassifikation motorischer Funktionen. Buch. 1. Aufl. Huber; 2006.
17. Rethwilm R, Böhm H, Haase M, Perchthaler D, Dussa CU, Federolf P. Dynamic stability in cerebral palsy during walking and running: Predictors and regulation strategies. Gait Posture 2021;84:329-334.
18. Cheng HYK, Ju YY, Chen CL, Chuang LL, Cheng CH. Effects of whole body vibration on spasticity and lower extremity function in children with cerebral palsy. Human Movement Science 2015;39:65-72.
19. Dickin DC, Faust KA, Wang H, Frame J. The acute effects of whole-body vibration on gait parameters in adults with cerebral palsy. JMNI 2013;13(1):19-26.
20. Pulay MÁ, Nagy R, Kói T, et al. The Effect of Additional Whole-Body Vibration on Musculoskeletal System in Children with Cerebral Palsy: A Systematic Review and Meta-Analysis of Randomized Clinical Trials. J Clin Med 2023;12(21):6759.
21. Kirkwood RN, Franco R de LLD, Furtado SC, Barela AMF, Deluzio KJ, Mancini MC. Frontal Plane Motion of the Pelvis and Hip during Gait Stance Discriminates Children with Diplegia Levels I and II of the GMFCS. ISRN Pediatr 2012;2012:163039.
22. Duran I, Martakis K, Stark C, Schafmeyer L, Rehberg M, Schoenau E. Effect of an interval rehabilitation program with home-based, vibration-assisted training on the development of muscle and bone in children with cerebral palsy – an observational study. Journal of Pediatric Endocrinology and Metabolism 2020;33(8):1083-1092.
23. Park C, Park ES, Choi JY, Cho Y, Rha D wook. Immediate Effect of a Single Session of Whole Body Vibration on Spasticity in Children With Cerebral Palsy. Ann Rehabil Med 2017;41(2):273-278.
24. El-Shamy SM. Effect of Whole-Body Vibration on Muscle Strength and Balance in Diplegic Cerebral Palsy: A Randomized Controlled Trial. American Journal of Physical Medicine & Rehabilitation 2014;93(2):114-121.
25. Krause A, Schönau E, Gollhofer A, et al. Alleviation of Motor Impairments in Patients with Cerebral Palsy: Acute Effects of Whole-body Vibration on Stretch Reflex Response, Voluntary Muscle Activation and Mobility. Front Neurol 2017;8:416.
26. Miller F. Gait Treatment Outcome Assessments in Cerebral Palsy. In: Miller F, Bachrach S, Lennon N, O'Neil ME, eds. Cerebral Palsy. Springer International Publishing; 2020:1429-1436.
27. Chakraborty S, Nandy A, Kesar TM. Gait deficits and dynamic stability in children and adolescents with cerebral palsy: A systematic review and meta-analysis. Clinical Biomechanics 2020;71:11-23.
28. Taube W. Neuronale Mechanismen der posturalen Kontrolle und der Einfluss von Gleichgewichtstraining. 2013;14(2):55-63.
29. Cai X, Qian G, Cai S, Wang F, Da Y, Ossowski Z. The effect of whole-body vibration. on lower extremity function in children with cerebral palsy: A meta-analysis. PLoS One 2023;18(3):e0282604.
30. Martakis K, Stark C, Rehberg M, Semler O, Duran I, Schoenau E. Reference Centiles to Monitor the 6-minute-walk Test in Ambulant Children with Cerebral Palsy and Identification of Effects after Rehabilitation Utilizing Whole-body Vibration. Dev Neurorehabil 2021;24(1):45-55.
31. Martakis K, Stark C, Rehberg M, Semler O, Duran I, Schoenau E. One-Minute Walk Test in Children with Cerebral Palsy GMFCS Level 1 and 2: Reference Values to Identify Therapeutic Effects after Rehabilitation. Developmental Neurorehabilitation 2020;23(4):201-209.