Upper Extremity Exoskeletons in Children with Cerebral Palsy: An ICF-Based Systematic Review

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Abstract

Background: This systematic review investigates the impact of upper extremity exoskeletons on children with CP using the International Classification of Functioning, Disability and Health (ICF) framework.

Methods: Following PRISMA guidelines, five electronic databases were searched without time limitations (PROSPERO ID: CRD42021282377). Randomized and non-randomized trials examining upper extremity exoskeleton interventions in children with CP and published in English were included. Data were independently screened and extracted by two reviewers. Risk of bias was assessed using the Revised Cochrane Risk of Bias Tool and the Risk of Bias in Non-Randomized Studies of Interventions.

Results: Twenty-two studies involving 274 participants evaluated upper extremity exoskeletons across ICF domains. Study designs included randomized controlled trials, cohort studies, and case series, primarily focusing on body functions and structures.

Conclusion: Although improvements in body function and structure were observed, they did not consistently translate into enhanced activity or participation. Further research is needed to clarify the effectiveness of exoskeletons in improving participation outcomes for children with CP.

Introduction

Cerebral palsy (CP) is a common childhood physical disability (2–3 per 1000 live births) characterized by permanent movement and posture disorders due to non-progressive brain disturbances. Upper limb dysfunction affects more than half of children with CP, limiting essential activities such as reaching, grasping, and object manipulation, and consequently restricting participation in daily life. Rehabilitation aims to improve functional independence and quality of life, yet conventional therapies are often limited by therapist dependency and challenges in providing intensive, repetitive training. Upper extremity exoskeletons offer a promising solution by enabling task-specific, high-intensity, and repetitive movements aligned with motor learning principles, potentially enhancing neuroplasticity and motivation.

The International Classification of Functioning, Disability and Health (ICF) provides a comprehensive framework to evaluate outcomes across impairments, activity, and participation. Despite growing interest in robotic rehabilitation, evidence regarding the effects of upper limb exoskeletons in children with CP—particularly within the ICF framework—remains limited.

This systematic review evaluates the impact of upper extremity exoskeletons on impairments, activity, and participation in children with CP using the ICF model.

Methods and Materials

This systematic review followed **PRISMA guidelines** and was registered under CRD42021282377.

Searches were performed in PubMed, Scopus, Science Direct, Cochrane, and Google Scholar up to August 2024, using keywords related to *cerebral palsy*, *exoskeleton*, *robotics*, and *upper extremity*.

Eligible studies included children (<18 years) with CP receiving upper limb exoskeleton interventions, assessed within the ICF framework.

Two reviewers independently conducted screening, data extraction, and risk-of-bias assessments using **ROB2 and ROBINS-I tools**.

A narrative synthesis combined qualitative and quantitative findings to evaluate effects on impairments, activity, and participation.

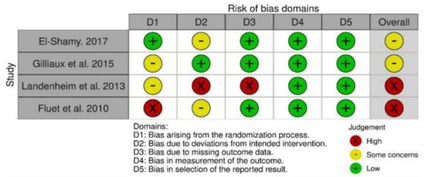

FIGURE 2 | Presentation of risk-of-bias assessment via ROBVIS for randomized trials in systematic review.

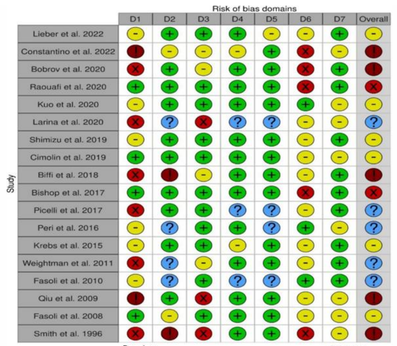

FIGURE 3 | Presentation of risk-of-bias assessment via ROBVIS for non-randomized trials in systematic review.

Results

Study Characteristics

22 studies included (4 RCTs, 18 non-randomized)

Participants: children with CP, **4–18 years** (mostly hemiplegic CP)

Interventions: 13 upper-extremity exoskeletons

- wrist–hand and whole-arm systems
- active and passive devices

Settings: clinic, laboratory, and home-based

Dosage: 9–35 sessions, 45–60 min

Outcomes mapped to **ICF domains**

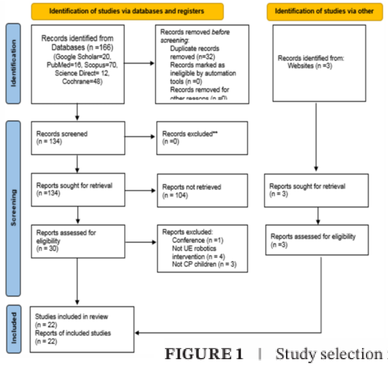

FIGURE 1 | Study selection flowchart.

Main Outcomes & Risk of Bias

Body Functions: improvements in

- joint mobility (b710)
- muscle power (b730)
- muscle tone (b735)
- voluntary movement control (b760)

Activity & Participation: improved

- hand and arm use (d440, d445)
- object manipulation and self-care activities

Neuroplastic effects reported in one study (EEG reorganization)

Risk of bias:

- RCTs: mostly *some concerns*
- Non-RCTs: *moderate to critical* risk

→ Overall evidence is **promising but methodologically limited**

Discussion

This systematic review is the first to evaluate upper extremity exoskeletons in children with CP using the ICF framework. Despite methodological heterogeneity, findings consistently showed positive effects across ICF domains, including body functions, activity, and participation. Exoskeleton-based interventions improved joint mobility, muscle strength, voluntary motor control, and upper limb tasks such as reaching and grasping, supporting their therapeutic potential.

Implications & Limitations

Improvements in motor function and activity do not always translate into participation, which is shaped by environmental and contextual factors—largely unexamined in current studies. Evidence remains limited by few RCTs, small sample sizes, and moderate-to-high risk of bias. Future research should prioritize robust design, longer follow-up, and systematic evaluation of participation and context to capture real-world impact. Clinically, upper extremity exoskeletons may bridge the gap between impairment-based training and functional practice by providing adaptive assistance, precise guidance, and high-intensity repetition. These features align with motor learning and neuroplasticity principles, enhancing engagement and adherence in children. Exoskeleton therapy may also ease therapist burden and support standardized, goal-directed interventions across clinical and home settings. Yet, variability in device design, control strategies, and outcome measures limits comparability. Establishing standardized protocols, ICF-linked outcomes, and child-centered goals will optimize translation and guide evidence-based implementation.

Conclusions

This systematic review underscores the significant potential of upper extremity exoskeletons for advancing rehabilitation in children with CP. Consistent improvements were observed across body structure, function, activity and participation lev els, highlighting the efficacy of exoskeleton technologies in en hancing motor function and functional independence. However, notable gaps remain, including the need for high- quality RCTs, long- term follow- up studies and in- depth analyses of contextual factors. Addressing these gaps will strengthen the evidence base and enable the development of tailored rehabilitation programs that align with the unique needs and aspirations of children with CP. Exoskeletons hold transformative promise as innova tive tools for empowering children with CP to achieve greater independence and improved quality of life.

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