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DIGITAL HEALTH IN PEDIATRIC PHYSIOTHERAPY: MODERN TOOLS AND EMERGING APPROACHES — A SCOPING REVIEW

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ABSTRACT

Pediatric physical therapy is drifting away from traditional therapist-led protocol sessions to technology-supported and family-centered models of care. This scoping review reviews clinical framework, assesses digital health interventions (including artificial intelligence (AI)-driven computer vision screening, robotic lower-limb exoskeletons, virtual reality exergaming, and digital therapeutics), and identifies key research gaps in pediatric rehabilitation in motor, oncological, and chronic pain domains. A literature search was performed in six electronic databases (PubMed, MEDLINE, Embase, CINAHL, Scopus, and IEEE Xplore) and trial registries for studies published between January 2014 and December 2024 according to PRISMA-ScR guidelines. Evidence was synthesized using the International Classification of Functioning, Disability and Health for Children and Youth (ICF-CY) and the Digital Pediatric Physiotherapy Framework (DPPF). From 412 initial records, 42 studies met the inclusion criteria and were selected for synthesis. Task-specific training with high intensity and constraint-induced movement therapy were shown to have good empirical support. New therapies like smartphone-based computer vision for screening infants, exoskeletons of the lower limbs, virtual reality technologies, and telerehabilitation applications show promise in enhancing motor function and gait as well as increasing patient engagement. Nevertheless, the widespread use of digital health in physiotherapy is hindered by lack of standardization of dosages, difficulties in monitoring adherence, expensive technology, and issues related to privacy of data. For development of digital health in pediatric physiotherapy, multi-center randomized controlled trials, patient follow-up, validation of remote assessments, and ensuring equal access are necessary.

KEYWORDS: Pediatric Physiotherapy, Digital Health, Pediatric Exoskeletons, Early Intervention, Virtual Reality, Telerehabilitation, Computer Vision, ICF-CY.

INTRODUCTION

Pediatric physical therapy involves the enhancement of motor abilities, functional independence, and engagement in daily living throughout childhood and adolescence.[1] The treatment of pediatric disorders is entirely distinct from adult rehabilitation since clinicians always need to consider the child's physical development, neurodevelopment, biomechanics, and family involvement.[1,2]

In the last ten years, the field has outgrown from static and impairment-focused stretches towards dynamic and goal-directed motor skill training during play and involvement in family activities.[3,4] Simultaneously, new technologies like machine learning video analysis, wearables, robotic gait training devices, and VR systems have increased the scope and objective accuracy of therapeutic interventions.[5-8,9,12]

This scoping review summarizes the current applications of new technologies in pediatric subdisciplines, represent their clinical relevance in the context of existing theoretical concepts, and highlights the major research gaps that restrict the clinical application.[1,15]

There are three theoretical frameworks that provide guidance on current practices in pediatric physiotherapy and use of technology:[1,15]

1. ICF-CY Framework

In the ICF-CY Framework, the focus of outcome measures moves from assessment of Body Functions and

Structures to assessing functional Activities and participation in playground, school, and community life.[1]

2. Digital Pediatric Physiotherapy Framework (DPPF)

The DPPF identifies types of digital interventions according to therapeutic goals.[15] In this framework, wearable sensor technology, telerehabilitation software, and virtual reality games are presented as interactive facilitators of movement, not replacements for the work of the physiotherapist.[5,8,12,16]

3. Family-Centered Care (FCC) and Caregiver Coaching

Motor interventions promote advanced movement capabilities in the long run if parents and caregivers are coached by the physiotherapists in using therapeutic strategies in everyday care at home.[1,2,4,16]

METHODS

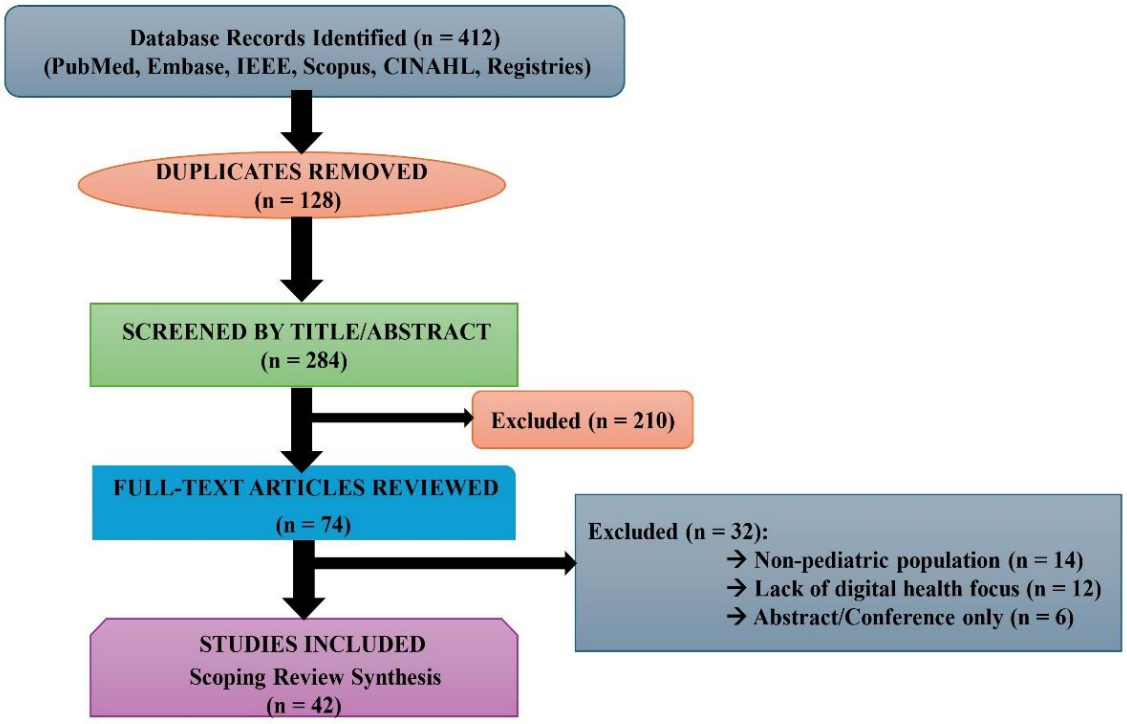
Search Strategy and Eligibility Criteria

The current scoping review was performed in line with PRISMA extension for Scoping Reviews (PRISMA-ScR)[1,15,17] recommendations. Systematic literature searches were performed in PubMed, MEDLINE, Embase, CINAHL, Scopus, IEEE Xplore, and ClinicalTrials.gov to obtain peer-reviewed articles published between January 1, 2014, and December 31, 2024.[3,17]

For the database searches, a combination of MeSH terms and keywords was used: ("pediatric physiotherapy" OR "pediatric physical therapy") AND ("digital health" OR "exoskeleton" OR "virtual reality" OR "computer vision" OR "telerehabilitation" OR "digital therapeutics").

Eligible literature sources included peer-reviewed original studies (randomized controlled trials [RCTs], observational cohort studies, feasibility pilot studies, and systematic reviews) involving assessment of digital health interventions for pediatric population (0–18 years old).[3,10,12,17,18] Literature sources such as case reports, conference abstracts, non-English articles, and studies that examined adult population were excluded from analysis.[1,15,17]

Flow chart



A total number of 412 citations was obtained during the initial database searches.[3,17] Elimination of 128 duplicates led to screening 284 titles/abstracts out of which 210 irrelevant citations were excluded.[17] 74 full texts were assessed for eligibility, 32 were excluded because of adult population (n=14), non-focusing on digital health (n=12), or methodological issues (n=6).[17] Eventually, 42 studies that fulfilled all inclusion criteria were used for the review.[3,17]

1. Computer Vision and Early Infant Screening using Artificial Intelligence

Identification of neurodevelopmental movement disorders during infancy helps clinicians in providing focused interventions during key neuroplasticity periods.[2,4] The markerless motion capture technologies in combination with the use of AI and computer vision algorithms can help clinicians and parents to evaluate the movement pattern (such as General Movements

Assessment (GMA)) of infants from normal video recordings using smartphones.[5-7] This would help in diagnosing early CP and SMA, thereby referring them to early intervention programs.[2,5-7] Because these tools rely on parent-recorded video data, broad implementation requires strict adherence to privacy regulations, including encrypted data transmission and compliance with Health Insurance Portability and Accountability Act (HIPAA) and General Data Protection Regulation (GDPR) standards.[5,16]

2. Wearable Robotic Exoskeletons and Active Assistance Devices

Wearable robotic exoskeletons and active assistance devices are modifying motor learning in children who have difficulty in walking patterns.[8-10] Lower-extremity robotic exoskeletons aid with knee extension in stance phase and help children who have crouch gait due to cerebral palsy or spina bifida improve their posture and symmetry of their gait pattern.[8,9,11] Combination of wearable Inertial Measurement Units (IMUs) and dynamic standers is enabling clinicians to monitor weight bearing and volume of movements during outside clinic hours.[5,8-10] However, clinical appropriateness requires proper screening in terms of physical maturation, height and weight, cooperation, joint contractures and bone mineral density.[8,10,11]

3. Virtual Reality, Exergaming, and Digital Therapeutics

Immersive virtual reality (IVR) along with interactive exergaming offers repetitive and intense motor training through games.[12-14] Research indicates that use of biofeedback-assisted exergames in physical therapy increases dynamic balance, upper limb reach coordination, and compliance.[12-14] Furthermore, software digital therapeutics are being developed for motor and executive function impairments in children having Developmental Coordination Disorder (DCD) and Attention-Deficit Hyperactivity Disorder.[13,15] The operational challenges include avoidance of cybersickness and visual fatigue, and development of dose protocols.[12-14]

4. Pediatric Oncology, Chronic Pain, and Telerehabilitation

Exercising while under cancer treatments or post-cancer treatments prevents muscle loss, fatigue, and Chemotherapy-Induced Peripheral Neuropathy (CIPN).[18,19] For children with compromised immune systems receiving oncology treatments, telerehabilitation can provide an effective mode of administering exercises without exposing them to hospital-acquired infections.[16,18,19]

In the field of chronic pain in pediatrics, an interdisciplinary approach including physical therapy using Pain Neuroscience Education (PNE), gradual exposure to movements, and autonomic self-regulation can alleviate disability in Complex Regional Pain Syndrome (CRPS) and other somatic pain disorders.[20] Some modifiable objectives may include the reduction of fear-avoidance behavior in both children and their parents.[20]

Lastly, parent-led, app-assisted telerehabilitation increases access to specialist care in remote areas.[15-17]

Table 1: Summary of Innovative Technology, Results, and Quality of Evidence in Pediatric Physiotherapy.

Clinical Domain	Key Authors and Year of publication	Technological / Clinical Innovation	Primary Focus	Evidence Quality Level	Key Implementation Challenge
Infant Motor Screening	Passmore et al., 2024[5]; Adde et al., 2018[6]	Markerless Video Analysis and IMUs	Early detection of CP and motor delay[2,6,7]	Moderate *(Pilot studies and validation cohorts)*[5,6]	Algorithm cross-validation across heterogeneous populations; data security[5,7]
Pediatric Exoskeletons	Lerner et al., 2017[8]; Chen et al., 2021[9]; Bania et al., 2020[10]	Wearable Robotic Lower-Limb Suits	Knee extension, stride alignment, posture.[8,9,11]	Moderate *(Small RCTs & feasibility trials)*[9,10]	Capital equipment cost; growth adjustment limits; patient selection criteria[8,10]
Exergaming & VR	Komariah et al., 2024[12]; Inchingolo et al., 2022[13]	Immersive Haptic & Visual Biofeedback	Balance, reach precision, task engagement[12,14]	High *(Balance)*; Moderate *(Upper limb)*[12,13]	Dosing standardization; mitigating cyber-sickness and eyestrain[13,14]
Telerehabilitation & DTx	Önal et al., 2021[15]; Camden et al., 2020[16]	Parent-Coached Video & Sensor Apps[15,17]	Functional home participation[1,16]	High *(Feasibility)*; Moderate *(Functional equivalence)*[15,17]	Digital divide; internet connectivity; caregiver cognitive burden[16,17]
Pediatric Oncology	Braam et al., 2016[18]; Morales et al.,	Individualized Exercise Training	Strength, fatigue reduction, quality of	High *(Cochrane & Systematic*	Adjusting treatment intensity around

	2018[19]		life[18,19]	*Reviews)*[18,19]	fluctuating chemotherapy side effects[18]
Pain	Fisher et al., 2018[20]	Graded Exposure & Pain Science	Functional mobility and desensitization[20]	Moderate *(Observational & clinical trials)*[20]	Managing fear-avoidance behaviors in children and caregivers[20]

DISCUSSION

Analysis of existing literature using the frameworks of the ICF-CY and DPPF shows some practical challenges in various branches of pediatrics. Computer vision techniques provide an efficient screening tool, however, have high false positive rates under real-world conditions.[7] Instead of acting as diagnostic devices, the algorithms are used as triage tools for faster specialist referral to remote regions.[5,6] Similar is the tension regarding robotic gait training: while the lower limb exoskeleton helps in stance extension during assisted movements,[8,9] studies show that the results are not easily applicable to unassisted overground walking.[10] Mechanical support has to be gradually reduced to promote neural drive. Again, while VR provides a better engagement rate,[12] exergaming systems may lack movement specificity needed for physical therapy.[14]

There are difficulties involved in adapting the technology into household and community settings. Moving to full family-based management of therapy puts caregivers under increased stress and cognitive strain.[1,16] It is necessary to adopt hybrid care systems involving remote application guidance in addition to clinical oversight for ensuring compliance without inducing caregiver burnout.[1,16] Also, the processing of video records by the parents necessitates adherence to HIPAA and GDPR guidelines.[5,6] Financially, the high cost of capital equipment limits the use of advanced robotic systems to tertiary centers, leading to inequality in health care.[8,10] The wide adoption of this technology will need a third-party reimbursement approach.[8,10,16]

Several methodological limitations must be kept in mind while interpreting these results. As per the usual scoping review methodology, no formal assessment of the risk of bias was done for the 42 included studies.[15,17] A large body of evidence is based on small scale pilot studies as well as unblinded feasibility studies, reducing the external validity of effect size estimates.[5,8,10] Also, by not including non-English studies, gray literature, and clinical trial registries, there is a possibility of publication bias.[17] Lastly, due to rapid technological advancements, any commercially available system studied in literature might change quite drastically even before clinical use.

For the implementation of pediatric digital health into regular clinical practice, further research is essential in pursuing five key directions. Firstly, large-scale randomized controlled trials are critically required to develop standard prescription parameters, such as session frequency, intensity, and duration for various pediatric diagnoses and levels of functional severity.[3,12,18] Secondly, longitudinal studies of 12-24 months should change the focus of outcome measures from acute motor variables to participation in real-life activities at the community, school, and play level according to the ICF-CY model.[1,3] Thirdly, research is needed to promote frugal innovations by testing low-cost, non-proprietary technologies, including smartphone 2D body position recognition, video-based motion analysis, and low bandwidth tele-coaching to address inequities in healthcare in disadvantaged and rural environments.[5,16,17] Fourthly, it is necessary to implement wearable IMU devices and biofeedback programs into the clinical workflow for continuous remote monitoring and home exercise compliance tracking.[5,8,12]

CONCLUSION

Early AI screening tools, robotic gait training, virtual reality exergaming, and telerehabilitation approaches are emerging in pediatric physical therapy practice. In order to implement those technologies in clinical practice, further research needs to concentrate on the following: multi-center randomized clinical trials that will measure long-term adherence, dosing protocols, secure storage of data, and equality in technology distribution to diverse populations.

LIST OF ABBREVIATIONS

- **AI:** Artificial Intelligence
- **CIPN:** Chemotherapy-Induced Peripheral Neuropathy
- **CP:** Cerebral Palsy
- **CRPS:** Complex Regional Pain Syndrome
- **DCD:** Developmental Coordination Disorder
- **DPPF:** Digital Pediatric Physiotherapy Framework
- **DTx:** Digital Therapeutics
- **FCC:** Family-Centered Care
- **GDPR:** General Data Protection Regulation
- **HIPAA:** Health Insurance Portability and Accountability Act
- **ICF-CY:** International Classification of Functioning, Disability and Health for Children and Youth
- **IMU:** Inertial Measurement Unit
- **IVR:** Immersive Virtual Reality
- **PNE:** Pain Neuroscience Education
- **PRISMA-ScR:** Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews

- **RCT:** Randomized Controlled Trial
- **SMA:** Spinal Muscular Atrophy
- **VR:** Virtual Reality

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