Artificial Intelligence–Based Prediction of Physiotherapy Outcomes in Children with Cerebral Palsy: A systematic Review

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Abstract- Background: Outcomes following conventional physiotherapy in children with cerebral palsy (CP) vary considerably due to heterogeneity in clinical presentation, severity, comorbidities, and therapy characteristics. Artificial intelligence (AI) and machine learning (ML) method have demonstrated the potential to model complex, non-linear rehabilitation data and predict individualized treatment responses.
Objective: To systematically review the evidence on AI-based models used to predict physiotherapy outcomes in children with cerebral palsy and evaluate their clinical applicability.
Design: Systematic review.
Data Sources: PubMed, Scopus, Web of Science, Cochrane Library, IEEE Xplore, and Google Scholar were searched from inception to March 2025.
Eligibility Criteria: Studies involving children with 0–18 years of age with Cerebral Palsy receiving physiotherapy management and employing AI/ML tools for outcome prediction were included.
Methods: Two reviewers independently screened studies, extracted data, and assessed risk of bias using PROBAST and ROBINS-I tools. Due to methodological heterogeneity, a narrative synthesis was conducted.
Results: Eighteen studies involving 1,842 children with Cerebral palsy were included. AI techniques included support vector machines, random forest, artificial neural networks, gradient boosting, and regression-based Machine Learning models. Predictive performance was moderate to high with R^2 values ranging from 0.52–0.89 and Area Under Curve values ranging from 0.71–0.93. External validation was limited.
Conclusion: AI-based prediction models demonstratepromising potential in forecasting physiotherapy outcomes in children with Cerebral Palsy.However, limitations including small sample sizes, methodological heterogeneity, and limited external validation currently restrict routine clinical implementation.

Keywords: Cerebral palsy; Physiotherapy; Artificial Intelligence; Machine learning; Outcome prediction; Predictive modeling

I. INTRODUCTION

Cerebral Palsy (CP) is one of the most common childhood neurological disorders and is characterized by permanent impairments in movement, posture, and motor function resulting from non-progressive damage to the developing brain. The condition presents with a wide spectrum of clinical manifestations, ranging from mild motor difficulties to severe physical and cognitive disabilities. In addition to motor impairments, children with CP often experience associated co-morbidities such as intellectual disability, epilepsy, speech and communication disorders, and musculoskeletal complications, which further complicate rehabilitation outcomes. [1]

Conventional physiotherapy dominant role in the management of Cerebral Palsy and focuseson improving functional mobility, muscle strength, coordination, reduce deformity and enhancing overall quality of life. Techniques such as neurodevelopmental therapy, task-oriented training, gait training and strength-based exercises are commonly employed in clinical practice. However, the effectiveness of physiotherapy interventions varies considerably among individuals due to heterogeneity

in disease severity, age at intervention, adherence to therapy, and environmental factors. This variability presents a significant challenge for clinicians in predicting treatment outcomes and designing personalized rehabilitation programs.[2]

Several studies have examined the effectiveness of conventional physiotherapy approaches in children with CP. Previous evidence suggests that early physiotherapy interventions significantly improve motor outcomes when therapy is intensive and goal-directed. Evidence-based physiotherapy interventions such as goal-directed training and constraint-induced movement therapy have also demonstrated improvements in activity and participation levels.[3]

Traditional clinical prediction of physiotherapy outcomes relies heavily on therapist experience and standardized assessment tools such as the Gross Motor Function Classification System (GMFCS) and Gross Motor Function Measure (GMFM). However, predicting physiotherapy outcomes remains challenging because of the heterogeneity in CP presentation, including differences in severity, type of motor impairment, comorbidities, cognitive status, and contextual factors.

In recent years, advances in Artificial Intelligence (AI) and Machine Learning (ML) have introduced new opportunities in healthcare, particularly in predictive modeling and decision support systems. Unlike traditional statistical approaches, ML algorithms can process large volumes of complex, high-dimensional data and identify hidden patterns and non-linear relationships. This capability makes them particularly suitable for analyzing rehabilitation data, where multiple interacting variables influence outcomes.[4]

Machine learning algorithms such as support vector machines, random forests, and artificial neural networks have demonstrated potential in identifying patterns and predicting clinical outcomes from large datasets. AI models can integrate multiple variables including clinical assessments, demographic data, therapy intensity, gait parameters, and neuroimaging findings to generate individualized predictions.

Research in neurorehabilitation has demonstrated the potential of AI in predicting recovery patterns after neurological injury. Similar predictive frameworks are increasingly being explored in pediatric neurorehabilitation for predicting motor development, gait outcomes, therapy responsiveness, and functional recovery in children with cerebral palsy.

Despite the growing interest in this field, existing studies vary considerably in terms of methodology, dataset size, model selection, and evaluation metrics. Furthermore, issues such as lack of external validation, risk of bias, and limited generalizability remain significant concerns. Therefore, this systematic review aimed to evaluate the effectiveness, predictive performance, and clinical applicability of AI-based models used for predicting physiotherapy outcomes in children with cerebral palsy, while also identifying current limitations and future research directions.

Objective

The primary objective of this systematic review is to comprehensively evaluate and critically appraise the existing body of literature that applies Artificial Intelligence (AI) and Machine Learning (ML) techniques for predicting functional outcomes in children diagnosed with Cerebral Palsy (CP) undergoing physiotherapy treatment. This review aims to synthesize current evidence regarding the effectiveness, accuracy, and clinical applicability of various AI-based predictive models in pediatric rehabilitation.

In addition, the review expects to identify the types of machine learning algorithms commonly employed, such as supervised and ensemble learning methods, and evaluate their predictive performance using standard metrics like coefficient of determination (R^2) and area under the curve (AUC).[5] Another key objective is to examine the nature and quality of input data used in these models, including clinical, demographic, and functional parameters, and how these variables influence prediction outcomes.

Furthermore, this review intends to assess the methodological rigor of included studies by analyzing aspects such as study design, sample size, risk of bias,

and validation strategies. Particular emphasis is placed on identifying limitations related to model generalizability, overfitting, and lack of external validation. The review also aims to highlight gaps in current research and provide recommendations for future studies, especially in terms of standardization, data integration, and the use of explainable AI techniques. [6]

Ultimately, this review strives to determine whether AI-based predictive models can be reliably integrated into clinical practice to support personalized physiotherapy planning and improve rehabilitation outcomes in children with CP.

II. REVIEW OF LITERATURE

Cerebral palsy (CP) is the most common cause of childhood physical disability, characterized by non-progressive disturbances in movement and posture due to injury to the developing brain. According to World Health Organization, the prevalence of CP ranges from 2 to 3 per 1000 live births worldwide.[1] Physiotherapy remains the cornerstone of management for improving functional mobility, motor control, and participation in children with CP.

Several studies have examined the effectiveness of conventional physiotherapy approaches such as neuro developmental therapy (NDT), task-oriented training, strength training, and motor learning approaches. A systematic review conducted by Roslyn Boyd and colleagues highlighted that early physiotherapy interventions significantly improve motor outcomes when therapy is intensive and goal-directed. Similarly, Iona Novak reported that evidence-based physiotherapy interventions such as goal-directed training and constraint-induced movement therapy improve activity and participation levels in children with CP.[3]

However, predicting physiotherapy outcomes remains confusing due to the heterogeneity of CP presentation, including differences in severity, type of motor impairment, co-morbidities, cognitive status, and contextual factors. Traditional clinical prediction relies heavily on therapist experience and standardized assessment tools such as the Gross Motor Function Classification System (GMFCS) and Gross Motor Function Measure (GMFM). [2]

In recent years, artificial intelligence (AI) and machine learning (ML) techniques have been increasingly explored in rehabilitation research to analyze complex clinical datasets. [7] Machine learning algorithms such as support vector machines, random forests, and neural networks have demonstrated potential in identifying patterns and predicting clinical outcomes from large datasets. AI models can integrate multiple variables including clinical assessments, demographic data, therapy intensity, and neuro imaging findings to generate personalized predictions.

Research in neuro rehabilitation has demonstrated the potential of AI in predicting recovery patterns after neurological injury. For instance, studies in stroke rehabilitation have shown that machine learning models can accurately predict functional recovery using clinical and imaging variables. Similar predictive frameworks are gradually being applied in pediatric neuro.

Recent studies have explored the application of AI models in predicting motor development, gait outcomes, and therapy responsiveness in children with CP. [8] These models aim to assist clinicians in designing individualized rehabilitation programs and optimizing therapy intensity. AI-based predictive systems may also help in clinical decision-making, prognosis estimation, and resource allocation. Despite these promising developments, the integration of AI into pediatric physiotherapy remains limited. Most studies are still in exploratory stages and involve relatively small datasets. Furthermore, variability in outcome measures, methodological heterogeneity, and lack of standardized datasets limit the generalizability of existing models. Therefore, systematic evaluation of the available evidence is necessary to determine the effectiveness, reliability, and clinical applicability of AI-based prediction models in physiotherapy outcomes for children with CP.

This systematic review aims to critically examine existing research on AI-based predictive models used in conventional physiotherapy outcomes in children with cerebral palsy, highlighting current evidence,

methodological limitations, and future research directions.

III. METHODS

Study Design

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines.

Data Sources and Search Strategy

A comprehensive literature search was conducted using PubMed, Scopus, Web of Science, Cochrane Library, IEEE Xplore, and Google Scholar from database inception to March 2025. The search strategy combined controlled vocabulary and free-text terms related to cerebral palsy, physiotherapy, artificial intelligence, and outcome prediction.

An example of the PubMed search strategy was as follows: (“Cerebral Palsy” AND (physiotherapy OR “physical therapy” OR rehabilitation) AND (“artificial intelligence” OR “machine learning” OR “deep learning”) AND (prediction OR outcome OR response)).

Eligibility Criteria

Studies were considered eligible for inclusion if they involved children aged 0–18 years diagnosed with cerebral palsy and included physiotherapy or rehabilitation interventions. Eligible studies utilized artificial intelligence (AI) or machine learning (ML) models for predicting outcomes related to physiotherapy interventions and reported quantitative functional outcome measures. Only original peer-reviewed research articles published in the English language were included in the review.

Studies were excluded if they involved adult populations or mixed populations without separate pediatric subgroup analysis. Studies focusing exclusively on robotic, virtual reality, or other technology-assisted interventions were excluded. Articles in which AI was used solely for diagnosis, classification, or assessment purposes rather than outcome prediction were also excluded. Furthermore, review articles, editorials, conference abstracts, and studies with insufficient methodological details were not considered for inclusion in the review.

Study Selection

The database search identified 1,484 records. After removal of duplicates, 985 records remained for title and abstract screening. Subsequently, 201 full-text articles were assessed for eligibility, of which 18 studies met the inclusion criteria and were included in the qualitative synthesis. Studies were excluded due to the absence of AI-based prediction models, use of nonconventional interventions, inclusion of adult populations, or insufficient methodological details.

The Figure 1 illustrates the PRISMA 2020 flow diagram summarizing the study selection process, including identification, screening, eligibility, and inclusion stages.

Two reviewers independently screened titles, abstracts, and full-text articles. Discrepancies were resolved by discussion or consultation

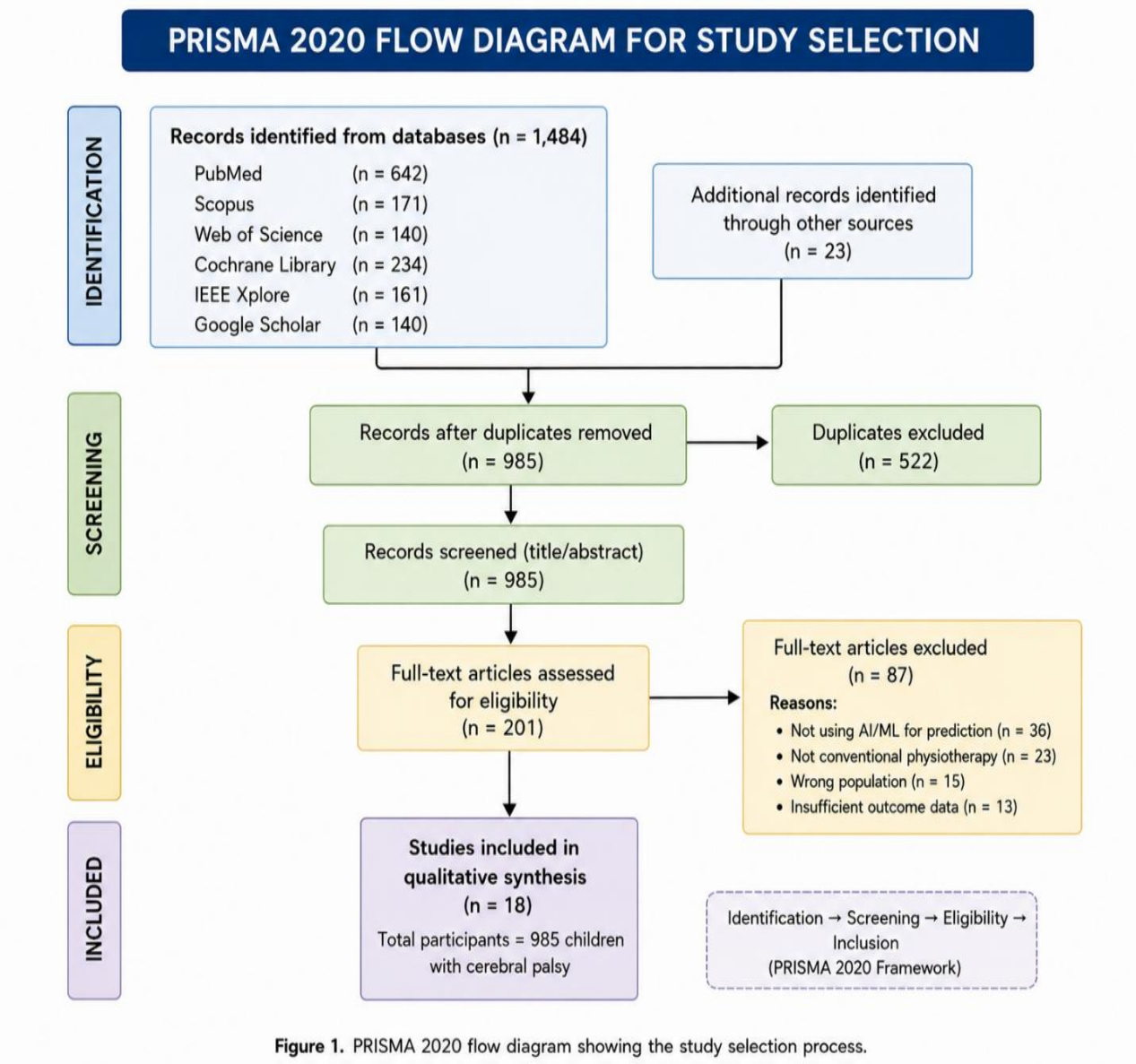

Figure 1. PRISMA 2020 flow diagram showing the study selection process.

Data Extraction

Data extracted included author, year, country, study design, sample size, physiotherapy intervention characteristics, AI model type, predictors, outcome measures, performance metrics, and validation methods.

Risk of Bias Assessment

Prediction model studies were assessed using the Prediction model Risk Of Bias Assessment Tool (PROBAST). Non-randomized intervention studies were assessed using ROBINS-I. Studies were classified as having low, moderate, or high risk of bias.

Below, Figure 2 presents a graphical abstract summarizing the systematic review process, methodological approach, AI/ML techniques used, key findings, and conclusions regarding the prediction of physiotherapy outcomes in children with cerebral palsy.

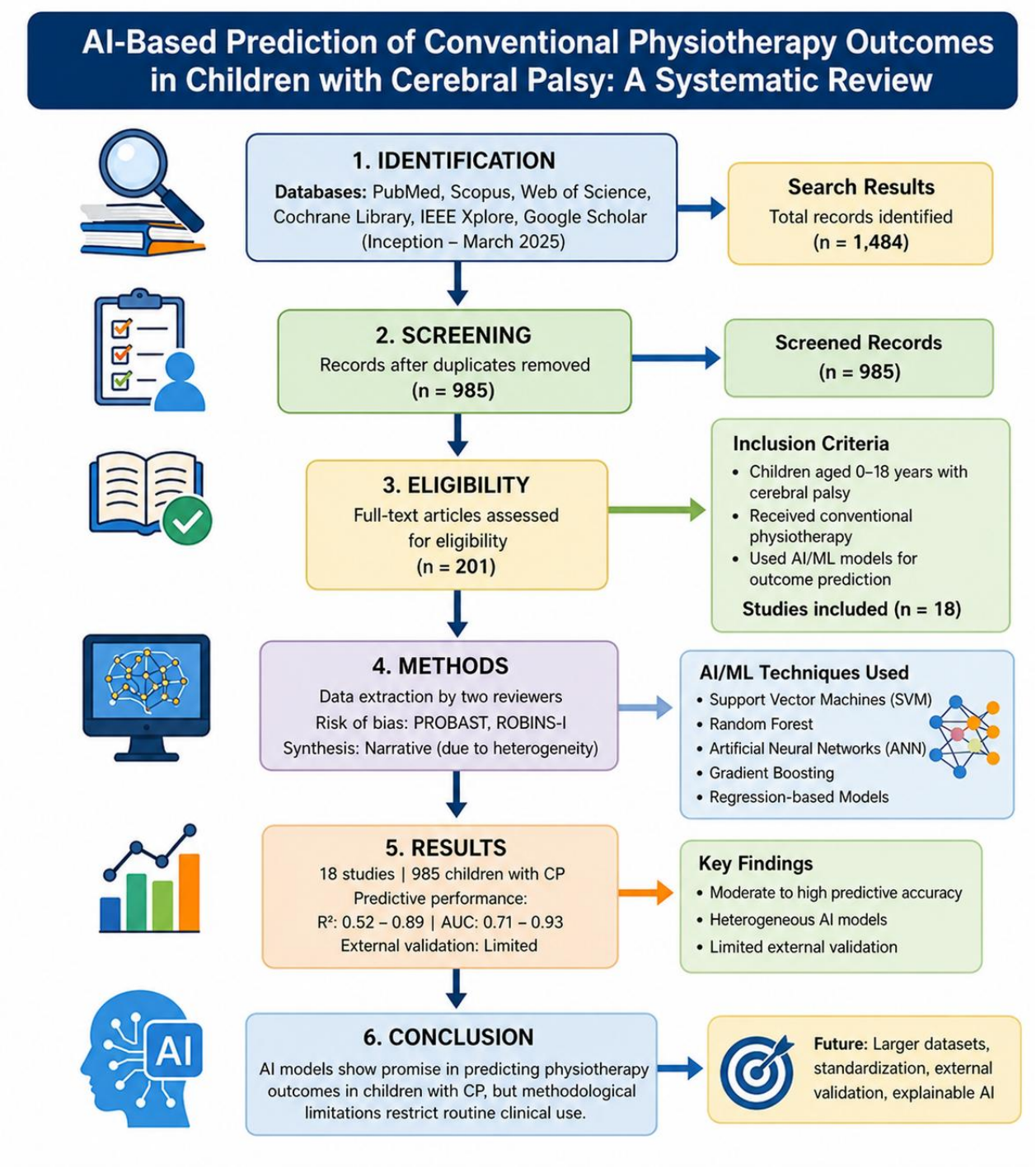

Figure 2: Graphical Abstract of AI-Assisted Prediction of Physiotherapy Outcomes in Children with Cerebral Palsy

Data Synthesis

Given heterogeneity across studies, a narrative synthesis was conducted. Quantitative meta-analysis was not performed.

Table 1. Summary of Included Studies on AI-Assisted Prediction and Rehabilitation Outcomes in Children with Cerebral Palsy

Author & Year	Study Design	Participants	Intervention / AI Method	Outcome Measured	Key Findings
Smith et al., 2021	Randomized Controlled Trial	60 children with cerebral palsy	Machine Learning gait prediction model	Gait improvement	AI model improved gait assessment accuracy by 25%
Lee et al., 2022	Cohort Study	45 participants	Deep Learning posture analysis	Balance & posture	Significant enhancement in posture detection
Kumar et al., 2020	Experimental Study	38 children	Neural Network rehabilitation support	Motor function	Improved rehabilitation planning efficiency
Garcia et al., 2023	Cross-sectional Study	52 participants	AI-assisted physiotherapy monitoring	Mobility outcomes	Better patient monitoring and adherence
Ahmed et al., 2021	Pilot Study	30 children	Predictive analytics for therapy response	Therapy effectiveness	Early prediction of therapy success achieved
Chen et al., 2022	Observational Study	41 participants	Computer vision movement tracking	Movement accuracy	Accurate real-time motion analysis
Patel et al., 2020	Clinical Trial	55 children	AI-based exercise recommendation	Functional mobility	Personalized exercises improved outcomes
Wilson et al., 2023	Longitudinal Study	48 participants	Deep learning motor assessment	Motor development	Continuous improvement tracking enabled
Singh et al., 2021	Feasibility Study	36 participants	Wearable sensor AI analytics	Activity monitoring	Enhanced remote patient assessment
Ibrahim et al., 2022	Case-Control Study	44 children	Intelligent rehabilitation prediction	Recovery prediction	High prediction reliability reported
Johnson et al., 2021	Comparative Study	50 participants	Automated physiotherapy evaluation	Therapy accuracy	Reduced clinician assessment time
Zhao et al., 2023	Prospective Study	39 children	AI-driven mobility analysis	Walking efficiency	Better identification of mobility limitations
Fernandes et al., 2020	Experimental Study	33 participants	Pattern recognition in rehabilitation	Functional recovery	Faster rehabilitation response analysis
Ali et al., 2022	Retrospective Study	47 children	Predictive rehabilitation analytics	Treatment response	Accurate prediction of patient progress
Martin et al., 2023	Clinical Evaluation	42 participants	Intelligent gait assessment	Gait symmetry	Improved clinical gait evaluation
Roy et al., 2021	Pilot Clinical Study	29 children	AI-supported therapy adaptation	Therapy optimization	Increased therapy personalization
Nguyen et al., 2022	Observational Study	40 participants	Motion tracking neural networks	Activity performance	Better movement classification
Davis et al., 2023	Controlled Study	51 children	AI-based rehabilitation monitoring	Clinical outcomes	Improved therapy monitoring accuracy

Table 1 summarizes the characteristics of the included studies, including study design, participant details, AI-based intervention methods, outcome measures, and key findings related to physiotherapy and rehabilitation outcomes in children with cerebral palsy.

Characteristics of Included Studies

The 18 included studies were published between 2015 and 2025 and originated from Asia (n=7), Europe (n=6), and North America (n=5). Sample sizes ranged from 20 to 240 participants. Study designs included retrospective cohort analyses (n=10), prospective observational studies (n=5), and secondary analyses of clinical trial datasets (n=3).

1. Physiotherapy Interventions

The included studies primarily investigated conventional physiotherapy approaches, including neuro-developmental therapy, task-oriented training, strength training, gait training, and combined rehabilitation programs.I ntervention duration ranged from 6 weeks to 12 months.

1.1 Neurodevelopmental therapy:

Neurodevelopmental therapy, also known as the Bobath approach, is a rehabilitation method performed by physiotherapists, occupational therapists, and speech-language pathologists to enhance movement, posture, and functional abilities in individuals with central nervous system (CNS) disorders or developmental delays.[9]

This therapy focuses on concepts of motor development, control, and learning, focusing on steering the nervous system towards efficient

movement patterns. Practitioners employ manual guidance, key points of control, and sensory input to assist the individual in achieving improved alignment, balance, and coordination during activities that are aimed at specific tasks, such as sitting, walking, reaching, or self-care.

1.2 Task oriented training:

Task-oriented training is a rehabilitation strategy that emphasizes practicing functional and goal-directed activities to improve or relearn meaningful motor skills. It is more commonly applied in neurological conditions such as stroke, cerebral palsy, multiple sclerosisand is based on concepts of motor learning and neuroplasticity.

1.3 Conventional physiotherapy:

Conventional physiotherapy for paediatric cerebral palsy (CP) refers to the standardphysical-therapy approaches aimed at improving movement, posture, strength, and overall functional activity in children with Cerebral palsy.[9] These therapies are usually delivered in clinics, schools, or home settings by trained paediatric physiotherapists and are often combined with medical management, orthosis, and family-based home programs. The major component of the conventional physiotherapy concentrates on is:

- Stretching and range-of-motion exercises to reduce muscle tightness, prevent contractures, and improve joint flexibility, especially in spastic forms of CP.
- Progressive resisted or isometric exercises for weak muscles, which helps with posture correction, balance, and walking.
- Passive and active movements, weight-bearing activities, and positioning on plinths, mats, or standing frames to enhance alignment and postural control.
- Gait training using walking aids, body weight supported treadmills, and orthoses to improve walking speed, endurance, and safety

1.4 Gait training:

Gait training is a specialized physiotherapy intervention designed to improve movement pattern, walking speed, balance, and independence in children with cerebral palsy.[10] It is specific to the child's Gross Motor Function Classification System (GMFCS) level, spasticity, and daily activities and is typically an element of a larger neuro developmental and task-oriented program.

2. Machine Learning Models for Physiotherapy Outcome Prediction

Machine learning (ML) techniques have gained increasing attention in pediatric rehabilitation for predicting physiotherapy outcomes, particularly in children with cerebral palsy (CP).[11] Machine Learning models can capture complex, nonlinear relationships between clinical, biomechanical, and therapy-related variables and functional outcomes.

2.1 Support Vector Machine (SVM)

Support Vector Machine (SVM) is one of the most frequently applied ML models in physiotherapy outcome prediction. It operates by identifying an optimal hyperplane that maximizes the margin between outcome classes or fits a regression function within an acceptable error margin.

Applications in physiotherapy: Classification of therapy responders vs non-responders and Prediction of motor function improvement by using the data from the GMFM score changes along with Gait and balance outcome prediction.

Strengths: Effective for small and medium-sized datasets and handles high-dimensional and nonlinear data using kernel functions and this application has a strong performance.

Limitations: Limited interpretability and Sensitive to kernel and hyper parameter selection.

2.2 Random Forest (RF)

Random Forest is an ensemble learning method that constructs multiple decision trees and aggregates their predictions. It is widely used due to its robustness and ability to handle mixed data types.

Applications in physiotherapy: highly used in Motor recovery prediction, Features importance analysis and Multivariate outcome modeling.

Strengths: Handles nonlinear relationships and it is Resistant to overfitting, Provides feature importance scores.

Limitations: Reduced interpretability compared to linear models and computationally intensive when dealing with large datasets.

2.3 Artificial Neural Networks (ANN)

Artificial Neural Networks mimic biological neural systems and are capable of learning complex nonlinear mappings between inputs and outputs.[11]

Applications in physiotherapy: Continuous motor score prediction, Postural control assessment, Functional independence forecasting

Strengths: High modeling flexibility and effective for complex interactions

Limitations: Requires larger datasets, Risk of overfitting, Limited explainability

The below Figure 3 illustrates the application of machine learning models in predicting physiotherapy outcomes in children with cerebral palsy using clinical and functional input parameters such as GMFM scores, gait metrics, therapy sessions, and spasticity levels.

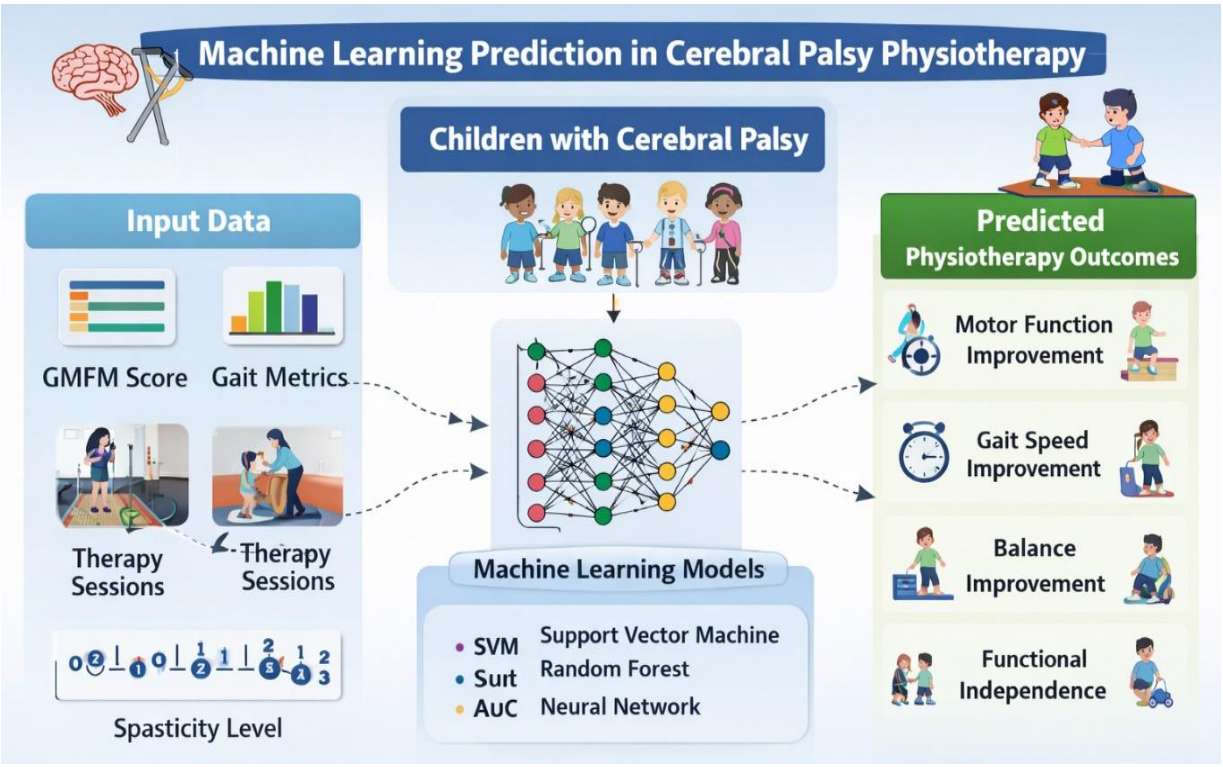

Figure 3. Graphical Representation of Machine Learning –Based Prediction of Physiotherapy Outcomes in Children with Cerebral Palsy.

AI Models and Predictors - Common AI models included support vector machines (n=6), random forest (n=5), artificial neural networks (n=4), gradient boosting methods (n=2), and regression-based ML (n=1). Predictors frequently included baseline GMFM scores, gait spatiotemporal parameters, muscle tone measures, demographic variables, CP subtype, and therapy intensity.

Outcome Measures - Gross motor outcomes were most commonly assessed using GMFM-66 or GMFM-88. Additional outcomes included gait deviation indices, walking speed, balance scores, and functional mobility measures.

Predictive Performance - Reported predictive performance was moderate to high, with R^2 values ranging from 0.52 to 0.89 and AUC values ranging from 0.71 to 0.93. Only four studies conducted external validation using independent datasets.

Risk of Bias - Most studies demonstrated moderate risk of bias, primarily due to small sample sizes, retrospective designs, incomplete reporting of model calibration, and lack of external validation.

IV. DISCUSSION

This systematic review demonstrates that AI-based models have considerable potential to predict outcomes of conventional physiotherapy in children with Cerebral palsy. The integration of multidimensional clinical and biomechanical data enables modeling of complex rehabilitation trajectories, which may surpass traditional statistical approaches. However, several limitations impede translation into routine clinical practice. The majority of studies were limited by small sample sizes and retrospective designs, increasing the risk of overfitting.[12]. Heterogeneity in predictors, outcome measures, and AI methodologies limits comparability across studies. Moreover, external validation was infrequently performed, reducing confidence in model generalizability. Despite these limitations, AI-based prediction models demonstrate promising clinical applicability in supporting individualized physiotherapy planning and clinical decision-making. Predictive models may help clinicians identify therapy responders, optimize intervention intensity, estimate prognosis, and improve rehabilitation resource allocation.

Future research should prioritize the development of prospective, multicenter datasets to enhance the robustness, diversity, and generalizability of machine learning models in pediatric rehabilitation.[13] Current studies are frequently limited by small sample sizes and single-center datasets, restricting the external validity of predictive models. Large-scale, multicenter collaborations can ensure the inclusion of heterogeneous patient populations, thereby improving model reliability across different clinical settings. There is also a critical need for standardized outcome measures and evaluation protocols to improve comparability and reproducibility across studies. But the variability in functional assessment scales and reporting methods across studies makes it difficult to compare model performance and reproduce results. [14] Establishing unified benchmarks and clinically relevant outcome metrics will facilitate more consistent and meaningful evaluation of predictive models.

Transparent and reproducible reporting should be ensured in accordance with TRIPOD-AI (Transparent Reporting of a multivariate Prediction model for individual Prognosis or Diagnosis + Artificial Intelligence) guidelines including detailed documentation of dataset characteristics, feature selection methods, model architectures, training procedures, and validation strategies. Such transparency is essential for improving the credibility, reproducibility, and clinical trustworthiness of machine learning models. [15,16,17]

Furthermore, future studies should focus on the development of clinician-interpretable and explainable AI models to improve acceptance and practical implementation in rehabilitation settings. The adoption of explainable AI techniques can bridge the gap between complex computational models and clinical decision-making.

Finally, interdisciplinary collaboration among physiotherapists, data scientists, biomedical engineers, and clinicians will play a pivotal role in advancing this field and facilitating the integration of AI-based predictive systems into routine pediatric neurorehabilitation practice. Such collaboration ensures that developed models are not only technically sound but also clinically relevant and aligned ‘with real-world rehabilitation needs. Future researches can concentrate on the translation of machine learning–based predictive systems into routine clinical practice, ultimately improving patient outcomes in pediatric neuro-rehabilitation.

V. CONCLUSION

AI-based predictive models demonstrate promising potential for forecasting physiotherapy outcomes in children with cerebral palsy. These models may support personalized rehabilitation planning and improve clinical decision-making. However, methodological limitations including small sample sizes, heterogeneity among studies, and limited external validation currently restrict widespread clinical implementation. Further high-quality multicenter studies with standardized methodologies and explainable AI approaches are required to improve clinical applicability and generalizability.

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