Measurements and digital technology solutions to monitor physical activity in pediatric oncology patients: a scoping review

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Abstract

Background: Pediatric oncology patients often experience reduced physical activity (PA) due to treatment-related fatigue, functional limitations, and lack of structured exercise programs. Digital health solutions, including wearable sensors and augmented reality (AR)-based interventions, offer new possibilities for monitoring and improving PA in this population.

Objective: This scoping review aimed to address existing research gaps by identifying the instruments—both conventional and digital—used to monitor PA in pediatric oncology patients during treatment. In addition, this study examined PA monitoring methods, identified the variables collected, and explored the applicability of digital technologies in facilitating PA engagement among pediatric oncology patients.

Methods: Following the Joanna Briggs Institute (JBI) methodology, a systematic search was conducted in eight scientific electronic databases. Eligible studies included children aged 7–19 years undergoing cancer treatment or within two years post-treatment. Both objective (accelerometers, wearables) and subjective (questionnaires, self-reports) PA monitoring tools were explored. A narrative synthesis was performed to summarize key findings.

Results: Twelve studies met the inclusion criteria, utilizing a range of PA monitoring tools. The wearable technologies, such as Actical and Garmin VivoFit® 3, were used in five studies for assessing step counts, gait cycles, and movement intensity. Self-reported measures were identified in 11 studies, including the Activities Scale for Kids© and PedsQL Multidimensional Fatigue Scale proving insights into mobility and fatigue. Despite their feasibility, subjective assessments had limitations due to recall bias and motivation factors. While digital solutions such as gamification and mobile applications demonstrated potential for improving PA adherence, technology application is underused and research on their integration in pediatric oncology remains limited.

Conclusions: Existing PA monitoring methods provide valuable insights, yet gaps remain in utilizing interactive digital solutions such as AR-based interventions. Future research should focus on integrating digital tools that not only track PA but also actively engage patients, enhance motivation, and facilitate rehabilitation in clinical and home settings.

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Original Manuscript

Original Paper

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integrating digital tools that not only track PA but also actively engage patients, enhance motivation, and facilitate rehabilitation in clinical and home settings.

Keywords: Pediatric oncology; cancer; physical activity monitoring; augmented reality; digital solutions; gamification.

Introduction

Every year, approximately 400,000 children and adolescents aged 0–19 are diagnosed with cancer worldwide [1]. Advances in childhood cancer treatments have significantly improved survival rates, with more than 80% of patients receiving modern cancer therapy surviving at least five years beyond diagnosis, and many achieving full remission [2,3]. However, despite improved medical care, childhood cancer survivors remain at risk of recurrence, secondary malignancies, chronic conditions, and functional impairments [4]. These late effects of cancer and its treatment contribute to early mortality among survivors, making ongoing health management a critical concern [5]. Physical activity (PA) is increasingly recognized as a key component in mitigating the adverse effects of cancer and its treatment [6]. However, published data indicate that less than 50% of pediatric oncology patients meet PA guidelines, highlighting a serious issue in maintaining adequate activity levels [7]. The World Health Organization (WHO) defines PA as any bodily movement produced by skeletal muscles that requires energy expenditure, including activities performed during leisure time, transportation, and daily routines—not just structured exercise [13]. Cancer-related fatigue (CRF) is a major barrier to PA, contributing to sedentary behavior and reduced mobility [8]. Additionally, some pediatric oncology patients experience physical limitations that affect their ability to perform daily activities, as seen in cases of Clear Cell Sarcoma (CCS), which often affects the legs, feet, arms, hands, and torso [9]. Given these challenges, implementing interventions to counteract cancer-related side effects is a major priority in pediatric oncology. There is growing evidence that PA is not only safe during both the acute treatment phase and survivorship [10] but also effective in reducing cancer treatment-related side effects [11,12]. Encouraging PA in pediatric oncology patients is essential, yet existing approaches face significant barriers. Currently, hospital-based PA interventions are the most common approach, led by physiotherapists, occupational therapists, and nurses who encourage children to stay active during therapy sessions [14]. However, pediatric oncology rehabilitation services are often underutilized, with few children referred for specialized rehabilitation. Medical professionals have identified a shortage of dedicated pediatric oncology rehabilitation services, while rehabilitation specialists have indicated the lack of appropriate environment and equipment [15]. These limitations increase challenges related to organizing PA, particularly for patients who experience fatigue and mobility restrictions [7]. To address these gaps, digital technology is emerging as a valuable complement to conventional PA interventions. Technologies such as wearable sensors, augmented reality (AR), and the Internet of Things (IoT) offer new approach to engage pediatric oncology patients in PA and monitor their progress. For instance, wearable devices can track step counts, gait cycles, and movement patterns in real time, providing immediate feedback about PA performance [16]. Mobile health applications that incorporate gamification techniques have proven effective in increasing PA by offering interactive challenges and motivational feedback, helping to sustain engagement among pediatric oncology patients [17, 18]. Additionally, virtual reality (VR) and AR-based rehabilitation tools can create immersive exercise environments, overcoming the lack of dedicated rehabilitation spaces while providing personalized and engaging PA experiences [19]. These technologies offer scalable, flexible, and patient-centered solutions that could enhance PA participation and adherence in pediatric oncology care [20, 21]. Understanding the specific individual needs of pediatric oncology patients is crucial in developing effective PA interventions that align with their physical capabilities and treatment constraints. This scoping review aimed to address existing research gaps by identifying

the instruments—both conventional and digital—used to monitor PA in pediatric oncology patients during treatment.

The research questions guiding this review are:
1) What methods are used for physical activity monitoring in pediatric oncology patients?
2) What variables are collected to monitor PA in pediatric oncology patients?
3) What is the applicability of different instruments in monitoring PA levels in pediatric oncology patients?
4) What interventions are used to improve PA in pediatric oncology patients?

In addressing these questions, the authors use the term "variables" specifically to refer to objective measurements such as step count and gait cycles per minute, distinguishing them from subjective values obtained through self-reported questionnaires. By mapping the available PA monitoring tools and interventions, this review aims to contribute to a more comprehensive understanding of how digital solutions can support PA promotion in pediatric oncology patients.

Methods

Protocol and registration

The review study was conducted from April to September 2024. This review was conducted in accordance with the Joanna Briggs Institute (JBI) methodology for scoping reviews [22, 23] and reported in accordance with PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines [24]. We followed the 6-stage framework for a scoping review proposed by Arksey and O'Malley [25]. The protocol was registered in the Center for Open Science (Registration DOI: https://doi.org/10.17605/OSF.IO/ZW48R) [26].

Eligibility criteria

Based on recommendations from the JBI [22, 23] and research questions to refine the focus of our scoping study and develop an effective search strategy, we defined the eligibility criteria for Population, Concepts, and Context (PCC) [23].

Population: children and adolescents with oncology

- Children and adolescents with oncology during treatment or 2 years after treatment. Based on studies, this two-year period—including active treatment and early recovery—is used because it allows researchers to assess how PA supports the restoration of cardiorespiratory fitness and muscle strength while helping to alleviate lingering post-treatment fatigue and physical limitations [25].
- Study includes children and adolescents aged 7- 19 years old. This decision was based on the age group that corresponds to the category of children with oncology that are treated or 2 years after the treatment. Younger children cannot complete the questionnaire or PA independently. Older age groups would correspond with the category of adults with oncology. The children and adolescents aged 7 to 19 years were selected because this age group can effectively engage in self-directed activities and structured exercise programs. Older adolescents face unique physical and psychological challenges during the transition to adulthood, making their inclusion vital for understanding the impact of PA during and after cancer treatment [7].

Concepts: augmented reality

- Augmented reality and gamification can be used as a tool to measure and improve PA levels

for children and adolescents with oncology.
- Augmented reality is defined as a tool that can be implemented in the clinical environment for children's ongoing oncology treatment to improve PA levels.
- The incorporation of augmented reality and gamification in pediatric oncology is justified by their proven effectiveness in enhancing PA levels among children and adolescents.
- Studies indicate that interactive tools engage young patients, making PA more enjoyable and motivating [12].

Context: physical activity (PA)

- Physical activity, as defined by the World Health Organization (WHO), encompasses the overall bodily movement that allows individuals to perform daily activities effectively and engage in exercise [13].
- The term “physical activity” includes all forms of bodily movement done in educational, recreational, home, and/ or community settings including but not limited to aerobic exercises, resistance training, flexibility, endurance exercises, and stretching routines.
- Key parameters for evaluating PA include frequency, intensity, duration, type of activities, and distance completed.
- For example, in pediatric oncology, assessing a child's engagement in daily PA can provide valuable insights into their recovery and health outcomes after treatment.

Selection of sources of evidence

Individual studies published from 2000 to March 2024 were decided for inclusion. The selection of sources for this review was guided by predefined inclusion and exclusion criteria to ensure a comprehensive and relevant assessment of digital technologies for monitoring physical activity in pediatric oncology patients. The inclusion and exclusion criteria were developed to align with the study objectives and the PCC framework. Given the rapidly evolving nature of digital health technologies, it was essential to consider a broad range of study designs while maintaining a focus on clinically relevant applications.

Inclusion criteria:

- Population: children and adolescents diagnosed with oncology;
- Concept: digital technologies related to physical activity;
- Context: physical activity outcomes;
- Setting: clinical environment;
- Study type: original studies with any design or data type (quantitative and qualitative);
- Publication status: published in a peer-reviewed journal;
- Publication language: English;
- Full-text available;
- Included keywords: cancer, pediatric, oncology, exercise, monitoring, physical activity, fitness, movement, augmented reality, gamification, digital tools, digital environment.

Exclusion criteria:

- Population: children and adolescents more than 2 years after cancer treatment. Although other studies define the post-treatment period as 1 year, due to patients frequently transitioning between home and hospital for treatments, the authors consider the treatment cycle to be complete, on average, within 2 years.
- Concept: digital technologies not related to PA (e.g. for health management);
- Context: non-physical activity outcomes;
- Setting: Nonclinical;

- Study type: other study types (e.g. protocols, narrative reviews, or systematic reviews);
- Publication status: published without peer review, dissertations, books, conference papers, letters, or editorials;
- Publication language: written in a language other than English;
- Full-text not available;
- Excluded keywords: drug, in vitro, animal, mice, mouse, animals, bacteria, murine, rat, fish, canine, rodents, transgenic, rodent, piglets, rabbits;
- Mental health outcomes are excluded unless they are mentioned in combination with a physical activity outcome.

Information sources

For this scoping review the peer-reviewed articles were searched in following databases: ProQuest, the Web of Science, EBSCO Complete, Google Scholar, Science Direct, Scopus, MEDLINE (PubMed), and Cochrane. The search results were compiled in the Rayyan intelligent systematic review reference manager and duplicates were removed by multiple reviewers. A preliminary search conducted on April 18 and 19, 2024 for ProQuest, the Web of Science, EBSCO Complete, Google Scholar, Science Direct, Scopus, MEDLINE (PubMed), and Cochrane databases provided 7876 references before deduplication. In the final search, only articles written in English were selected excluding any grey literature.

Search strategy and search

The search terms employed were:
“Pediatric oncology patients” OR “Pediatric oncology patients” OR “Pediatric cancer patients” OR “Pediatric cancer patients” OR “Pediatric cancer patients” OR “Adolescents”
AND
Technology “Digital environment” OR “Digital solutions” OR “Digital tools” OR “Augmented reality” OR “AR” AND “Gamification” OR “Game elements”
AND
Physical activity and exercise “Physical Activity” OR “PA” OR “Mobility” OR “Limited sedentary behavior” OR “Fitness” OR “Exercise” OR “Sport” OR “Movement.”

In constructing our search strategy, we employed the Boolean operator "OR" to encompass a broad range of related physical activity, digital solutions, and terms referring to children and adolescents with oncology. After searching databases, the references were imported into the Rayyan, followed by the study selection process in three phases. First, titles and abstracts were screened, followed by a full-text review to identify articles relevant to the primary and secondary research questions of our scoping review. In the final phase, a data extraction template was created within Rayyan to facilitate the systematic collection of key information from selected articles. This template covered participant age, treatment phase for children and adolescents with oncology, the digital technologies used to measure physical activity, methods for assessing physical activity outcomes, physical activity variables, and core findings from the studies. Due to the anticipated volume of articles, all co-authors participated in the selection process at each stage, with each article reviewed by two team members. If Rayyan detected a conflict regarding inclusion or exclusion, a third person resolved it. Additionally, the team met regularly online to address any issues arising during the article selection phases.

Data charting process

This review outlined a systematic approach to analyzing data from studies focusing on physical activity monitoring in pediatric oncology patients. Extracted data from the reviewed articles were

categorized and analyzed based on a structured set of variables. Key elements of the analysis included the Paper ID, First Author (name and surname), Journal Name, and Title of the Article, providing a bibliographic foundation for the review. To contextualize the research geographically and demographically, the Country of the study, Study Aim, and Participant Information (age and sex) were detailed. Additionally, specifics regarding participants' Diagnosis and Treatment were documented to understand the clinical context. The methodology of each study was assessed, including the Study Type (e.g., cross-sectional, longitudinal), Applied Methods, and specific tools used for monitoring. Particular attention was paid to Physical Activity Monitoring Instruments and the use of Digital Technologies to facilitate monitoring. These insights were integral to identifying current practices, technological innovations, and gaps in measuring physical activity among pediatric oncology patients.

In this study, the treatment period was defined as the active treatment phase, extending up to two years post-treatment. This timeframe aligns with the average duration of active follow-up for pediatric patients receiving cancer therapy. During this period, patients may undergo various clinical trajectories, including hospitalization, discharge, subsequent follow-up visits, and rehabilitation. As a result, the classification of study populations varies among the included studies, with some describing participants as “hospitalized” or “undergoing treatment,” while others refer to them as “cancer survivors.” This discrepancy reflects the different stages within the defined treatment period, encompassing both active therapy and the follow-up phase, by capturing a broad spectrum of patient experiences and outcomes in different clinical settings, recovery trajectories, and rehabilitation needs.

Synthesis of results

Followed by the rest of the 6-stage framework for a scoping review proposed by Arksey and O’Malley [25], after identifying the research question, identifying the relevant studies, selecting studies, and charting the data were collated, summarizing and reporting results as described below:

- Analyzing research findings, which included both a descriptive numerical summary and a qualitative thematic analysis.
- Evaluating the research findings to identify outcomes that aligned with the research question, which were presented narratively.
- Interpreting and discussing the findings in the context of additional research questions, practical applications, and policy implications.

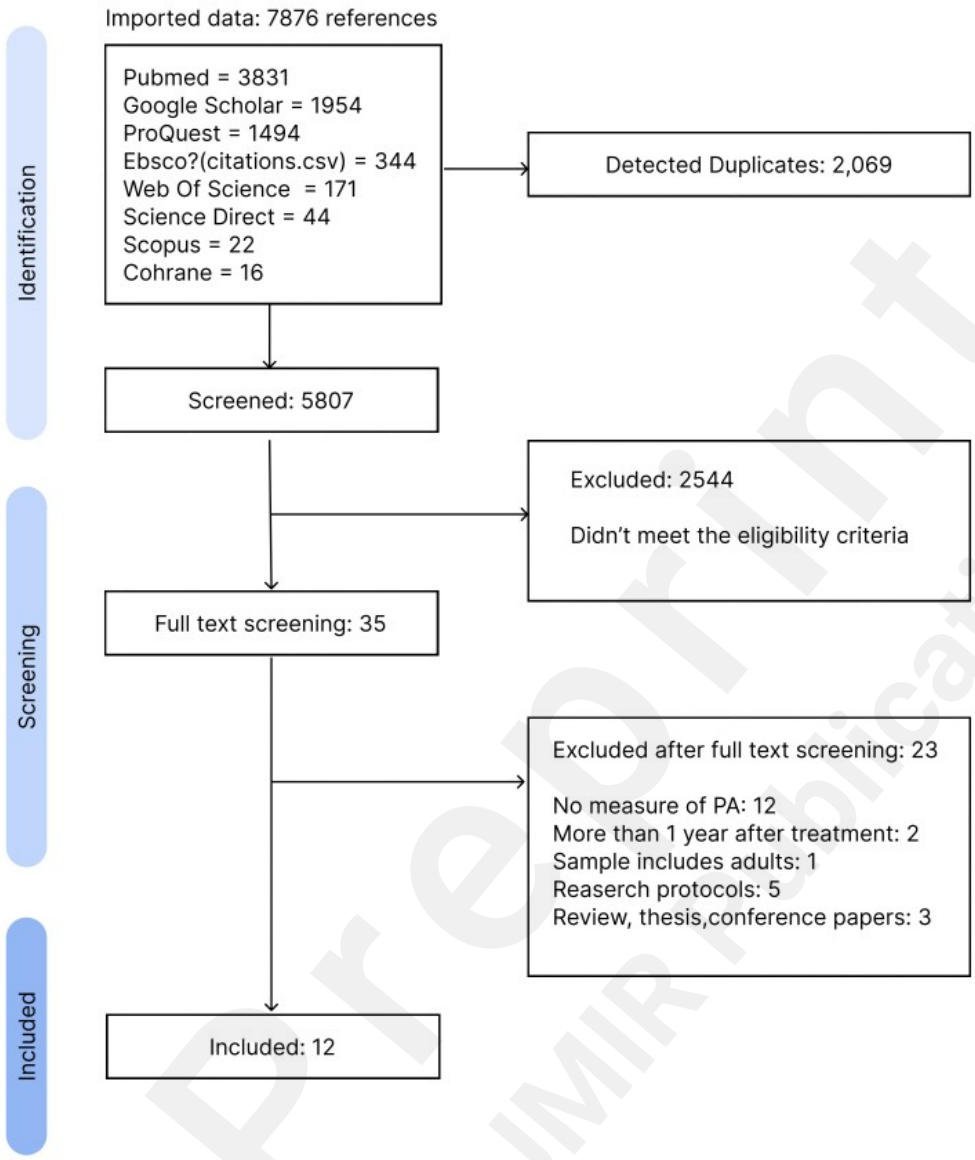
Results were reported descriptively and presented using tables with accompanying narrative synthesis.

Results

Selection of sources of evidence

Our search identified a total of 7,876 records from the eight electronic databases. Among them 2,069 duplicate records were identified and removed for a total of 5,807 records eligible for screening, suggesting the feasibility of our search strategy. After the first analysis by the eligibility criteria, 2,544 reports were excluded, and 35 were sought for retrieval. Of the 35 reports sought for retrieval, 23 were not retrieved because they did not include a measure of PA, research was done more than 2 years after treatment, the sample included adults, and there were research protocols, reviews, theses, or conference papers. A total of 12 publications met all the eligibility criteria and were included in this scoping review. For this scoping review, the selection source of evidence is presented in the PRISMA flow diagram (Figure 1).

Figure 1. PRISMA flow diagram for selection of sources of evidence



Characteristics of included studies

The characteristics of the 12 selected studies in this review are summarized in Table 1. The studies encompassed various research designs, including 4 randomized controlled trials [27,29,30,39], 1 quasi-randomized trial [31], 4 cross-sectional studies [16,32,33,34], 1 multicenter cohort study [34], and 1 pilot study [16]. The included studies investigated physical activity (PA) levels, motor performance, and quality of life among children and adolescents diagnosed with oncology, both during and post-treatment. The studies were conducted in Germany [16,27,33,35], the Netherlands [16,29,30,32], the United States [28,34], Hong Kong [36], and South Korea [31]. The interventions utilized objective PA monitoring tools such as accelerometers (Actical, Move 3, Step Watch 3TM, Garmin VivoFit® 3) and subjective self-report measures, including the Activities Scale for Kids© (ASK), PedsQL Multidimensional Fatigue Scale, and other health-related quality-of-life instruments. Across the 12 studies, a total of 1,083 participants (ages 3–20 years) were assessed, with sample

sizes ranging from 25 to 482. Most participants had leukemia (ALL, AML) or lymphoma (NHL, Hodgkin's), while others had solid tumors (bone tumors, brain tumors, neuro-oncology cases). Some studies included mixed cancer diagnoses without specific classifications. Two studies examined participants post-treatment [31,35], while the other ten focused on patients undergoing active treatment or within the first year after completion. For example, Kang (2024) investigated a mobile game-based healthy lifestyle program for childhood cancer survivors in South Korea, while Stössel (2020) compared PA behaviors before, during, and after cancer treatment in Germany.

Table 1. Characteristics of included studies for analysis

Nr.	**Year**	**Author**	**Country**	**Name of the Study**	**Participants, age and setting**	**Disease**	**Research Design**	**Physical activity assessment monitoring instrument objective results**	**Physical activity assessment monitoring instrument subjective results**
1.	2022	Gaser [27]	Germany	Analysis of self-reported activities of daily living, motor performance and physical activity among children and adolescents with cancer: Baseline data from a randomised controlled trial assessed shortly after diagnosis of leukaemia or non-Hodgkin lymphoma	Participants (N=41)4-18 years. During the treatment	61% (N = 25) ALL, 29% (N=12)NHL, 10% (N = 4) AML	Randomised controlled trial	The accelerometer Move 3; The Functional ADL(activity of daily living) Screen with everyday tasks; the Motor Performance in Paediatric Oncology (MOON) test	The self-reported Activities Scale for Kids© (ASK).
2.	2022	Gaser [39]	Germany	Effects of strength exercise interventions on	Participants (N=41)4-18 years. During treatment	ALL(N=25), AML(N=4), NHL(N=12), Second primary	Randomised controlled study.	The accelerometer Move 3; The Functional	The self-reported Activities Scale for Kids©

				activities of daily living, motor performance, and physical activity in children and adolescents with leukemia or non-Hodgkin lymphoma: Results from the randomized controlled ActiveADL Study		cancer(N=2)		ADL(activity of daily living) Screen with everyday tasks; the Motor Performance in Paediatric Oncology (MOON) test	(ASK).
3.	2016	Braam [32]	Netherlands	Cardiorespiratory fitness and physical activity in children with cancer	Participants(N=60)8-18 years Treated with chemotherapy and/or radiotherapy, during or within the first year after cancer treatment	Acute lymphoblastic leukemia (N=17); Acute myeloid leukemia(N=8); Brain tumor(N= 8); Hodgkin's lymphoma (N=7); Bone tumor(N= 7); Non-Hodgkin lymphoma(N= 5); Rhabdomyosarcoma(N=3); Chronic Myeloid Leukemia(N=2); Others(N=3)	Cross-sectional study	Actical activity monitor; (for cardiorespiratory system and muscle strength assessment: cardiopulmonary exercise test on an electronically braked cycle ergometer-Godfrey protocol.; hand-held dynamometry was used to measure muscle strength; were used).	PedsQLTM Multidimensional Fatigue Scale; The participation in sports before the cancer diagnosis-questionnaire; a subscale of the Self Perception Profile Questionnaire for children aged 8–11 years (CBSK) and for adolescents aged 12–18 years (CBSA); Children's Depression Inventory (CDI)
4.	2017	Go ̈tte [33]	Germany	Objectively measure	Participants (N=28) 13.8±2.8	Leukemia (N=13); ALL |(N= 9);	Cross-sectional	Step Watch 3TM, uniaxial	physical activity ques-

				versus self-reported physical activity in children and adolescents with cancer	years of age During cancer treatment	AML(N= 4); Bone tumor (N= 9); Ewing sarcoma (N=3); Osteosarcoma (N=6); Localized at lower limb (N= 3); Localized at trunk/upper limb (N= 6); Lymphoma(N = 2); Other solid tumor (N=4).	study design	accelerometer (7.5 x 5 x 2 cm; 38 g) counts the number of gait cycles (gcs) per time interval. Gait cycles are defined as two steps and the monitor was programmed to measure in 1-minute intervals.	tionnaire (AQ) from the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) of the Robert Koch Institute
5.	2022	Withycombe [28]	United states	Can Steps per Day Reflect Symptoms in Children and Adolescents Undergoing Cancer Treatment	Participants (N=65) 8–17 years old Enrollment generally occurred during the first six months of cancer therapy, but at least 4 weeks after diagnosis and at least 3+ weeks post-cancer definitive surgery (if applicable)	Leukemia/ Lymphoma (N=38); Solid Tumor(N= 16); Neuro-oncology (N=11)	Cross-sectional study design.	ACCELEROMETER— The Garmin VivoFit® 3- available for at least 4 days during a defined 7-day period. Eligible days-minimal 10h	A 9-question ecological survey; PATIENT-REPORTED OUTCOME MEASUREMENT INORMATION SYSTEM® (PROMIS®);
6.	2019	Bekkering [16]	The Netherlands	Physical Activity level objectively measured by accelerometery in children undergoing cancer treatment at home and in a	Participants (N=25)3.1-17.0 undergoing active cancer treatment	Haematological malignancy (N=17); Solid tumours(N= 8).	Cross-sectional study design.	accelerometery	

				hospital setting: A pilot study.					
7.	2020	Mack [34]	United states	Agreement Between Child Self-report and Caregiver-Proxy Report for Symptoms and Functioning of Children Undergoing Cancer Treatment	Participants (N=482 caregivers). Patient age 7-18 years. Participants received up-front cancer treatment, including chemotherapy and radiotherapy.	First diagnosis of cancer of any type	Multicenter cohort study		Child self-report and caregiver-proxy report of PROMIS pediatric domains of mobility (physical functioning), pain interference, fatigue, depressive symptoms, anxiety, and psychological stress.
8.	2019	Van Dijk-Lokkart [30]	The Netherlands	Longitudinal development of cancer-related fatigue and physical activity in childhood cancer patients	Participants(N =68). Aged 7-18 years Patients still receiving treatment or were within the first year after cessation of treatment	Diagnosed with any type of childhood cancer	Randomized controlled trial	accelerometer (Actical activity monitor)- a wear time of at least 500 min/day	Cancer-related fatigue was assessed by the self-report and parent proxy report version of the PedsQL Multidimensional Fatigue Scale Acute Version (PedsQL-MFS).
9.	2016	Lam [36]	Hong Kong	The impact of cancer and its treatment on physical activity levels and quality of life among young Hong Kong Chinese cancer	Participants(N =76). Aged 9-18 years. After treatment.	Leukemia(N=32 (42.1%); Lymphoma (N=7 (9.2%); Brain and spinal tumor (N= 16 (21.1%); Bone tumor (N=10 (13.2%); Others (N= 11 (14.5%)	A cross-sectional study		1. The Chinese university of Hong Kong: physical activity rating for children and youth (CUHK-PARCY); 2. Physical activity self-efficacy (PA-SE); 3. The

				patients					pediatric quality-of-life InventoryTM (PedsQLTM) cancer module v. 3.0; 4. The pediatric quality-of-life inventory (PedsQL)
10.	2024	Kyung-ah Kang [31]	South Korea	Effectiveness of a healthy lifestyle program based on a mobile serious game for childhood cancer survivors: A quasi-randomized trial	Participants (N=51) 6-13 years The participants were childhood cancer survivors (CCSs) whose treatment was terminated at least 12 months prior.	Childhood cancer survivors	A quasi-randomized trial		The Child Healthy Lifestyle Profile (CHLP) adapted for children+ parents or guardians filling out the CHLP
11.	2020	Stössel [35]	Germany	Physical activity behaviour in children and adolescents before, during and after cancer treatment	Participants (N=114) PaC and 37 healthy controls. Age 4-20, completed intensive cancer treatment	Diagnosed with any type of cancer	Cross-sectional, multicentre study		PA questionnaire which is in parts based on the German Health Interview and Examination Survey for Children and Adolescents (KiGGS)
12.	2018	Braam [29]	Germany	Effects of a combined physical and psychosocial	Participants(N=66, age 8-18, during treatment or within 12-months		A randomized controlled trial	The accelerometer / (VO2peak expressed in ml•kg•min−1) using the	Overall-fatigue score of the child self-report version of the

				training for children with cancer: a randomized controlled trial	post-treatment			Godfrey protocol./a hand-held dynamometer	PedsQL™ Multidimensional fatigue scale (acute version)/Total general-HrQoL- the Dutch self-report version of the PedsQL™/e havioural problems were assessed using the Youth Self-Report/ Athletic competence, global self-worth- athletic competence and global self-worth subscales of the 'Self-Perception Profile'/ pressive symptoms were assessed with the Children's Depression Inventory/

PA Monitoring Methods, Obtained Variables in Pediatric Oncology

The objective and subjective methods were used to assess physical activity (PA) levels, motor performance, and fatigue in children and adolescents with cancer. The objective PA monitoring was employed in five studies [27,28,30,32,33], using accelerometers, for example, Actical, Move 3, Step Watch 3TM, and Garmin VivoFit® 3. Van Dijk-Lokkart et al. [30] used the Actical accelerometers with a required wear time of at least 500 minutes per day to measure PA levels in children undergoing or recently completing cancer treatment. Similarly, Gaser et al. [27] utilized the Move 3 accelerometer and motor performance tests to examine PA in leukemia and lymphoma patients. Withycombe et al. [28] used the Garmin VivoFit® 3 over a four-day period to track step counts and correlate them with symptom reports.

Subjective PA assessments were applied in eleven studies [27,30,32-34] incorporating self-reported instruments. For example, Activities Scale for Kids© (ASK) including 30 items in seven sub-

divisions (personal care, dressing, other skills, locomotion, play, standing up and movement) and the PedsQL Multidimensional Fatigue Scale. Gaser et al. [27] combined ASK with motor performance testing to evaluate functional abilities such as mobility and locomotion, balance and coordination, strength and endurance as well as fatigue and energy levels. Mack et al. [34] employed caregiver-reported measures to assess mobility, pain interference, and fatigue. Fatigue, which impacts overall physical performance, was assessed through the PedsQL Multidimensional Fatigue Scale, capturing general, sleep-related, and cognitive fatigue [33]. Mack et al. [34] employed caregiver-reported measures to assess mobility, pain interference, and fatigue, incorporating surveys that evaluated children's ability to perform daily tasks, experience of pain, and levels of physical exhaustion. Additional self-report instruments such as the Child Health Utility 9D (CHU9D) [36] were used to assess health-related quality of life, while structured questionnaires like the Pediatric Outcomes Data Collection Instrument (PODCI) provided insights into mobility and participation in physical activities [32].

While some studies focused on the active treatment phase, others, such as Kang et al. [31] and Stössel et al.[35], specifically examined PA behaviors in post-treatment survivors. Kang et al. [31] investigated the effects of a mobile game-based healthy lifestyle program on physical activity levels, sedentary behavior, and overall quality of life in childhood cancer survivors in South Korea. Stössel et al. [35] analyzed PA behaviors before, during, and after cancer treatment, focusing on changes in daily activity levels, mobility patterns, and engagement in sports or recreational activities. Both studies provided insights into long-term functional outcomes, highlighting the impact of cancer treatment on sustained physical activity and overall well-being in survivors.

Applicability of PA Monitoring Instruments in Pediatric Oncology

Overall, studies included in this review demonstrated that PA monitoring instruments were feasible to use for pediatric cancer patients. Withycombe et al. utilized the Garmin VivoFit® 3, worn on the wrist for four consecutive days, to measure step counts and activity patterns. They observed that wearable technology effectively tracked PA, while obtained results varied according to the treatment stage and location (for example, less steps performed during hospitalization). Van Dijk-Lokkart et al. reported good compliance with accelerometer-based PA monitoring, using Actical accelerometers worn on the hip for at least 500 minutes per day over a one-week period [30]. Gaser et al. [27] employed the Move 3 accelerometer, also positioned on the hip, with a minimum required wear time of five days. Some studies imposed restrictions on PA measurement, such as excluding non-ambulatory patients or requiring a minimum number of valid wear days for data inclusion [33, 34].

Several barriers to PA monitoring were noted. Mack et al. found that fatigue, treatment side effects, and hospitalization affected step counts and overall compliance [34]. Braam et al. identified psychological factors, including lack of motivation and fear of overexertion, as key barriers to PA engagement [29]. Lam et al. cited time constraints and limited access to PA resources as additional challenges for participants [36]. Despite these barriers, authors suggested that self-monitoring through wearable devices served as a motivational tool, encouraging participants to maintain PA levels [28].

Interventions for Improving PA in Pediatric Oncology

PA interventions varied across the selected studies, incorporating individualized exercise programs, supervised training, and digital health tools to enhance and monitor PA level. Intervention durations ranged from 4 weeks to 12 months, depending on study design and patient condition. Most studies

showed high retention rates and adherence to the interventions. For instance, Braam et al. [29] reported strong adherence to supervised PA sessions, which included aerobic training, resistance exercises, and motor performance activities 2–3 times per week at moderate-to-high intensity. Similarly, Kang et al. [31] found high engagement with a mobile game-based lifestyle program for childhood cancer survivors, encouraging daily movement, while Van Dijk-Lokkart et al.[30] implemented individually tailored programs with varying intensity and duration based on the child's physical condition. Gaser et al. [27] also employed individualized exercise protocols for leukemia and lymphoma patients, focusing on moderate-intensity exercises.

Table 2 summarizes the physical activity monitoring methods, variables, applicability, and interventions across the studies in pediatric oncology, providing further detail on the tools and strategies used for assessing and promoting PA in this population.

Digital health interventions, such as Kang's mobile game-based program, and step-count-based monitoring were used across studies to assess PA levels and motivation [31, 16, 27, 28, 39]. These programs were conducted in hospital settings [29], at physical therapy sports centers [29, 30], or home environments [31] with supervision provided by physiotherapists, pediatric oncology specialists, or digital applications. Despite challenges, for example, fatigue and other treatment related side effects, authors emphasized that structured PA programs improved adherence to physical activity participation [30].

PA intervention durations varied across studies exploring their effects on physical functioning [28-30], fitness [29,39], fatigue [30,34], quality of life [31,36], and psychological well-being [29, 34]. For example, Kang et al. [31] evaluated a mobile game-based intervention, which increased daily activity, improved health behaviors, and enhanced self-reported well-being. Van Dijk-Lokkart et al. [30] implemented a structured PA program, which was found to reduce fatigue and improve functional capacity over time. Rehorst-Kleinlugtenbelt et al. [16] examined a structured physical exercise intervention, delivered in both hospital and home settings, which led to increased PA levels and better adherence to exercise programs over time. Braam et al. [29] examined a structured physical exercise intervention, delivered in both hospital and at a local physical therapy practice, which showed no significant beneficial effects on physical outcomes.

Table 2. Summary of Physical Activity Monitoring Methods, Variables, Applicability, and Interventions in Pediatric Oncology

Paper ID	**1. What methods are used for physical activity monitoring in pediatric oncology patients?**	**2. What variables are collected to monitor PA in pediatric oncology patients?**	**3. What is the applicability of different instruments to facilitate PA level (monitoring) in pediatric oncology patients?**	**4. What interventions are used to improve PA in pediatric oncology patients?**	**5. Which research questions are answered in this research?**
1. [27]	The accelerometer, self-reported questionnaire	Step count, amplitude of moderate-to-vigorous PA (MVPA), body position and wear time.	Gaser et al. employed the Move 3 accelerometer, positioned on the hip, with a minimum required wear time of five days.		1.2.3.

2. [39]	The accelerometer, self-reported questionnaire	Step count	PA was measured using the accelerometer Move 3 at outpatient periods for seven consecutive days.	Exercise program-specific strength training combined with a standard care exercise program (2–3 exercise sessions per week).	1.2.3.4.
3. [32]	The accelerometer, self-reported questionnaires	Counts per minute (cpm)	PA of each patient were measured by the Actical activity monitor. It was attached to an elastic waist belt and worn on the left hip during daytime at waking hours (between 6:00 a.m. and 11:59 p.m.) for four consecutive days (Wednesday–Saturday).		1.2.3.
4. [33]	The accelerometer, self-reported questionnaire	The volume of activity per day (gcs per day) and intensity of activity (gcs per minute). Gcs = gait cycles (2 steps) per time interval (1 min).	Gotte et al.: measures were obtained with the Step Watch 3™ Activity Monitor (SAM). The device is attached to the ankle with an elastic strap.Participants wore the SAM for seven consecutive days from morning after waking up until bedtime.		1.2.3.
5. [28]	The accelerometer, self-reported questionnaire	Step count	Participants were provided Garmin VivoFit® 3 monitors and instructed to wear them for 7 days.		1.2.3.
6. [16]	The accelerometer	Step count, count per minute, 15s epoch	The level of PA and SB were assessed using the Actical. The device was fastened to an elastic waist belt strap and worn on the right hip The minimum wearing time of 8 h per day was required, and the minimum number of 4 valid days a week was required.		1.2.3.

7. [34]	Self-reported questionnaire, caregiver-proxy report	PROMIS- assessments of the child's physical function (mobility) and symptoms, including pain interference, fatigue, depressive symptoms, anxiety, and psychological stress; 5 response categories. Each question's recall period is the past 7 days.			1.2.
8. [30]	The accelerometer, self-reported questionnaire, caregiver-proxy report	Count per minute, 15s epoch	Actical accelerometer was worn on the hip for at least 500 minutes per day over a one-week period.	Cardiorespiratory and muscle strength training twice a week, 12 weeks at a physical therapy sports center near the child's home.	1.2.3.4.
9. [36]	Self-reported questionnaires	The Chinese university of Hong Kong: physical activity rating for children and youth- score ranges from no exercise at all (0) to vigorous exercise on most days (10). Physical activity self-efficacy- score self-confidence in participation in PA, from 'not sure', 'a little sure', to 'very sure'. The pediatric quality-of-life inventoryTM (PedsQLTM) cancer module v. 3.0- how much a problem was a task over last month, from 0 to 4 (0 ¼ never, 1 ¼ almost never, 2 ¼ sometimes, 3 ¼ often, 4 ¼ almost always).			1.2.
10. [31]	Self-reported questionnaire, caregiver-proxy report		A healthy lifestyle program based on a mobile serious game (HLP-MSG)-observed such sub-dimensions as health responsibility, PA, nutrition, positive life perspective, interpersonal relations,	HLP-MSG: Healthy lifestyle program based on a mobile serious game that promote a healthy lifestyle by solving 26 quests, including seven sub-elements (nutrition, exercise, hygiene	1.3.4.

			stress management, spiritual health. No significant effect was observed on any of the sub-dimensions except physical activity.	interpersonal relationships, stress management, meaning of life, and health responsibility)	
11. [35]	Self-reported questionnaire	On a visual analogue scale (VAS), participants were asked how physically active they were- from “not at all physically active” to “very physically active”. And how physically active they were in the various domains, type of activity,minutes per day and the intensity level. The amount of physical activity in minutes per week and intensity levels light (LPA), moderate (MPA) and vigorous (VPA) were used for analysis of the results.			1.2.
12. [29]	The accelerometer, Self-reported questionnaires, caregiver-proxy report.	Mean counts per minutes, 15s time-interval.		The 12-week intervention consisted of 24 individual physical exercise sessions (two 45-min physical exercise sessions per week at a local physical therapy practice and one 60-min psychosocial training session once every 2 weeks for the child in the treating pediatric oncology hospital).	1.2.4.

Discussion

Principal Findings

This scoping review identified various physical activity (PA) assessment instruments, including digital solutions, used to monitor PA in pediatric oncology patients. Self-reported questionnaires remain the most frequently used instruments due to their access and cost-effectiveness [27-36, 39]. However, while these instruments provide valuable insights from a patient’s perspective, their reliability is limited by recall bias and motivational factors, making them inherently subjective. Although self-reported questionnaires remain widely utilized, the integration of accelerometry has

advanced physical activity monitoring by providing empirical, quantifiable measurements [28,37,38] Despite growing interest in interventions using digital tools, this review found that only one study utilized a mobile game-based approach for PA tracking in pediatric oncology patients [31], which also served as a mobile engagement tool. In this study, children participated in a serious game requiring them to complete 26 quests, including seven sub-elements (nutrition, exercise, hygiene, interpersonal relationships, stress management, meaning of life, and health responsibility) to promote a healthy lifestyle [31]. The integration of physical activity (PA) monitoring with patient engagement strategies for PA behavior change, such as gamification and augmented reality (AR), holds promise for enhancing data accuracy and patient motivation [19,31]. This highlights a gap in research where interactive digital solutions could play a pivotal role in optimizing PA interventions for pediatric oncology patients. As prior studies have extensively examined the effectiveness of digital technology in promoting PA, fewer have explored how PA monitoring itself can facilitate PA participation and adherence. While most studies used accelerometers and questionnaires, a research gap still remains in augmented reality and gamification usage for PA monitoring in pediatric oncology patients. There is a need for interventions implementing augmented-reality-based interactive games that enable monitoring and facilitation of PA in pediatric oncology patients. That would provide the healthcare professionals accurate information about a patient’s PA level in real time and would improve the patient's motivation to engage in PA. Due to the limited number of studies utilizing digital technologies, such as virtual reality (VR) and gamification, for physical activity (PA) monitoring, there is insufficient evidence on patient acceptance of these technologies as part of their treatment, as well as their integration into a clinical environment."

Implication for Practice

The findings emphasized the importance of integrating an innovative digital solutions, such as AR and gamification, into PA monitoring for pediatric oncology patients. By incorporating interactive engagement tools, clinicians can potentially enhance motivation and adherence to PA interventions., Additionally, this review highlighted the need for a standardized approach of PA monitoring in pediatric oncology patients. The diversity of accelerometers [16, 27-33,39], and self-report questionnaires [27-36, 39] underscored the necessity for unified guidelines to ensure consistency in data collection and interpretation. Developing a standardized guidelines for PA assessment would enhance comparability across studies and support the integration of digital monitoring solutions in clinical practice.

Limitations

This review has several limitations. It included only articles published in English, which may have led to the exclusion of relevant research in other languages. Additionally, the focus on children and adolescents aged 7–19 years who were undergoing treatment or within two years post-treatment may have limited insights into long-term PA outcomes beyond this period. Furthermore, the heterogeneity in study designs, PA measurement tools, and intervention methodologies posed challenges for direct comparisons. The limited adoption of interactive digital solutions highlights a critical research gap, underscoring the need for further studies to evaluate their feasibility, appropriateness and long-term impact on PA engagement in this population.

Future directions

Our findings showed that future research should focus on exploring how PA monitoring can actively facilitate PA participation in pediatric oncology patients. While numerous studies have examined PA monitoring tools, limited research has assessed their impact on actual PA levels. There is also a need for further investigation into the use of AR and gamification for PA monitoring in pediatric oncology. Interactive digital interventions have the potential to both measure and enhance PA engagement, providing real-time feedback and motivation [19]. Evaluating patient acceptance, clinical integration, and long-term adherence to such technologies would be crucial in optimizing their effectiveness. Furthermore, the absence of a standardized PA monitoring protocol highlights the need for developing unified guidelines for digital monitoring solutions tailored to pediatric oncology patients. Establishing consistent assessment criteria would improve the comparability of research findings and facilitate the integration of digital monitoring solutions into routine clinical practice.

Conclusions

Despite the growing need for monitoring and promoting PA for pediatric oncology patients, there remain limited possibilities for monitoring and enhancing PA more interactively. The findings of this scoping review suggest that there is an emergence of literature about digital technologies, including accelerometers, mobile health applications, and gamification, that are being explored for PA assessment and engagement. Future research is needed to continue to explore the purpose, level, and breadth of technology-enabled integration to facilitate an interactive approach to monitoring and enhancing PA effectively in clinical and home-based settings.

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Authors' contributions

All authors during the brainstorming session conceptualized and formulated the research questions. G.S., A.K., and E.D. led the data collection methods, but all authors were involved in data collection and analysis. K.A., K.B., E.D., A.C., and G.F.J. conducted a 3-step search process to identify relevant peer-reviewed literature studies. To ensure that the search yielded relevant studies, variations of the search strategy were pilot-tested by authors: K.A., K.B., and A.C., and refined before the final search was conducted. All authors during the brainstorming session conceptualized the eligibility criteria. K.A., A.C., K.B., E.D., and G.F.J. developed the data charting form. All authors conducted data charting of the sample of studies selected for inclusion. K.A., E.D., K.B., A.C., and G.F.J. synthesized the data, and D.B., M.B., E.S., and A.K. performed quality checks on the reported results. K.A., A.C., E.D., K.B., G.F.J., and G.S. led the manuscript development. All coauthors had the opportunity to read, edit, and approve the final manuscript.

Conflicts of Interest

Disclose any personal financial interests related to the subject matters discussed in the manuscript

here. For example, authors who are owners or employees of Internet companies that market the services described in the manuscript will be disclosed here. If none, indicate with “none declared”.

Abbreviations

JMIR: Journal of Medical Internet Research
RCT: randomized controlled trial
PA - physical activity
PCC - Population, Concepts, and Context
CRF - Cancer-Related Fatigue
CCS - Clear Cell Sarcoma
WHO - World Health Organization
AR - Augmented reality
VR - Virtual reality
IoT - Internet of Things
JBI - Joanna Briggs Institute
PRISMA ScR - Preferred Reporting Items of Systematic Reviews and Meta Analyses
ASK - Activities Scale for Kids
ALL, AML - leukemia
NFL - lymphoma, Hodgkins
ADL - Activity of Daily Living
PA -SE - Physical Activity Self-Efficacy
PedsQLTM - The Pediatric Quality-Of-Life Inventory ™ Lifestyle Profile
CHU9D - Child Health Utility 9D
PODCI - Pediatric Outcomes Data Collection
MVPA - Moderate to Vigorous Physical Activity
HLP-MSG - Healthy Lifestyle Program Based on a Mobile
VAS - Visual Analogue Scale
LPA - Light Intensity Levels
MPA - Moderate Intensity Levels
VPA - Vigorous Intensity Levels
PEDSQL - The Pediatric Quality-Of-Life Inventory
CUHK-PARCY - The Chinese University of Hong-Kong: physical activity rating for children and youth
CDI - Children's Depression Inventory

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