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Virtual reality-based fine motor skills training in paediatric rehabilitation: a protocol for a scoping review

Jeromine Hervo ,[1,2] Lexie Lançon,[3,4] Danielle E Levac,[3,4] Johanne Mensah-Gourmel,[2,5] Sylvain Brochard,[2,5] Rodolphe Bailly,[1,2] Christelle Pons[5,6]

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RB and CP contributed equally.

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[1]Fondation Ildys, Brest, France
[2]INSERM UMR 1101, LATIM, Brest, Bretagne, France
[3]Centre de recherche Azrieli, CHU Sainte-Justine CRME, Montreal, Québec, Canada
[4]University of Montreal, Montreal, Québec, Canada
[5]CHU Brest, Brest, Bretagne, France
[6]Université Bretagne Occidentale, UBO, Brest, Bretagne, France

Correspondence to
Jeromine Hervo;
jeromine.hervo@gmail.com

ABSTRACT

Introduction Fine motor skill (FMS) development during childhood is essential to many learning processes, especially in school. FMS impairment can have a major impact on children's quality of life. Developing effective and engaging rehabilitation solutions to train FMS that engage children in the abundant practice required for motor learning can be challenging. Virtual reality (VR) is a promising intervention option offering engaging FMS training tasks and environments that align with evidence-based motor learning principles. Other potential advantages of VR for rehabilitation include accessibility for home-based use and adaptability to individual needs. The objective of this scoping review is to map the extent, range and nature of VR applications focused on FMS training in paediatric rehabilitation, including hardware, software and interventional parameters.

Methods and analysis We are following methodological guidelines for scoping review conduct and reporting from the Joanna Briggs Institute (JBI) Manual for Evidence Synthesis and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews recommendations. We will search four databases (Pubmed, Web of Science, PsycInfo and Scopus) for articles that meet inclusion criteria defined by the Population, Concept, Context method; specifically studies focused on development or evaluation of immersive or non-immersive VR applications to deliver FMS training in paediatric rehabilitation. Different populations of children with FMS impairments will be included (such as children with cerebral palsy, children with developmental coordination disorder or attention deficit hyperactivity disorder). The first search took place in December 2023, and a second is planned for February 2025. One reviewer will complete title, abstract and full paper screening, with consultation by a second reviewer in case of uncertainty. A data extraction framework will be tested by two reviewers on five randomly selected studies to ensure inter-rater reliability, and one reviewer will complete data extraction. Quantitative and qualitative extraction will follow JBI guideline recommendations. Results will be presented in a descriptive and tabular format, including a narrative summary. Results will enhance understanding of the potential of FMS training in VR and inform subsequent directions for research and clinical practice.

Ethics and dissemination Data for this review will be collected from the published literature. Ethical approval is not required. We will present our findings at scientific conferences and submit this review to a peer-reviewed journal for publication.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This scoping review will follow recommendations from the Joanna Briggs Institute methodology and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews.

⇒ Results will identify gaps in the literature to inform subsequent research directions.

⇒ This study will include only studies published in English, French or Spanish.

⇒ To provide a comprehensive overview of the literature, no publication date restriction will be applied.

⇒ This scoping review will systematically explore the implementation of different virtual reality (VR) devices for fine motor skill (FMS) training, taking into account specific rehabilitation goals and technical considerations, without analysing the barriers and facilitators specific to FMS training in VR.

INTRODUCTION

Fine motor skills (FMS) can be defined as small movements requiring eye-hand coordination.[1 2] FMS are an essential component of several learning domains, including handwriting. The prevalence of handwriting problems in children is between 5% and 30%.[3] Children with conditions such as cerebral palsy (CP), developmental coordination disorder (DCD) or attention deficit hyperactivity disorder have a higher risk of handwriting difficulties as compared with typically developing children.[3–6] FMS impairments can negatively impact children's participation in daily activities at school and at home. The potential consequences of reduced participation include lowered self-esteem, decreased academic performance[7–11] and increased risk of depression,[8 10] thereby considerably affecting quality of life.[4]

Virtual reality (VR), defined as the simulation of a virtual environment with which a person can interact using body movements,[12] may be a promising tool for FMS rehabilitation. Rehabilitation is defined as 'a set of interventions designed to optimise functioning and reduce disability in individuals with health conditions in interaction with their environment'.[13] VR systems may be immersive or non-immersive.[14] Immersive VR devices use a head-mounted display that enables full visual immersion in the virtual environment. Non-immersive VR devices involve two-dimensional virtual environment in flat-screen displays and include the category of active video games.[14 15] Non-customised systems are designed for the general public, while customised systems are designed for rehabilitation. Evidence from systematic reviews suggests that upper limb training with non-immersive VR may improve upper limb function in children with CP;[16–18] there are no knowledge syntheses of non-immersive VR use for upper limb training in other paediatric populations. To our knowledge, there are no evidence syntheses of immersive VR use for upper limb training in paediatric rehabilitation. However, a systematic review demonstrates promising results for immersive VR to improve motor and cognitive function in children with CP.[19]

Given our emphasis on exploring the current scope of the evidence, rather than its quality, a scoping review is the most appropriate methodology for our objective of understanding the extent, range and nature of FMS training using VR in paediatric rehabilitation.

Interaction and immersion are important features of VR. Interaction refers to how the user interacts with the virtual environment.[20 21] For example, interaction methods can be hand tracking methods, when the user's hand movements are followed using motion tracking systems or controllers to integrate the hand into the game.[22] Interaction methods that provide a high degree of movement fidelity, such as haptic gloves providing tactile information when users interact with virtual objects,[23] or motion tracking of precise finger movements, enable precise fine motor interaction with virtual tasks. Immersion relates to the level of involvement with the virtual environment. Virtual environments provide auditory, visual or haptic feedback, depending on their hardware and software components. These different types of sensory feedback can increase the level of immersion.[20] Immersion can contribute to a high sense of 'presence', defined as 'a psychological state in which virtual objects are experienced as actual objects in either sensory or nonsensory ways'.[24]

Emerging trends in VR technology, particularly the integration of artificial intelligence (AI), have shown promise in adult populations such as poststroke patients[25] and older adults.[26] These advances could be beneficial for paediatric populations as well. AI applications in rehabilitation can enable quantitative training assessment, precise data collection and real-time feedback delivery.[26]

VR is an increasingly promising tool for FMS training given recent advances in haptic technology (enabling haptic feedback about virtual object interaction) and hardware improvements that increase the accuracy of hand and finger movement tracking.[4]

A recognised rationale for VR system use in rehabilitation is the potential to target the motor learning principles essential to effective interventions.[27] Motor learning is defined as 'a set of processes associated with practice or experience leading to relatively permanent changes in the capability for skilled movement'.[28] VR systems integrate motor learning principles such as abundant repetition, extrinsic feedback, and engaging environments known to promote motor learning.[29]

VR systems involve engaging and entertaining tasks and graphics that may enhance children's motivation and engagement to participate in rehabilitation.[30 31] Interventions that enhance motivation to engage in repeated intensive practice are required because children with disabilities undergo long periods of rehabilitation, and risk decreasing their participation over time.[32]

An additional advantage of practice in virtual environments is the possibility to provide task-specific training. Task-specific training involves the repeated practice of goal-oriented, context-specific motor tasks with some form of feedback provision[33] and includes part of whole task practice.[34] Task specificity of training in VR depends on movement fidelity and interaction methods. One example of task-specific training in VR is sports like tennis, Frisbee, table tennis, archery or bowling : a study with children with DCD demonstrated that both the non-immersive VR group and the conventional therapy group improved their gross motor performance.[35] Task-specific training is of particular importance for FMS training, such as handwriting, as haptic feedback is required for proprioception and sensorimotor perception. Therefore, such a 'sensorimotor deficit' inherent to task interaction in a virtual environment could negatively impact fine motor abilities and decrease their ecological validity.[36–38]

While VR shows promise for paediatric rehabilitation, several challenges must be acknowledged, including the high cost of some types of VR equipment, limited accessibility in some clinical settings, and potential concerns about ecological validity when transferring skills learnt in virtual environments to real-world tasks.[12] Additionally, the need for appropriate technical support and maintenance of VR systems may present practical barriers to implementation in rehabilitation settings.[39 40] The rapid evolution of consumer VR technology has led to increasingly affordable and user-friendly systems, potentially making VR-based rehabilitation more feasible for clinical settings. Recent iterations of VR devices offer improved functionality at lower price points, suggesting that accessibility may become less of a constraint in the future.

There is currently no knowledge synthesis of immersive or non-immersive VR use specific to FMS training in paediatric rehabilitation. The specific hardware, software or interventional parameters that are relevant for VR-based FMS training require exploration. A greater understanding of the current state of the literature in

VR-based FMS paediatric rehabilitation will identify gaps in the evidence base and inform subsequent research directions.

OBJECTIVES

The objective of this scoping review is to map the extent, range and nature of VR applications to train FMS in paediatric rehabilitation.

Our specific objectives are to (1) characterise the context of VR use for FMS training (eg, the clinical population, duration of programmes, frequency of use, duration of sessions, exercise modalities, type of device, intervention settings, type of feedback, and method of task interaction (such as hand tracking method, haptic devices)) and (2) identify and describe the hardware, software or interventional parameters, as described by authors, relevant to FMS training in paediatric rehabilitation.

A secondary objective is to identify gaps in the evidence base about VR-based FMS training in paediatric rehabilitation.

METHODS

We are following the Arksey et O'Malley methodological guidelines[41] further advanced by Levac *et al*,[42] and by recommendations of the Joanna Briggs Institute (JBI) Manual for Evidence Synthesis for scoping reviews.[43 44] Reporting of scoping review results will follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR) reporting guidelines.[45]

The protocol has been registered on the Open Science Framework (OSF) (DOI : 10.17605/OSF.IO/FDZYJ). OSF is an open platform to support collaboration and allows research protocols to be registered. The first search took place in December 2023, and the scoping review will be carried out in 2025.

Patient and public involvement

Patients and their families were not included in the drafting of this protocol, and will not be included in the scoping review procedures. Results of the scoping review will be shared with professional organisations and to inform service delivery for patients and their families.

Stage 1: identifying the research question

We defined the following research questions in line with the purpose of our scoping review:

1. What is known about the use of VR to train FMS in paediatric rehabilitation?
2. What hardware, software or interventional parameters of VR application do authors propose as relevant for FMS training in paediatric rehabilitation?

Stage 2: identifying relevant studies

We searched for studies on Web of Science, PubMed, PsycInfo and Scopus, databases chosen for their technology and rehabilitation content.

We defined four concepts to answer the two research questions: children, VR, FMS and rehabilitation.

The first search strategy step was conducted on Web of Science to check appropriate key terms. We combined search terms related to each concept with the Boolean terms 'OR' and linked each concept with the Boolean term 'AND'; then, we adapted the syntax to each database. The search terms are presented in table 1. The search strategy for each database is presented in online supplemental Appendix 1. A research librarian verified our search strategy. We used no restrictions regarding publication date.

The references from the four electronic databases will be imported into Covidence, and duplicate records will be removed.

Table 1 Search terms

	Key terms	Descriptors
Concept 1: population: children	(Children OR paediatrics OR "cerebral palsy" OR "hemipleg*" OR "neurodevelopmental disorders" OR "developmental disabilities" OR "Neuromotor Impairments" OR "hemiparesis" OR "developmental coordination disorder" OR "DCD" OR "ADHD" OR "burns" OR "traumatic brain injury" OR TBI OR "Pediatric neuromuscular disorders" OR "Duchenne muscular dystrophy" OR "Friedreich ataxia" OR "children with difficult*" OR "children with disabilit*")	("child" (MeSH Terms) OR "pediatrics" (MeSH Terms) OR "cerebral palsy" (MeSH Terms))
Concept 2: virtual reality	("virtual reality" OR "virtual environment" OR "augmented reality" OR "mixed reality" OR "computer gam*" OR "serious gam*" OR "active video gam*" OR "video gam*" OR "exergame" OR "Wii" OR "Kinect" OR "leap motion" OR "haptic feedback" OR haptic OR "haptic guidance" OR "haptic devices")	("virtual reality" (MeSH Terms) OR "augmented reality" (MeSH Terms) OR "haptic interfaces" (MeSH Terms) OR "haptic technology" (MeSH Terms))
Concept 3: fine motor skills	("motor skills" OR "fine motor skills" OR "fine motor function" OR "fine motor development" OR "fine motor control" OR "upper limb" OR "upper extremity" OR "upper limb function" OR "hand function" OR "visuo-motor abilities" OR "manual dexterity" OR "hand" OR "fingers" OR dexterity OR "handwriting" OR "hand tracking")	("handwriting" (MeSH Terms) OR "motor skills" (MeSH Terms) OR "upper extremity" (MeSH Terms))
Concept 4: context: rehabilitation	("rehabilitation" OR "physical therapy" OR "occupational therapy" OR therapy OR treatment OR intervention)	("rehabilitation" (MeSH Terms) OR "physical therapy modalities" (MeSH Terms) OR "occupational therapy" (MeSH Terms))

Table 2 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Children (<18 years old) undergoing rehabilitation to train for FMS	Language (studies which are not published in English, French or Spanish will be excluded)
Use of immersive or non-immersive virtual reality	Robot-assisted training (as exoskeleton or Armeo)
FMS test as the primary outcomes or devices developed to train FMS in paediatric rehabilitation but which have not yet been tested	
All quantitative studies types (experimental design study, quasi-experimental, case-study and observational studies) Mixed method studies and qualitative studies that examine devices designed to train FMS will also be included	Reviews or meta-analyses

FMS, fine motor skills.

Stage 3: study selection

We used the Population-Concept-Context approach, according to the JBI recommendations, to define eligibility criteria. Inclusion and exclusion criteria are presented in table 2.

We will use Covidence (www.covidence.org) to screen titles and abstracts. As suggested by PRISMA-ScR reporting guidelines,[45] one author will undertake full-text review, and uncertainties will be resolved by a second reviewer.

Inclusion criteria

Population

Children (<18 years old) undergoing rehabilitation to train for FMS.

Concept

1. Use of immersive or non-immersive VR. To define which devices will be included, we will use the definition presented in the Introduction ('simulation of a virtual environment with which a person can interact using their own movements').[12] We will include devices that can produce movements similar to those produced by the avatar in the virtual environment. For example, devices like PlayStation 4 are not considered VR for this scoping review.
2. FMS test as the primary outcomes, or devices developed to train FMS in paediatric rehabilitation but which have not yet been tested. Studies using tests assessing fine and gross motor skills will be included if the results of FMS are exploited in the study

Context

Rehabilitation needed, in a rehabilitation centre, at home or at school.

Type of evidence sources

We will include all quantitative studies types (experimental design study, quasi-experimental, case-study and observational studies). Mixed method studies and qualitative studies that examine devices designed to train FMS will also be included.

Exclusion criteria

1. Language (studies which are not published in English, French or Spanish will be excluded).
2. Robot-assisted training (as exoskeleton or Armeo). Robotic devices are excluded from this review as they represent a fundamentally different technological approach compared with VR systems. While VR environments allow for naturalistic, self-initiated movements with six degrees of freedom, robotic devices typically constrain movement through mechanical interfaces and predetermined pathways. These distinct characteristics create different technical considerations and therapeutic implications, warranting separate investigation of these technologies in paediatric rehabilitation.
3. Reviews or meta-analyses.

Stage 4: charting the data

Data extraction

The data extraction chart is presented in online supplemental Appendix 2.

The list of parameters that are relevant for FMS training will be categorised into three levels, inspired by Levac *et al*:[46] (1) level 1 will involve parameters that will be explicitly described and linked to the results or outcomes of the study (eg, user motivation, if measured within the study); (2) level 2 will include parameters identified from a description of the specific device used in the study, not explicitly linked with the results or outcomes of the study (such as user motivation, if this is stated by the authors but not measured in the study); and (3) level 3 will include parameters derived from general statements about features or attributes of VR interventions to train FMS more generally (such as user motivation, if the authors state it to be a feature of VR interventions and reference other published studies). These parameters will be extracted from any sections of the included manuscripts (introduction, discussion, conclusions and supplementary information).[47]

Two reviewers will perform a pilot test on a random sample of five studies to check the data extraction process. Following discussion to reach consensus on each category of the data extraction chart, one reviewer will perform the data extraction. The second reviewer will be consulted in case of uncertainty.

Stage 5: collating, summarising and reporting the results

Numerical analysis will be used to characterise the context of VR-based FMS training in paediatric rehabilitation: populations, duration of programme, frequency of use, duration of a session, total duration of training, motor learning principles (repetition, functional task, goal-oriented training), exercise modalities (whole body training, upper limb training, gross motor skills training, FMS training), type of device (customised or non-customised), place of use, type of feedback, hand tracking method, haptic devices, etc. Data from the numerical analysis will be presented in descriptive and tabular form to map the nature, range and extent of the use of VR on FMS training in paediatric rehabilitation.

A content analysis of data extracted from the text following the JBI methodology guidelines[47 47] will be performed to identify hardware, software and interventional parameters that are relevant to train FMS, according to the study authors. Finally, we will classify the parameters considered relevant to train FMS by theme such as motivation, repetitive practice and specific practice using a narrative summary.

DISCUSSION

This paper presents the background and design for a scoping review. VR-based FMS training has garnered interest across diverse populations. In adults recovering from stroke, VR shows promise as a complementary tool to conventional therapy for FMS training, potentially enhancing patient engagement in rehabilitation.[48]

To our knowledge, this is the first scoping review to systematically examine how different VR devices can be implemented for FMS training, taking into account specific rehabilitation goals and technical considerations. This scoping review will help to identify new potential promising devices or parameters that may represent a potential area of research.

There are potential challenges to immersive VR use in paediatric rehabilitation, including physical effects such as cybersickness, psychological impacts like over-reliance on virtual environments, and social considerations such as reduced face-to-face therapeutic interaction. While immersive VR shows promise for rehabilitation, limited research exists regarding its long-term effects on children's development, particularly in terms of visual system maturation and social skill acquisition.[21 49] Understanding these potential risks is essential for developing appropriate guidelines for VR implementation in paediatric rehabilitation and ensuring that technological benefits are balanced against therapeutic best practices.

This scoping review has several limitations, including the absence of studies in languages other than English, French or Spanish. This could lead to language bias, potentially excluding relevant research published in other languages. In addition, we chose not to include a grey literature search in our review, which could introduce publication bias, potentially missing relevant unpublished research, technical reports, conference proceedings and ongoing clinical implementations of VR in paediatric rehabilitation. Additionally, the use of a single reviewer for article selection could introduce selection bias, as the absence of independent verification through dual screening increases the risk of missed relevant studies or inconsistent application of inclusion criteria.

Scoping review strengths include the use of an established methodology and the inclusion of diverse paediatric populations. Results will inform knowledge about factors influencing the selection of specific VR devices in paediatric rehabilitation. A characteristic of the VR field is the heterogeneity of systems that vary substantially in their technical specifications (from low-cost smartphone-based systems to sophisticated room-scale setups) and in their interaction methods. By categorising our findings by interaction method and describing systems used, we aim to provide a comprehensive overview of how different VR approaches are being used in this field.

Ethics and dissemination

Data for this review will be collected from published literature. Ethical approval is not required for this scoping review. We will present our findings at scientific conferences and submit this review for publication in a peer-reviewed journal.

X Christelle Pons @Christelle Pons

Contributors Conceptualisation: CP, RB and JH; methodology: DEL, CP, LL, RB and JH; investigation: JH, CP, RB and JM-G; validation: SB and DEL; writing—original draft preparation: JH, CP and RB; writing—review and editing: JH, CP, RB, DEL and SB; supervision: CP, RB and DEL. All authors have read and agreed to the published version of the manuscript. The guarantor is CP.

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ORCID iD
Jeromine Hervo http://orcid.org/0009-0005-9646-6941

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