FORTEe

Get strong to fight childhood cancer: An exercise intervention for children and adolescents undergoing anti-cancer treatment

H2020 – 945153

D4.5 Report on augmented reality

WP Leader:	Professor Eila Watson, Associate Professor Peter Wright and Hayley Marriott (OBU)
Authors:	Professor Eila Watson, Associate Professor Peter Wright and Hayley Marriott (OBU, WP4)

Version	V1
Due date of deliverable	31/10/2025
Actual submission date	18/05/2026
Dissemination level	PU

Abbreviations

AR	Augmented reality
CAYA	Children, adolescents and young adults
EHCP	Exercise and Healthcare professionals
RCT	Randomised clinical trial

Executive Summary

Within the WP4 Augmented Reality (AR) App sub-study, all milestones and deliverables have been successfully achieved, with six clinical recruiting centres using the AR app to support the FORTE individualised exercise programme. The app reached the target participant numbers, with 101 children, adolescents, and young adults (CAYA) engaging with it during their study participation. The AR app supported at-home exercise through personalised training programmes, avatar-led demonstrations, an exercise diary, and an adaptive algorithm that tailored exercise prescriptions based on user input and health data.

Clinical teams received structured onboarding, continuous support, and shared resources to facilitate recruitment and implementation. CAYA participant feedback (n=46) and from exercise and healthcare professionals (EHCPs) (n=31) indicated that the AR app was well received and found to be engaging, though some technical issues required addressing, including improvements to diary usability. Both groups viewed the app as a valuable complement to, rather than a replacement for, face-to-face sessions. Recommendations to enhance engagement included incorporating gamification and avatar customisation. The full findings are provided in Annex A. The manuscript has been published in 'Frontiers in Pediatrics' as part of the research topic '*Expanding the Horizons of Supportive Care in Pediatric Oncology: Integrating Physical Rehabilitation and Nutrition'* (doi: *https://doi.org/10.3389/fped.2026.1743212).* Dissemination activities have extended beyond the randomised clinical trial (RCT), including training in using the AR app for teams external to the FORTE trial, patient outreach, and public engagement events. The AR app and associated research have been showcased through scientific publications, media features, and conference presentations. Future work within this work package will focus on the dissemination of results to both scientific and lay communities.

Table of Contents

1 AR App Subproject

1.1 AR app update

Within WP4, the AR component successfully achieved all planned milestones and deliverables. The final version of the AR app was used by six clinical sites, reaching the target participant numbers across centres, with teams reporting a total of 101 participants using the AR app at some point during study participation. The app was integrated into the wider individualised exercise programme, with particular emphasis on supporting at-home exercise. Intervention participants had access to the app throughout the intervention period, while control group participants were provided access post-intervention (i.e. from T1 onwards). Key app features included a personalised exercise programme, AR demonstrations delivered by a child-like avatar, and an integrated exercise diary. The aftercare setting within the app also includes an algorithm which prescribes appropriate exercises based on the information provided by the user (fatigue and activity questionnaires, sit-to-stand fitness test), and an exercise/healthcare professional (cancer diagnosis, treatment, contraindications etc). It also takes into consideration daily health status to advise the prescribed exercise session as intended, a lower exercise load or rest day.

Participating clinical sites received onboarding training, ongoing support from the WP4 leads through monthly WP4 meetings, regular updates, and technical assistance. To facilitate subproject recruitment, teams implemented monthly reporting, shared resources, and developed motivational materials. An additional clinical site, UKESSEN, was also incorporated into the sub-project. Individual exercise diaries were collected by site teams and securely transferred to WP4. Participant feedback was gathered via the wider FORTEe half-structured interviews conducted between T1 and T4. Healthcare and exercise professionals (EHCPs) involved in the FORTEe trial were invited to complete an online anonymous survey exploring their perspectives on the AR app's setup and implementation. Insights from both participant and professional feedback informed a scientific manuscript: *"The Use of an Augmented Reality App to Support an Exercise Intervention for Children and Young People with Cancer: Perspectives of Users and Exercise and Healthcare Professionals in the FORTEe Trial"* (Annex A). The manuscript has been published in 'Frontiers in Pediatrics' (Research topic - Expanding the Horizons of Supportive Care in Pediatric Oncology: Integrating Physical Rehabilitation and Nutrition (doi: 10.3389/fped.2026.1743212).

Of those that used the AR app, a total of 46 children, adolescents, and young adults (CAYA) provided feedback on the AR app during half structured interviews, and 31 EHCPs completed the online survey. Both CAYA and EHCPs reported generally positive experiences, finding the AR demonstrations engaging and the personalised workouts highly valued. However, technical difficulties affecting the reliability of AR features were noted, and some aspects, such as the exercise diary, were reported as lacking usability. EHCPs highlighted that the app should serve as a complementary tool, rather than a replacement for face-to-face sessions *(more extensive findings can be found in the attached manuscript)*. Suggestions to enhance the AR app included adding gamification elements and avatar customisation. The findings underscore the potential of AR technology to boost exercise engagement among CAYA with cancer and highlight opportunities for optimisation. While AR demonstrates promise in paediatric oncology care, it is most effective when used alongside in-person exercise interventions. Future development should prioritise user-friendly design, personalised experiences, and equitable access for young patients and their families.

In addition to the RCT, we have undertaken a number of dissemination activities. We have arranged online training sessions for non-WP4 and non-FORTEe teams on the use of the AR app to broaden use of the AR app. These sessions provided guidance to staff from other centres on onboarding procedures and app usage, enabling them to trial the app within their own settings. Outreach activities have also incorporated the AR app with patient and community groups, including summer activity days for children and young people with cancer and science bazaars for the general public. The WP4 team, in collaboration with other FORTEe colleagues have also published a peer-reviewed journal article presenting the protocol for a pilot study conducted with age-matched peers, which guided the development process of the AR app (*"The development of an augmented reality application for exercise prescription within paediatric oncology: App design and protocol of a pilot study"*, published in Sage Health Informatics, doi: 10.1177/1460458224128878) (Annex B). In addition, a results paper from this work *"Exploring User Experiences of an Augmented Reality Smartphone App Prescribing Exercise for Children and Young People With Cancer: Results From a Qualitative Study",* doi: 10.2196/76855) has been published in JMIR Formative Research (Annex C).

The development and application of the AR app have also been highlighted through a podcast, news articles, and scientific presentations, supporting dissemination to both scientific and lay audiences. Ongoing discussions are exploring the future of the app in terms of broader dissemination strategies and potential avenues for further development.

2 Acknowledgement and Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 945153.

This report reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

3 Supporting documents

Annex A: *"The Use of an Augmented Reality App to Support an Exercise Intervention for Children and Young People with Cancer: Perspectives of Users and Exercise and Healthcare Professionals in the FORTEe Trial"* (Published in Frontiers in Pediatrics, doi: 10.3389/fped.2026.1743212, publication date 09/03/2026)

Zenodo link: https://zenodo.org/records/18928926

Annex B: "*The development of an augmented reality application for exercise prescription within paediatric oncology: App design and protocol of a pilot study"* (published in Sage Health Informatics, doi: 10.1177/1460458224128878, publication date 24/10/2024)

Zenodo link: https://zenodo.org/records/14006880

Annex C: *"Exploring User Experiences of an Augmented Reality Smartphone Application Prescribing Exercise for Children and Young People With Cancer: Results From a Qualitative Study"* (published in JMIR Formative Research (doi: 10.2196/76855; publication date 22/04/26).

Zenodo link: - https://zenodo.org/records/19888486

frontiers in Pediatrics

TYPE Original Research
PUBLISHED 09 March 2026
DOI 10.3389/fped.2026.1743212

OPEN ACCESS

EDITED BY
Sabine Verena Kesting,
Technical University of Munich, Germany

REVIEWED BY
Peter Schmidt-Andersen,
University of Copenhagen, Denmark
Edmund Neo,
Singapore Health Services Pte Ltd,
Singapore

*CORRESPONDENCE
Eila Watson
ewatson@brookes.ac.uk

†These authors share first authorship

‡These authors share last authorship

RECEIVED 10 November 2025
REVISED 12 February 2026
ACCEPTED 16 February 2026
PUBLISHED 09 March 2026

CITATION
Marriott H, Solera-Sanchez A, Windsor S, Straun K, Neu MA, Dreismickenbecker E, Lanfranconi F, Villa E, Wiskemann J, Bauer N, Götte M, Beller R, Spreafico F, Zardo W, Wright P, Faber J and Watson E (2026) The use of an augmented reality app to support an exercise intervention for children and young people with cancer: perspectives of users and exercise and healthcare professionals in the FORTEe trial.
Front. Pediatr. 14:1743212.
doi: 10.3389/fped.2026.1743212

The use of an augmented reality app to support an exercise intervention for children and young people with cancer: perspectives of users and exercise and healthcare professionals in the FORTEe trial

Hayley Marriott[1†], Alba Solera-Sanchez[1†], Stanley Windsor[1], Kim Straun[2], Marie A. Neu[3], Elias Dreismickenbecker[3], Francesca Lanfranconi[4], Emanuele Villa[4], Joachim Wiskemann[5], Nikolai Bauer[5], Miriam Götte[6], Ronja Beller[7], Filippo Spreafico[8], William Zardo[9], Peter Wright[1], Joerg Faber[3‡] and Eila Watson[10*‡] on behalf of the FORTEe Consortium

[1]School of Sport, Nutrition and Allied Health Professions, Faculty of Health Science, and Technology, Oxford Brookes University, Oxford, United Kingdom, [2]School for Policy Studies, University of Bristol, Bristol, United Kingdom, [3]University Medical Center of the Johannes Gutenberg-University Mainz, Childhood Cancer Center Mainz, Mainz, Germany, [4]Fondazione Monza e Brianza per Il Bambino e La Sua Mamma, Monza, Italy, [5]Exercise Oncology Research Group, Department of Medical Oncology, Heidelberg University Hospital, Medical Faculty Heidelberg, Heidelberg University, Heidelberg, Germany; National Center for Tumor Diseases (NCT), NCT Heidelberg, a partnership between DKFZ and the Heidelberg University Hospital, Heidelberg, Germany, [6]University Hospital Essen, West German Cancer Center, Essen, Germany, [7]Clinics for Paediatrics III, Department of Paediatric Haematology/Oncology, West German Cancer Centre, University Hospital Essen, Essen, Germany, [8]Oncology Unit, IRCCS Istituto Giannina Gaslini, Genoa, Italy, [9]Pediatric Oncology Unit, Fondazione IRCCS Istituto Nazionale dei Tumori, Milan, Italy, [10]Oxford Institute of Applied Health Research, Faculty of Health Science, and Technology, Oxford Brookes University, Oxford, United Kingdom

Background: Mobile health (mHealth) technologies are increasingly used in paediatric oncology to promote physical activity, with growing evidence supporting their feasibility and effectiveness. Augmented reality (AR) is emerging as a promising addition, offering interactive features that may enhance participation in exercise for young people. As mHealth tools evolve, understanding user experiences and implementation challenges is essential to inform wider adoption in healthcare. The FORTEe clinical trial evaluates an individualised exercise programme designed for children, adolescents and young adults with cancer (CAYA). This sub-study explores the perspectives of CAYA and exercise and healthcare professionals involved in delivering the exercise intervention (exercise professionals) on the use of a novel AR application (app), designed to facilitate home-based exercise as part of the broader intervention. Key app features include personalised exercise programmes, AR demonstrations using a child-like avatar, and an integrated exercise diary.
Methods: CAYA (9–21 years), and exercise professionals from the FORTEe trial's technology sub-study (six centres) were eligible. To explore experiences and perceptions of the AR app, half-structured interviews were conducted with CAYA and an anonymous online survey administered to exercise professionals. Interview data and open-ended text from survey was analysed using inductive qualitative content analysis. Survey data was analysed using descriptive statistics.

Results: A total of 46 CAYA (mean age 13.6 ± 2.7 years, 39% female) provided feedback on the AR app via interviews, and 31 exercise professionals completed the survey. CAYA and exercise professionals reported generally positive experiences, finding the AR demonstrations novel and engaging. The personalised workouts were valued by both groups. However, both groups reported some technical difficulties that impacted reliability, and that some features, such as the exercise diary, lacked usability. Exercise professionals emphasised the app should complement rather than replace face-to-face sessions. To enhance the app further, both groups suggested incorporating gamification and avatar customisation.
Conclusion: This study emphasises the potential of AR technology to increase engagement in exercise among CAYA and highlights ways to optimise the technology. While AR shows promise in paediatric oncology care, it should complement in-person exercise interventions. Future development should prioritise user-friendly design, personalised approaches, and equal access for young patients.

KEYWORDS

augmented reality, childhood cancer, exercise, exercise oncology, smartphone app

Introduction

Mobile health (mHealth), a subset of electronic health (eHealth), is described as a class of health technologies, specifically applications that are delivered through mobile and often internet-connected communication devices. One of the main characteristics of mHealth is the delivery through devices that are "tethered" to the user such as smartphones and smartwatches (1). The benefits of mHealth interventions, such as their accessibility, cost-effectiveness, ability to personalise and tailor content, and the capacity to deliver real-time strategies to users, have likely contributed to the noticeable increase in their prevalence (2). mHealth has been identified as a promising tool to promote self-management in long-term health conditions in children and adolescents (3). Exercise interventions with mHealth components are emerging in paediatric oncology, offering tailored exercise programmes that meet participants' unique health needs and demonstrating both feasibility and effectiveness (4). mHealth interventional research has shown an enhanced adherence to exercise programmes (5), improved symptom monitoring and management (6, 7), body mass index (BMI) scores (4), physical fitness and body composition (8) and positive behaviour change (9). Findings suggest that integrating mHealth tools into standard care has been well-received by children and young adults with cancer (CAYA) (10), indicating their potential as effective adjuncts to standard cancer care pathways.

These developments position mHealth as a promising but incomplete solution, particularly for complex, engagement-dependent interventions such as exercise in paediatric oncology. While healthcare professionals often recognise the potential benefits of digital tools, concerns have been raised regarding their impact on patient-clinician relationships and long-term sustainability (11). Barriers related to infrastructure, training, and perceived clinical necessity further underscore that facilitators and challenges may vary across different mHealth tools (11). For these reasons, alongside evaluating feasibility and acceptability among paediatric users, it is critical to consider the perspectives of professionals delivering mHealth-supported interventions.

Within the mHealth context more immersive and interactive technologies have attracted growing interest. Among these, augmented reality (AR) and virtual reality (VR) are emerging as potentially transformative technologies in healthcare (12). VR involves the use of a specialised headset to simulate an environment in which the user is fully immersed (12), whereas AR overlays digital information in the physical environment, enhancing real-world perception and interaction (13). In paediatric oncology VR has shown promise, with evidence indicating its potential to reduce procedure-related anxiety and pain through immersive distraction, particularly when used alongside caregiver involvement (14). AR, by contrast, overlays digital elements onto real-world environments rather than fully immersing the user in a virtual one (15). The differences may be particularly relevant for exercise-based interventions as AR allows users to interact with their physical surroundings while engaging in digital content, whereas VR is associated with higher rates of cybersickness, including nausea and dizziness (16). Both AR and VR offer unique affordances and challenges for exercise interventions and considerations such as tolerability, treatment-related side effects and type of exercise must be considered when designing interventions.

While general AR applications, such as Pokémon GO, are popular among young people, no AR apps, to date, have been designed to tailor exercise programmes specifically for CAYA undergoing cancer treatment. To fill this gap, an interdisciplinary team of software developers, digital health academics, and exercise professionals collaborated to create an AR smartphone application suitable for CAYA with cancer aged 9–21 years old (17). The AR application has been designed to use as a supplementary technology alongside an individualised 8–10 week personalised exercise programme, as part of the FORTEe clinical trial (18). The FORTEe trial is a large cross-Europe multi-centre, randomised clinical trial, investigating the effects of a personalised exercise intervention in children and young people undergoing cancer treatment. The purpose of this study is to explore the perspectives of both CAYA with cancer and professionals involved in delivering the exercise intervention (hereafter exercise professionals) regarding use of the novel AR app delivered as part of the broader FORTEe clinical trial.

Methods

Overview

This technology sub-study of the FORTEe trial was conducted in six of the 10 trial centres, including one UK centre, two Italian centres, and three German centres (Appendix A). This sub-study was designed as a qualitative evaluation of user perspectives, complemented by supplementary descriptive survey data from professionals involved in delivering the exercise intervention.

FORTEe trial design

The FORTEe trial protocol is detailed elsewhere (18) was conducted in 10 centres across 7 countries in Europe. The study is examining the effects of an individualised exercise programme in CAYA (aged 4–21) receiving cancer treatment. The FORTEe study, including this sub-study, was approved by the Ethics Committee of the Medical Chamber of Rhineland-Palatinate (Ref No: 2021- 15904) as well as the local ethic committees of all FORTEe trial sites. Trial participants were randomly assigned to one of two groups: the exercise group, offered an individualised exercise programme over a period of 8–10 weeks, and the control group, which received usual care. The exercise intervention consisted of face-to-face supervised sessions and optional remote supervised sessions.

FORTEe AR app

The AR app was developed for the FORTEe clinical trial to enable participants to perform strength and mobility exercises with animated avatar demonstrations using AR technology. It was specifically designed to enhance engagement, particularly outside clinical settings, by delivering personalised workouts tailored to participants diverse health and fitness needs. The app operates entirely offline (both use and data collection), ensuring privacy-by-design. The app was developed with two settings: intensive treatment phase and aftercare. As the majority of study participants used the app in the intensive treatment phase, this paper will focus on the "intensive" setting of the app. To personalise the app, an exercise professional was required to select exercises from a predefined list of 58 exercises, including seated variations, categorised into lower body, upper body, and core exercises. Each exercise session consisted of a circuit of six exercises randomly selected from the pre-selected exercise list. The exercise professional selected the number of repetitions (1–6) (the number of times to perform a single exercise), and sets (1–3) (a group of consecutive repetitions completed without rest) to create an individualised exercise programme. Following a supervised familiarisation session, designed to ensure participants understood the app's functionality and exercise form, participants were encouraged to use the AR app independently. Participants were guided through the exercises by AR avatar demonstrations. The avatar was designed to be child-like in appearance to enhance engagement. A usability study was conducted with age-matched children, and their feedback was incorporated into subsequent iterations of the app design (Marriott et al., 2026 *under review*). Once the exercise session was completed, the participant completed a rate of perceived exertion (RPE) scale, and the completed exercise session was automatically recorded in the app's exercise diary. Figure 1 shows a selection of example screens from the app interface. In the intensive setting of the app, progression required the exercise professional to re-select exercises and adjust the number of repetitions and sets. As the app operates offline, all adjustments were made in person.

Recruitment

FORTEe participants aged 9–21 years enrolled at the six centres were invited to use the AR app. Those who agreed were provided with a study iPhone, tripod, charging leads to borrow, and written instructions to take home. Centres only had a limited number of study iPhones to lend to participating CAYA. Familiarisation session(s) with each participant were conducted prior to use with a FORTEe exercise professional. Participants in the intervention group were invited to use the AR app during the intervention phase and beyond, whilst the control group were invited to use the AR app only once the intervention period had concluded. While participants were encouraged by the study exercise professionals to use the app, participation was optional, and no specific frequency of use was mandated.

Data collection

All study participants were invited to participate in a half-structured (semi-structured) interview at multiple time points throughout the FORTE trial: baseline (soon after diagnosis) (T0), post intervention (T1), and at three follow up assessments (T2-T4) (see Figure 2). Interviews were conducted by a member of the local FORTEe team, either face to face or over the telephone. During the interviews, participants in the intervention group were asked about their use of, and experiences of the AR app at T1-T4, while those in the control group were asked about the app at T2-T4. The interviewer followed a set of questions with example prompts (see Appendix B) which covered participant perspectives on app design, app interface, exercise demonstrations, exercise selection, AR technology and the equipment provided. Interviews were conducted in the native language of the respective centre. Interviews were not audio-recorded, but responses were written down by the interviewer and translation to English was then undertaken (by researchers within each centre).

Exercise professionals affiliated with FORTEe centres were invited to complete an anonymous, web-based survey. Invitations were distributed via internal project communication channels. The survey was administered towards the end of the overall data collection phase of the FORTEe trial. The survey tool, developed for this sub-study, comprised closed ($n = 12$), and open-ended ($n = 13$) items designed to explore key implementation components. Topics included perceptions of the onboarding process, experiences training other staff, conducting familiarisation sessions with study participants, and the integration of the AR app as a supplementary training tool during supervised exercise sessions. Closed-ended survey questions used five-point Likert scale responses (e.g., from

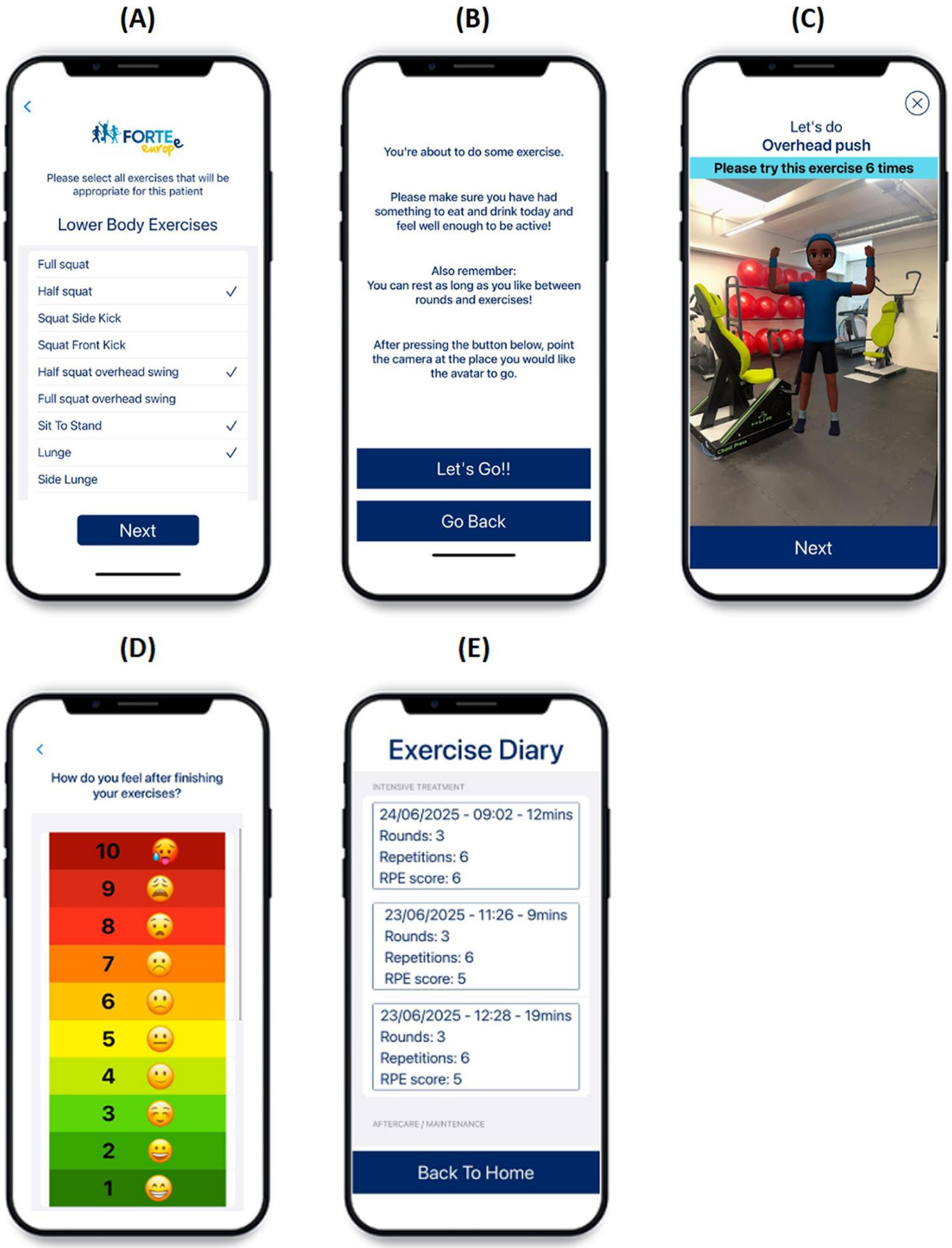


FIGURE 1
AR app screens **(A)** exercise selection, **(B)** Pre-exercise screen, **(C)** exercise session, **(D)** RPE scale, **(E)** exercise diary.

"strongly disagree" to "strongly agree"). The survey tool is available from the authors on request.

Data analysis

Written records from the CAYA interviews and open-ended text from the EHCP survey were analysed separately using an inductive content analysis approach (19, 20) Initial coding of the responses was conducted independently by two researchers (HM and AS) using an inductive approach. Following discussion (HM, AS and EW) a coding framework was agreed and applied to the data. Codes were then grouped into categories which summarised key patterns across the dataset. The analysis was descriptive in nature and aimed to systematically capture and structure participant perspectives rather than to generate theory.

For the survey data, descriptive statistics, including percentages, were used to summarise exercise professionals responses to each item. No inferential statistics were applied due to the exploratory nature of the survey.

Results

Figure 3 illustrates the inclusion of FORTEe participants eligible for the AR subproject.

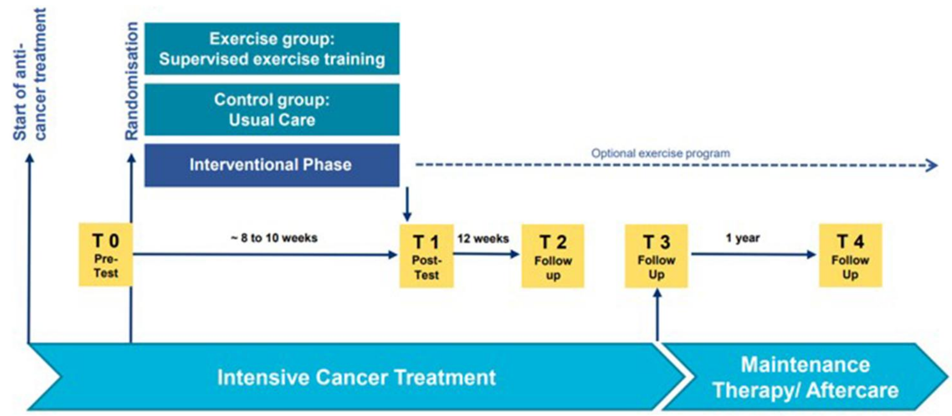


FIGURE 2
Data collection timeline (Neu et al. 2025).

Table 1 presents the demographic and clinical characteristics of CAYA who provided feedback on the app.

Qualitative findings

Experiences are grouped by themes and drawn from 46 CAYA who shared their perspectives during the half-structured interviews (35 responses at T1, 20 at T2, 5 at T3 and 6 at T4), along with open-ended text comments from the exercise professionals survey. Although the CAYA data was initially analysed by time point and intervention arm, no clear differences emerged either longitudinally or between the intervention and control groups. The findings are therefore presented collectively in the sections that follow. Additionally, 31 exercise professionals, from the FORTEe consortium, provided their feedback on the AR app in a series of open-ended questions. Survey responses indicated that these professionals had a range of experience with the app, including app set up, training other staff members, app onboarding, familiarisation sessions with participants, use during 1–1 sessions and data export. 14 respondents reported not using the app themselves, however had seen it being used.

Overall views of the AR app

Most CAYA described the app's interface and navigation as "user friendly" and "simple." Several CAYA commented positively on specific app features. Two noted that the RPE scale was a welcome addition, appreciating its use of colours and emojis. One CAYA reported that the exercise diary was helpful for tracking progress, while another expressed approval of the "skip" function, which allowed greater flexibility in navigating the exercise sessions.

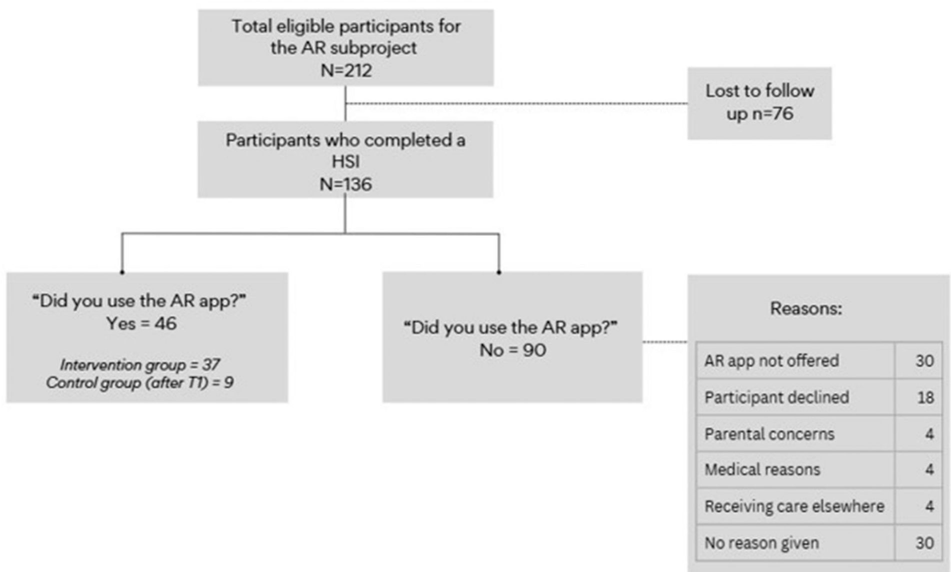


FIGURE 3
Flowchart of participant inclusion. HSI, half-structured interview; AR, augmented reality.

TABLE 1 CAYA demographic and clinical characteristics ($N = 46$).

Participant characteristic	Value
Age, years ± SD (age range)	13.6 ± 2.7 (9–19 years)
Sex (*n*, %)	
Male	28 (61%)
Female	18 (39%)
Diagnosis (*n*, %)	
Leukaemia	19 (41%)
Lymphoma	13 (28%)
Malignant bone tumours	5 (11%)
Soft tissue and other extraosseous sarcomas	4 (9%)
Neuroblastoma	2 (4%)
Renal tumours	1 (2%)
Germ cell tumours	1 (2%)
Other	1 (2%)

CAYA: children, adolescents and young adults with cancer.

68% of exercise professionals (13/19) who had gone through the onboarding process found it easy/very easy and all of those who had conducted familiarisation sessions ($n = 15$) reported finding it easy/very easy. Exercise professionals consistently described the app as "self-explanatory" and "easy to set up". However, most reported that practical demonstrations during the familiarisation session were more effective than verbal explanations alone. Exercise professionals also recognised the value of the exercise diary, noting its potential to support adherence and monitoring. However, some exercise professionals noted that resetting the app to modify an individualised exercise programme removed access to previously logged exercise entries. Similarly, CAYA sessions were not recorded unless the whole session was completed.

CAYA and exercise professionals suggestions for further development included incorporating gamification features such as earning points or coins, introducing levels and rewards, and enabling users to set personalised goals. Exercise professionals also proposed linking rewards (e.g., coins or points) to avatar customisation.

Portability of the device/remote training

CAYA provided largely positive feedback regarding the use of a mobile device they could take home. Younger participants particularly noted enjoying the opportunity to use the app collaboratively with siblings at home. Among teenage participants, several reported that the app facilitated independent exercise and enhanced motivation to engage in physical activity. Some within this teenage sample also expressed that the individualised nature of the app increased their confidence in the safety of the prescribed exercises. In contrast, a few CAYA reported barriers to use at home, citing lack of time, preference for alternative activities, or feeling too unwell to engage with the app.

Exercise professionals also reported that the app served as an effective remote tool to support and motivate unsupervised exercise. They emphasised that its transportable nature enabled CAYA to complete exercises in a variety of settings. While only 40% (6/15) of exercise professionals who used the app within one-to-one sessions found it useful/very useful, they did acknowledge its potential as a valuable supplementary tool, instead of a substitute for in person sessions.

Exercises

There was mostly positive feedback in relation to the exercises providing "'a good level of intensity'" and "'pace'", with "'good variety'". However, some CAYA and exercise professionals reported that the exercises were "'too easy and short'" for some users. Exercise professionals widely valued the app's capacity to individualise exercises for patients. Many reported that the range of available exercises was appropriate, and they appreciated the inclusion of exercises targeting the lower body, upper body, and core, along with seated versions to support accessibility for CAYA with specific physical needs. There was consistent feedback advocating for further individualising prescriptions, particularly with respect to adjusting repetitions and sets beyond the pre-set parameters. In addition, exercise professionals recommended incorporating further instructions within the app, such as the use of weights, to support progression.

AR technology

Perspectives varied regarding the AR technology used within the app. Several CAYA reported that they enjoyed the novel approach to physical activity facilitated by AR, describing the technology as "interesting" and "clever". Some noted that the AR-based demonstrations were preferable to traditional instruction formats such as videos or written instructions. For example, CAYA highlighted the usefulness of being able to move around and view the AR avatar from multiple angles. Across all age groups, participants frequently reported the AR demonstrations as "helpful" when the technology functioned as intended, particularly when the avatar appeared promptly and in an appropriate location. One participant said it was nice seeing the avatar appearing in a familiar location. Among younger participants, some described the experience of locating the avatar in their physical environment as "fun" or "funny," suggesting that the interactive element held some appeal.

Conversely, two CAYA expressed reservations about the use of AR. One indicated a general dislike for using technology to be active, while another stated that standard 2D video formats would be easier to follow. Technical issues were a recurring theme across all age groups, and by exercise professionals. Common concerns included the avatar "not appearing," "not appearing quickly", or "appearing in an odd location". CAYA frequently described these experiences as "annoying" and "demotivating." There were reports from CAYA and exercise professionals that the size of the room, and lighting seemed to affect the placement of the avatar within the environment which further impacted its usability. Additionally, some CAYA and exercise professionals reported finding the requirement to scan their surroundings between each exercise annoying.

Avatar design

CAYA generally responded positively to the avatar design, frequently describing it as "good" or "cool." There was, however, consistent feedback indicating a desire for greater avatar customisation. One participant expressed a preference for a more human-like avatar, while participants across all age ranges, and exercise professionals, recommended offering a wider selection of avatar types, including animals and superheroes. Additionally, one participant noted that the avatar's skin tone differed from their own, and several CAYA and exercise professionals suggested the option to personalise the avatar to resemble the user more closely and thus enhance user engagement.

Suggested improvements and views on future use

Specific suggestions for improvement to the app, provided by both exercise professionals and CAYA are presented in Table 2. Exercise professionals also provided their views on future use. 90% (28/31) exercise professionals said they would recommend the AR app to other childhood cancer centres, especially as a supplementary tool to support an existing in person programme. One exercise professional suggested that the app would be particularly helpful for isolated patients and another reflected that the app may be useful for "other chronically ill children". There were mixed views regarding the most appropriate target age range for the current version of the app. While some felt it could be suitable for children as young as four years, there was general consensus that the app may be most suitable for children aged approximately 8–14 years. Exercise professionals expressed that the current basic interface and child-like avatar design lends itself to younger users, while older users might benefit from additional features, such as a more sophisticated interface or integrated social functionalities, or might require a different app altogether. Moreover, some reported that parents expressed concerns about introducing additional technology into their child's daily routine.

Discussion

As physical activity and exercise plays a crucial role in ameliorating the physical and psychological side effects of cancer and its treatment (21), there is an increased interest in mHealth apps that support engagement in safe and accessible exercise interventions for CAYA with cancer (22). This is the first AR exercise app that has been developed specifically for children and young people with cancer. Our findings contribute to this growing field by providing insights into perspectives of AR technologies. Importantly, the study highlights both the potential and the challenges of integrating such tools into existing in-person exercise programmes in oncology care, from the dual perspectives of CAYA and exercise professionals.

Both CAYA and exercise professionals reported generally positive experiences of the app, reporting the AR demonstrations as novel, engaging and helpful. The portability of the smartphone was also viewed favourably by both CAYA and exercise professionals as it supported exercise programmes outside of the clinical setting. However, there was strong consensus that the app should serve to supplement and not replace face to face sessions. Despite many positive comments, technical limitations were also noted. There were comments that the AR technology did not always function reliably, and that the exercise diary required further development. Recommendations for further development included the addition of gamification elements, and the customisability of avatars.

The use of apps to support exercise programmes in paediatric oncology

Both CAYA and exercise professionals valued the flexibility of being able to use the app at home. This highlights how the integration of mobile apps into paediatric oncology exercise programmes offers a promising way to support and enhance engagement and continuity of care beyond clinical environments (22). It also aligns with previous research demonstrating the potential of digital health technology to mitigate barriers to access, especially for families living in rural or underserved areas (23). However, the financial and equity implications of implementing such technology outside of a research setting must be considered. In this study, CAYA were provided with a study smartphone and the necessary accessories, but this may not be feasible in routine clinical practice. The costs of devices, maintenance and technical support could represent a barrier for some healthcare systems and families, potentially exacerbating existing inequalities in access to supportive exercise interventions. Therefore, future implementation of AR-supported exercise programmes should prioritise equitable access, for example by ensuring compatibility with personal devices, offering institutional device lending schemes, or integrating them within existing digital health infrastructures.

It is equally important to consider concerns regarding digital tools in paediatric populations. These concerns are not limited to the healthcare context but rather reflect a broader societal apprehension surrounding the rise in excessive screen time in children and growing dependence on digital devices for entertainment and education (24). In the context of this work exercise professionals reported instances where parents were hesitant or avoided using the AR app due to these concerns. In addition to screen time, other research has highlighted parental concerns about data protection and the wider suitability of app content, including advertisements (25). While such issues are typically well-regulated within controlled research environments, the broader dissemination of mHealth tools must include safeguards to protect users.

Previous research has also identified concerns among parents of children with complex needs regarding the potential for such interventions to replace, rather than complement, essential supportive services (26). Notably, exercise professionals in this study emphasised that the AR app should serve as an adjunct to, rather than substitute for in person care. These findings underscore the importance of integrating digital tools in a way that enhances, rather than compromises, the delivery of personalised care in paediatric oncology.

TABLE 2 Suggested recommendations for app improvement.

Category	Recommendation	Reported by	Example quotes
AR	i) AR technology improved to ensure quick and consistent appearance	CAYA and exercise professionals	"Additionally, I think the AR technology within the application needs to be significantly improved as the avatar not appearing quickly was the most frequent problem reported" *(*exercise professional*)* "It was sometimes difficult to make the avatar appear." *(CAYA, age 11 years)*
Avatar	i) Additional avatar options (superheroes/animals)	CAYA and exercise professionals	"It would be nice to have other avatar options, for example animals or superheroes." *(CAYA, age 17 years)* "I think there should be more options for other styles of avatars to engage more children with different interests, such as superheroes or cartoons." *(*exercise professional)
	ii) Avatar customisation	CAYA and exercise professionals	"I liked the avatar but I think it would be better if you could customise it so it could look like you." *(CAYA, age 12 years)* "The avatar [should be] customised by each patient" *(*exercise professional*)*
Exercise prescription	i) Further flexibility when selecting sets/reps	Exercise professionals	"it would be helpful, if you can decide for each session how many reps and sets should be performed" *(*exercise professional*)*
	ii) Additional exercise options	CAYA and exercise professionals	"More stretches in the app." *(CAYA, age 16 years)* "I think that more exercises could be added to the exercise catalogue, to enable greater variety for the app users." *(*exercise professional*)* "It would also be nice to include other exercises including more stretches or balance exercises" *(*exercise professional*)*
Exercise diary	i) Diary saving workouts regardless of completion	Exercise professionals	"the programming needs to be changed so that the exercise session is recorded regardless of whether the participant completed the whole workout" *(*exercise professional*)* "There should be an option on each exercise to 'finish now' and the app record how many exercises were completed. Often we would receive feedback that a child did the exercise but because they did not get to the very end it was not recorded." *(*exercise professional*)*
	ii) Diary data saved when adjustments are made to the exercise prescription	Exercise professionals	"[..] This then required the app to be reset to change the exercise prescription. Unfortunately this meant that the exercise diary was cleared and the participant could no longer see their previous workouts. It would be a nice option if you were able to edit their exercise programme rather than restart the app all together" *(*exercise professional*)*
Gamification	i) Challenges	Exercise professionals	"Also some more playful content (challenges [..] might be helpful." *(*exercise professional*)* "But I think that the APP is target for young (8–12) and so it needs more game and challenges (like: if you do this training you earn a pair of shoes)" *(*exercise professional*)*
	ii) Levels	CAYA	"It would be great to have different levels, so it feels more like a game and you can reach new levels and get better by this." *(CAYA, age 16 years)*
	iii) Rewards (e.g., points or coins)	CAYA and exercise professionals	"It would be good to collect coins or points to earn things for your avatar, for example clothes" *(CAYA, age 17 years)* "[..] it would be a nice addition to include a reward system whereby participants receive coins or points which allow them to customise their avatar for example. *(*exercise professional*)*
	iv) Usage streaks	CAYA	"It would be good if there was some audio feedback and a streak function to motivate you to use it." *(CAYA, age 11 years)*
	v) Goal setting	CAYA	"It would be great if you can set goals" *(CAYA, age 16 years)*

CAYA: children, adolescents and young adults with cancer.

Usability and technical considerations of AR apps

Within this study, CAYA and exercise professionals appreciated the added benefits of the AR components, however both noted frustrations with technical issues. Usability challenges, such as problems with software design, interface, or content are well documented barriers to app adoption and continued use (27, 28). While AR technology appeared to offer added value over conventional exercise instructions methods (i.e., written or 2D videos) for many users, not all CAYA perceived it as beneficial. This highlights the importance of balancing technological novelty with usability, as well as the challenge of addressing diverse user needs and preferences within a single app. To optimise the effectiveness of AR-enhanced mHealth tools, developers should focus on ensuring reliability of the AR features, while also considering offering alternative formats to accommodate diverse user preferences.

Tracking engagement and adherence through app-based features

The exercise diary was intended to track usage patterns of the app and provide CAYA with the opportunity to monitor their own engagement with the app. Feedback and monitoring for users to track their performance and status are important factors to influence trust, motivation and engagement (25, 29). Incorporation of such features could support processes such as goal achievement, helping young people to enhance their physical fitness levels through self-monitoring, self-motivation, and self- surveillance (30). However, exercise professionals highlighted that there was sometimes a discrepancy between what CAYA verbally reported compared to what was recorded in the app exercise diary, with regards to completing exercise sessions. This variation raises important questions about user engagement and adherence to the prescribed programme. Additional feedback pointed at other potential pitfalls within the app design, as the exercise session had to be completed in order for the session to be recorded in the exercise diary. These findings highlight the need for more robust monitoring and feedback mechanisms within app-based exercise interventions. Features such as semi-automated tracking may be a favourable addition to support awareness in behaviour and engagement, while reducing the burden of fully manual tracking and accuracy challenges of fully automated tracking (31).

Enhancing engagement through personalisation and gamification

A key theme identified by both CAYA and exercise professionals was the potential to enhance user engagement through increased interactivity, personalisation and gamification within the app. Personalisation features, such as customising avatars, have been successfully implemented in other apps for childhood cancer patients (32). In their study, Fortier and colleagues (2016) allowed users to earn virtual coins through app engagement to purchase accessories and modify interface design. Evidence also suggests that avatars resembling the user can foster a stronger sense of identification and promote healthier behaviours compared to generic avatars (33). In parallel, CAYA and exercise professionals highlighted the value of gamified elements such as challenges, levels, and rewards to sustain interest and motivation. This aligns with wider trends in mHealth and eHealth, where gamification has been shown to support goal setting, provide positive reinforcement, and encourage long-term use (34). In paediatric oncology, where children face additional barriers to exercise (35), such features could be especially effective in boosting motivation and adherence. However, it is essential for these elements to be adaptable to the diverse needs and preferences of this population.

Strengths and limitations

A key strength of this study is its large, multi-centre design across multiple countries across Europe. By including a diverse range of clinical sites, the study enhances the generalisability of its findings to a broader European context with different clinical settings, staffing and resources. Secondly, this study is among the first to qualitatively explore the perspectives of both children and young people undergoing treatment for cancer, and exercise professionals, on the use of an AR exercise app. By including feedback of end users and professionals, this study provides a holistic understanding of the usability and perspectives of implementing an AR app to support an individualised exercise programmes. Finally, the study contributes to an emerging area of research in the field of mHealth within paediatric oncology care, highlighting the potential and limitations of AR tools. The inclusion of feedback of both functionality and user experience enables practical recommendations for further technology development.

The evaluation of the AR app was based on a sub-study of a larger randomised clinical trial. As such, only a small subset (approx. 10%) of the total RCT participants took part in the semi-structured interviews evaluating the AR app. This may be explained by the fact that only selected study sites participated in the AR app subproject. Moreover, additional eligibility criteria (e.g., age restrictions) were applied, and the duration of the subproject was shorter than that of the overall RCT. Additionally, the number of study iPhones available at participating centres was limited, which may have contributed to the proportion of participants who were not offered access to the app. Furthermore, it is possible that the interview responses were affected by confirmation or social desirability bias and the presence of a parent/guardian may have also affected participant responses. Interviews were not audio-recorded and were conducted in the native language of each centre and translated into English, which may have resulted in some loss of nuance. Exercise professional feedback was collected via an online form in English and depending on the fluency of the respondents, some information may have been lost or misreported.

Conclusion

This study highlights the potential of novel AR technology to enhance engagement in exercise among children and young people undergoing cancer treatment. CAYA and exercise professionals reported the value of features including visual exercise demonstrations, and the opportunity to continue the exercise programme during home stays or away from a clinical setting. Feedback emphasised the importance of technological reliability with regards to the AR components, and suggested improvements, such as a customisable avatar, and gamified features. While AR offers promising benefits within paediatric oncology care, it must be integrated in a way to support and not replace face-to-face exercise interventions. Future development should focus on user-centred design, increased individualisation, and equity of access for CAYA with cancer and their families. Additionally further research is needed to evaluate long-term engagement and clinical outcomes.

Data availability statement

The datasets presented in this article are not readily available because the data will be available from the corresponding author upon reasonable request. Requests to access the datasets should be directed to Eila Watson - ewatson@brookes.ac.uk.

Ethics statement

The studies involving humans were approved by the FORTEe study protocol and all related documents were approved by the Ethics Committee of the Medical Chamber of Rhineland-Palatinate under the application number 2021- 15904 on 04.08.2021 as well as the local ethic committees of all FORTEe trial sites and reviewed by the local data protection officer. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

HM: Writing – original draft, Writing – review & editing, Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration. AS-S: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. SW: Conceptualization, Methodology, Writing – review & editing. KS: Conceptualization, Methodology, Writing – review & editing. MN: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing. ED: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing. FL: Resources, Supervision, Writing – review & editing. EV: Investigation, Writing – review & editing. JW: Resources, Supervision, Writing – review & editing. NB: Investigation, Writing – review & editing. MG: Resources, Supervision, Writing – review & editing. RB: Investigation, Writing – review & editing. FS: Resources, Supervision, Writing – review & editing. WZ: Investigation, Writing – review & editing. PW: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision, Writing – review & editing. JF: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing. EW: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 945153. This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

Acknowledgments

We sincerely thank all participants who took part in this study and therefore made this work possible. Our gratitude also goes to the members of the FORTEe consortium for their ongoing support of this work. We are especially grateful to the following consortium partners for their great efforts in the AR subproject: Lena Wypyrsczyk, Mareike Kuehn, Tommaso Moriggi, Eleonora Corti, Linda Peli, Marco Chisari

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

References

1. Klimczak KS, Levin ME. Mobile health. In: Friedman-Wheeler DG, Wenzel A, editors. *The Sage Encyclopedia of Mood and Anxiety Disorders*. Thousand Oaks, CA: SAGE Publications, Inc. (2025). p. 783–7. doi: 10.4135/9781071886229.n278

2. Gentili A, Failla G, Melnyk A, Puleo V, Tanna GLD, Ricciardi W, et al. The cost-effectiveness of digital health interventions: a systematic review of the literature. *Front Public Health*. (2022) 10:787135. doi: 10.3389/fpubh.2022.787135

3. Edwards J, Waite-Jones J, Schwarz T, Swallow V. Digital technologies for children and parents sharing self-management in childhood chronic or long-term conditions: a scoping review. *Children (Basel)*. (2021) 8:1203. doi: 10.3390/children8121203

4. Cheung AT, Li WHC, Ho LLK, Ho KY, Chan GCF, Chung JOK. Physical activity for pediatric cancer survivors: a systematic review of randomized controlled trials. *J Cancer Surviv*. (2021) 15:876–89. doi: 10.1007/s11764-020-00981-w

5. Ramsey WA, Heidelberg RE, Gilbert AM, Heneghan MB, Badawy SM, Alberts NM. Ehealth and mHealth interventions in pediatric cancer: a systematic review of interventions across the cancer continuum. *Psychooncology*. (2020) 29:17–37. doi: 10.1002/pon.5280

6. Jibb LA, Cafazzo JA, Nathan PC, Seto E, Stevens BJ, Nguyen C, et al. Development of a mHealth real-time pain self-management app for adolescents with cancer: an iterative usability testing study [formula: see text]. *J Pediatr Oncol Nurs*. (2017) 34:283–94. doi: 10.1177/1043454217697022

7. Vaughn J, Shah N, Jonassaint J, Harris N, Docherty S, Shaw R. User-centered app design for acutely ill children and adolescents. *J Pediatr Oncol Nurs*. (2020) 37:359–67. doi: 10.1177/1043454220938341

8. Kim Y, Seo J, An S-Y, Sinn DH, Hwang JH. Efficacy and safety of an mHealth app and wearable device in physical performance for patients with hepatocellular carcinoma: development and usability study. *JMIR Mhealth Uhealth*. (2020) 8: e14435. doi: 10.2196/14435

9. Groarke JM, Richmond J, Mc Sharry J, Groarke A, Harney OM, Kelly MG, et al. Acceptability of a mobile health behavior change intervention for cancer survivors with obesity or overweight: nested mixed methods study within a randomized controlled trial. *JMIR Mhealth Uhealth*. (2021) 9:e18288. doi: 10.2196/18288

10. Berg CJ, Stratton E, Esiashvili N, Mertens A. Young adult cancer survivors' experience with cancer treatment and follow-up care and perceptions of barriers to engaging in recommended care. *J Cancer Educ*. (2016) 31:430–42. doi: 10.1007/s13187-015-0853-9

11. Roy I, Salles J, Neveu E, Lariviére-Bastien D, Blondin A, Levac D, et al. Exploring the perspectives of health care professionals on digital health technologies in pediatric care and rehabilitation. *J Neuroeng Rehabil*. (2024) 21:156. doi: 10.1186/s12984-024-01431-9

12. Iqbal AI, Aamir A, Hammad A, Hafsa H, Basit A, Oduoye MO, et al. Immersive technologies in healthcare: an in-depth exploration of virtual reality and augmented reality in enhancing patient care, medical education, and training paradigms. *J Prim Care Community Health*. (2024) 15:21501319241293311. doi: 10.1177/21501319241293311

13. Mendoza-Ramírez CE, Tudon-Martinez JC, Félix-Herrán LC, Lozoya-Santos JdJ, Vargas-Martínez A. Augmented reality: survey. *Appl Sci*. (2023) 13:10491. doi: 10.3390/app131810491

14. Liszio S, Bäuerlein F, Hildebrand J, van Nahl C, Masuch M, Basu O. Cooperative virtual reality gaming for anxiety and pain reduction in pediatric patients and their caregivers during painful medical procedures: protocol for a randomized controlled trial. *JMIR Res Protoc*. (2025) 14:e63098. doi: 10.2196/63098

15. Al-Ansi AM, Jaboob M, Garad A, Al-Ansi A. Analyzing augmented reality (AR) and virtual reality (VR) recent development in education. *Soc Sci Humanit Open*. (2023) 8:100532. doi: 10.1016/j.ssaho.2023.100532

16. Oh H, Son W. Cybersickness and its severity arising from virtual reality content: a comprehensive study. *Sensors (Basel)*. (2022) 22:1314. doi: 10.3390/s22041314

17. Straun K, Marriott H, Solera-Sanchez A, Windsor S, Neu MA, Dreismickenbecker E, et al. The development of an augmented reality application for exercise prescription within paediatric oncology: app design and protocol of a pilot study. *Health Informatics J*. (2024) 30:14604582241288784. doi: 10.1177/14604582241288784

18. Neu MA, Dreismickenbecker E, Lanfranconi F, Stössel S, Balduzzi A, Wright P, et al. Get strong to fight childhood cancer - an exercise intervention for children and adolescents undergoing anti-cancer treatment (FORTEe): rationale and design of a randomized controlled exercise trial. *BMC Cancer*. (2025) 25:1275. doi: 10.1186/s12885-025-14489-y

19. Kuckartz U. Qualitative Text Analysis: A Guide to Methods, Practice & Using Software (2014). Available online at: https://www.academia.edu/89311675/Qualitative_Text_Analysis_A_Guide_to_Methods_Practice_and_Using_Software (Accessed July 10, 2025).

20. Mayring P. Qualitative content analysis. *Forum Qual Soc Res*. (2000) 1(2):Art. 20. doi: 10.17169/fqs-1.2.1089

21. Morales JS, Valenzuela PL, Velázquez-Díaz D, Castillo-García A, Jiménez-Pavón D, Lucia A, et al. Exercise and childhood cancer—a historical review. *Cancers (Basel)*. (2022) 14:82. doi: 10.3390/cancers14010082

22. Skeens MA, Jackson DI, Sutherland-Foggio MS, Sezgin E. Mhealth apps in the digital marketplace for pediatric patients with cancer: systematic search and analysis. *JMIR Pediatr Parent*. (2024) 7:e58101. doi: 10.2196/58101

23. Ha L, Nevin SM, Wakefield CE, Jacovou J, Mizrahi D, Signorelli C. Exploring childhood cancer survivor, parent, healthcare and community professionals' experiences of, and priorities for, using digital health to engage in physical activity: a mixed methods study. *J Cancer Surviv*. (2024) 19:1403–18. doi: 10.1007/s11764-024-01560-z

24. Radesky JS, Schumacher J, Zuckerman B. Mobile and interactive media use by young children: the good, the bad, and the unknown. *Pediatrics*. (2015) 135:1–3. doi: 10.1542/peds.2014-2251

25. Lee J, Su Z, Chen Y. Mobile apps for children's health and wellbeing: design features and future opportunities. *AMIA Annu Symp Proc*. (2024) 2023:1027–36.

26. Apps J, Webb S, Hutton E. Parents' and carers' attitudes to the use of digital technology and its role in the care of children with complex needs. *Br J Occup Ther*. (2024) 87:452–60. doi: 10.1177/03080226241233112

27. Giebel GD, Speckemeier C, Abels C, Plescher F, Börchers K, Wasem J, et al. Problems and barriers related to the use of digital health applications: scoping review. *J Med Internet Res*. (2023) 25:e43808. doi: 10.2196/43808

28. Ajit G. A systematic review of augmented reality in STEM education. *Stud Appl Econ*. (2021) 39:1–19. doi: 10.25115/eea.v39i1.4280

29. Wang J-W, Zhu Z, Shuling Z, Fan J, Jin Y, Gao Z-L, et al. Effectiveness of mHealth app–based interventions for increasing physical activity and improving physical fitness in children and adolescents: systematic review and meta-analysis. *JMIR Mhealth Uhealth*. (2024) 12:e51478. doi: 10.2196/51478

30. Yang J, Casey A, Cale L. The influence of healthy lifestyle technologies on young people's physical activity participation and health learning: a systematic review. *Quest*. (2024) 76:72–92. doi: 10.1080/00336297.2023.2218038

31. Choe EK, Abdullah S, Rabbi M, Thomaz E, Epstein DA, Cordeiro F, et al. Semi-Automated tracking: a balanced approach for self-monitoring applications. *IEEE Pervasive Comput*. (2017) 16:74–84. doi: 10.1109/MPRV.2017.18

32. Fortier MA, Chung WW, Martinez A, Gago-Masague S, Sender L. Pain buddy: a novel use of m-health in the management of children's cancer pain. *Comput Biol Med*. (2016) 76:202–14. doi: 10.1016/j.compbiomed.2016.07.012

33. Franco M, Monfort C, Piñas-Mesa A, Rincon E. Could avatar therapy enhance mental health in chronic patients? A systematic review. *Electronics (Basel)*. (2021) 10:2212. doi: 10.3390/electronics10182212

34. Willinger L, Schweizer F, Böhm B, Scheller DA, Jonas S, Oberhoffer-Fritz R, et al. Evaluation of the gamified application KIJANI to promote physical activity in children and adolescents: a multimethod study. *Digital health*. (2024) 10:20552076241271861. doi: 10.1177/20552076241271861

35. Ross WL, Le A, Zheng DJ, Mitchell H-R, Rotatori J, Li F, et al. Physical activity barriers, preferences, and beliefs in childhood cancer patients. *Support Care Cancer*. (2018) 26:2177–84. doi: 10.1007/s00520-017-4041-9

Appendix A. FORTEe sub-project recruiting centres:

Oxford University Hospitals Foundation NHS Trust in collaboration with Oxford Brookes University (UK), Childhood Cancer Center of the University Medical Center of the Johannes Gutenberg-University Mainz (Germany) & Heidelberg University Hospital (Germany), Fondazione Monza e Brianza per Il Bambino e La Sua Mamma, Monza (Italy) & IRCCS National Cancer Institute Foundation (Italy)

Appendix B. Interview questions with prompts

Question 1 - What did you like about the AR app?
Question 2 - What did you not like about the AR app?

Interview topic prompts:

- Avatar design
- Exercise demonstrations
- AR technology [avatar (not) appearing]
- App interface (design, colours, font)
- What kind of avatar would be preferred
- Equipment (iPhone, tripod, accessories provided)
- The amount of exercises in the workouts (too intense or easy?)
- The types of exercises in the workouts
- The exercise diary (being able to check their workout history)
- Being able to take the phone home

Research Article

Health Informatics Journal

Health Informatics Journal
1–16

Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/14604582241288784
journals.sagepub.com/home/jhi
Sage

The development of an augmented reality application for exercise prescription within paediatric oncology: App design and protocol of a pilot study

Kim Straun
School of Sport, Nutrition and Allied Health Professions, Oxford Brookes University, Oxford, UK

Hayley Marriott
School of Sport, Nutrition and Allied Health Professions, Oxford Brookes University, Oxford, UK

Alba Solera-Sanchez
School of Sport, Nutrition and Allied Health Professions, Oxford Brookes University, Oxford, UK

Stan Windsor
Department of Sport and Health Science and Social Work, Oxford Brookes University, Oxford, UK

Marie A. Neu
Department of Pediatric Hematology/Oncology, Center for Pediatric and Adolescent Medicine, University Medical Center of the Johannes Gutenberg-University Mainz, Mainz, Germany

Elias Dreismickenbecker
Department of Pediatric Hematology/Oncology, Center for Pediatric and Adolescent Medicine, University Medical Center of the Johannes Gutenberg-University Mainz, Mainz, Germany

Joerg Faber
Department of Pediatric Hematology/Oncology, Center for Pediatric and Adolescent Medicine, University Medical Center of the Johannes Gutenberg-University Mainz, Mainz, Germany

Corresponding author:
Alba Solera-Sanchez, Department of Sport and Health Science and Social Work, Oxford Brookes University, Headington Rd., OX3 0BP, Oxford, United Kingdom.
Email: asolera-sanchez@brookes.ac.uk

Peter Wright and on behalf of the FORTEe consortium
School of Sport, Nutrition and Allied Health Professions, Oxford Brookes University,
Oxford, UK

Abstract

Background: Children and young people with cancer face barriers when engaging with exercise, such as treatment-related side effects, psychosocial burdens and lack of individualised provisions. Digital health tools, such as smartphone applications, have emerged as a promising driver to support healthcare provisions in exercise prescription among patients. It is vital to explore how such technologies can be developed more effectively in order to strengthen the evidence supporting their use and for more appropriate implementation within healthcare. This study aims to explore user experiences, preferences and suggested improvements from healthy children and young people aged 9-21 years. **Methods:** An augmented reality (AR) application was specifically developed for children and young people aged 9-21 years undergoing cancer treatment and a protocol for a pilot study was designed. The target sample of this pilot study is 90 healthy children and young people aged 9-21 years. Practical 30-min workshops will be conducted encouraging participants to engage with the smartphone app. Focus groups will explore participant experiences, preferences, and suggested improvements. Data will be analysed deductively with apriori themes derived from the semi-structured interviews. **Discussion:** Obtaining user experiences, preferences and suggested improvements is especially important for the development of novel apps, such as those prescribing exercise and using algorithms and augmented reality software. Results from this study will directly influence the development of an augmented reality application, which will also be applied within a long-term trial in paediatric oncology.

Keywords
mobile health, exercise, rehabilitation, health intervention, paediatric oncology

Introduction

Within society, it is now widely accepted that mobile phones are a ubiquitous commodity.[1–3] As a result, there has been a noticeable rise in the prevalence of mobile health (mHealth) focused interventions, with almost 83% of clinicians now using smart devices or medical apps.[4] The proliferation of mHealth technology has aided the development of smart apps as an effective medium for the delivery of digital health in several long-term health conditions such as asthma,[5] mental health conditions,[6] obesity,[7] and cancer.[8] mHealth, and more specifically digital health provisions, are continuing to gain traction as a contextually appropriate and accessible way to improve health-related behaviours for young people living with chronic diseases.[9–11]

Moreover, the emerging role of mHealth within cancer treatment is notable[12] with adherence and access to preoperative rehabilitation and rehabilitation considered the largest barriers for people suffering from the disease.[13] Paediatric oncology is also emerging as a focus within mHealth research,[14,15] often highlighting that paediatric populations undergoing cancer treatment have significantly lower health-related quality of life outcomes than other long-term health conditions populations.[16] Exercise has been shown to increase health related quality of life, strength and aerobic fitness and decrease fatigue.[17] However, paediatric oncology patients report additional barriers to exercise when compared to healthy age matched peers, such as fatigue, fear of injury, overprotective attitudes and lack of provisions in clinical and community settings.[18,19] A reduction in physical activity (PA) levels are almost always observed in childhood cancer patients,[20–22] with safety concerns surrounding PA persisting into survivorship.[23] These challenges have been exacerbated in recent years by the COVID-19 pandemic. In many cases, by immunocompromised children have faced stricter levels of precaution and constraints including longer periods of isolation, a greater lack of physical education resulting from school closures and the sudden termination of community-based exercise provisions.[14] Due to these particular barriers it is increasingly important to consider different mediums to deliver health-related behaviour change interventions.

Current literature has explored different tools for mHealth within paediatric rehabilitation[24] and paediatric oncology rehabilitation,[25] both with limited evidence of effectiveness. The main driver for digital health within the field of paediatric oncology exercise rehabilitation is cited as a lack of training and knowledge among healthcare professionals, such as nurses[26] to promote exercise participation. The development of a digital health that uses algorithmic prescription methodology could present a significant cost saving to health services.[27]

Previous work has highlighted that children and young people spend much of their time on screen-based activities,[28,29] with increases in total and leisure screen time observed during the COVID-19 pandemic.[30] However, user adherence and motivation to engage with mHealth has still been found to be low.[3] Existing suggestions for reducing the lack of adherence within oncology include elements of gamification to digital health solutions.[31] These have included, but not limited to; virtual reality[32] as well as tracking and progression charts[33] also implemented within mobile devices, such as in the form of smartphone applications (i.e. apps). Other literature has suggested the development of avatars to be an effective gamification technique to improve young people user adherence to a digital tool.[34,35] Literature has also suggested that Augmented Reality (AR) can be an effective mode of delivery for mHealth interventions[36] such as when implemented within smartphone apps.

Challenges while developing technology within child health (i.e., the present AR app and its exercise prescription algorithm) need solutions.[37] It is imperative to explore functionality and usability prior to assessing contextual user experiences and performance when implemented among paediatric oncology patients. Evidence has highlighted the difficulty of comparing healthy children with clinical immunocompromised peers who face stricter levels of precaution and constraints.[38] Nevertheless, it has been shown that healthy age-compatible peers have been successfully compared, for example, in several studies of social functioning,[39,40] and healthy peers are expected to provide comparable and meaningful insights into general user experience and functionality.

Therefore, the current study aims to explore healthy user's feedback of a smartphone app using an AR avatar to develop more effective technologies aiming to prescribe a structured exercise rehabilitation programme for paediatric oncology patients undergoing treatment.

Methods

The AR app to be tested in the described pilot study is novel and has been developed specifically for this research, as no other comparable apps are currently commercially available. Therefore, a comprehensive overview of the app development process as well as the design and functionality of the app is provided below. This work was supported by Horizon 2020, the European Union's research and innovation programme, as part of grant agreement no. 945153. This reflects only the author's view, and the European Commission is not responsible for any use that may be made of the information it contains.

For the reporting of methods to be applied within the pilot study, the 32-item Consolidated Criteria for Reporting Qualitative Research (COREQ) checklist will be used.[41]

AR app development

Development process. The AR app was specifically developed for children and young people aged 9-21 years undergoing cancer treatment. However, for the previous AR app evaluation the present study will be carried out in healthy children and young people. The app's main functionality is to support the performance of exercise sessions to promote physical and mental health via an algorithm prescribing exercise. During the development process, an interdisciplinary team of software developers, academics specialising in digital health and exercise professionals in paediatric oncology collaborated to design a child-friendly and user-centred app. Due to previous concerns with data protection and privacy within digital health tools,[42] the app was designed to operate offline.

Initially, the development process consisted of an exploration of existing mobile apps supporting exercise performance for children and young people, followed by an assessment of user needs within the target population. This included the following factors for consideration within the exercise prescription algorithm: user mental and physical health parameters, including fatigue and physical capability. Following this, an initial algorithm structure was generated and initial theoretical testing performed (i.e. confirmation of logical flow within the algorithm). As the app was planned to be used both during intensive treatment and during aftercare/maintenance treatment phases, the algorithm was then split into two separate functions. This process allowed for the specific parameters of the respective treatment phases, such as treatment schedule, clinician support and predicted physical and mental capabilities of users, to be considered. Several personas were designed to test the suitability of the algorithm for the two treatment phases[43] to ensure user input appropriately informed algorithm functionality and the respective exercise prescription was deemed safe and effective by the paediatric oncology exercise professionals.

App design and functionality

The AR app enables the user to perform strength-based exercise sessions with animated avatars in an AR setting. The virtual avatar performs the respective exercises on the screen of the device whilst the participant follows the prescribed workout. The app uses the above-mentioned algorithm to select or exclude exercises as well as generate the exercise prescription (volume and intensity) based on the input provided by a trained exercise professional and study participant. To enable the algorithm to accurately prescribe exercise, it was programmed to include initial on-boarding questionnaires to be completed by an exercise professional and the app user. This process also involves a low-level functional test performed by the user. The algorithm is programmed to adapt the exercise prescription based on the user's input, with rest days recommended should participation not be deemed safe or appropriate (e.g. due to recent hospital treatment, new infection or pain symptoms). Figure 1 demonstrates an overview of the on-boarding process for the aftercare/maintenance treatment functionality within the app, which was used during testing as part of this current study.

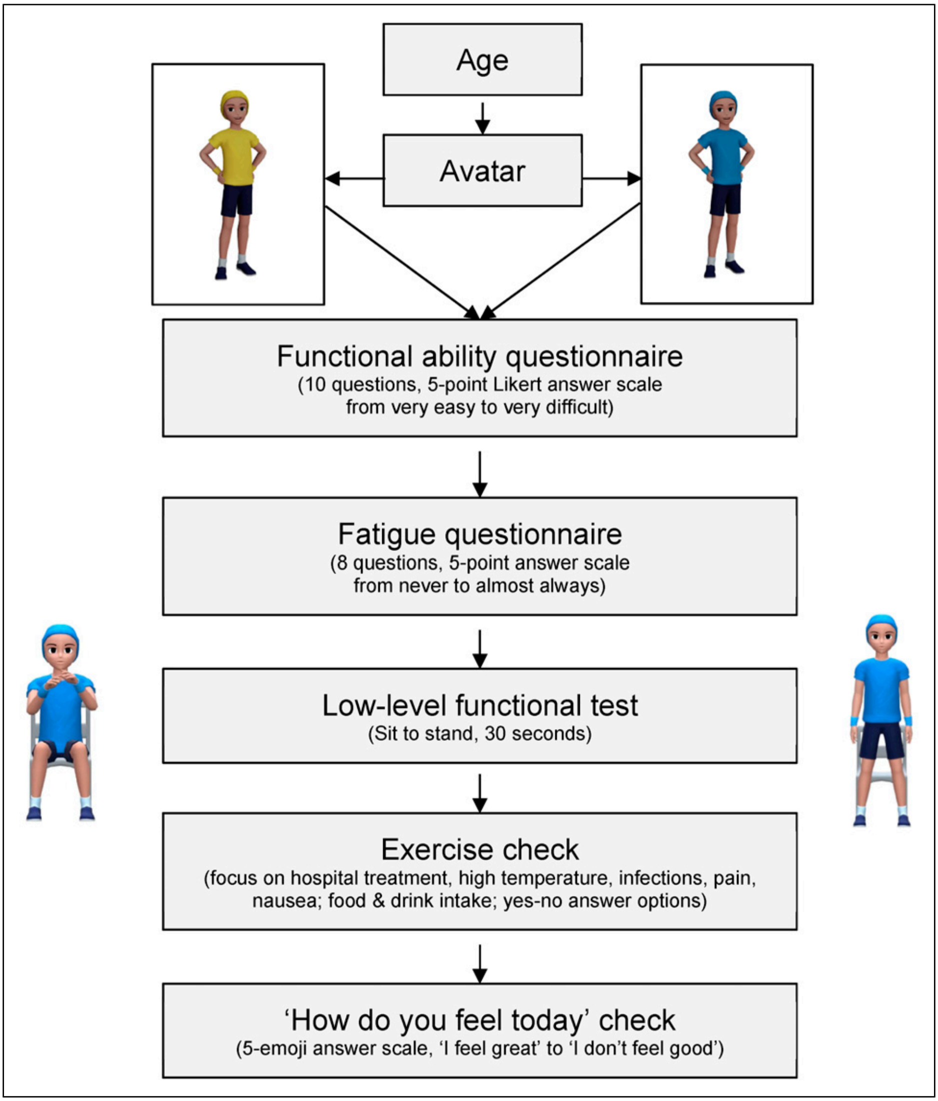


Figure 1. App onboarding process for aftercare/maintenance treatment functionality.

As the app was designed to be operated independently by users as well as those with potentially limited experience of engaging with digital health tools, a clean layout and clear colour, font and image options were chosen. Figure 2 contains a set of example screens from the app's maintenance/aftercare treatment functionality.

Recruitment and setting

Participants will be selected using convenience sampling. Participants are eligible if they are in year 4, five or six of primary school (ages 8-11), year 7, eight or 9 (ages 11-14) or sixth form within

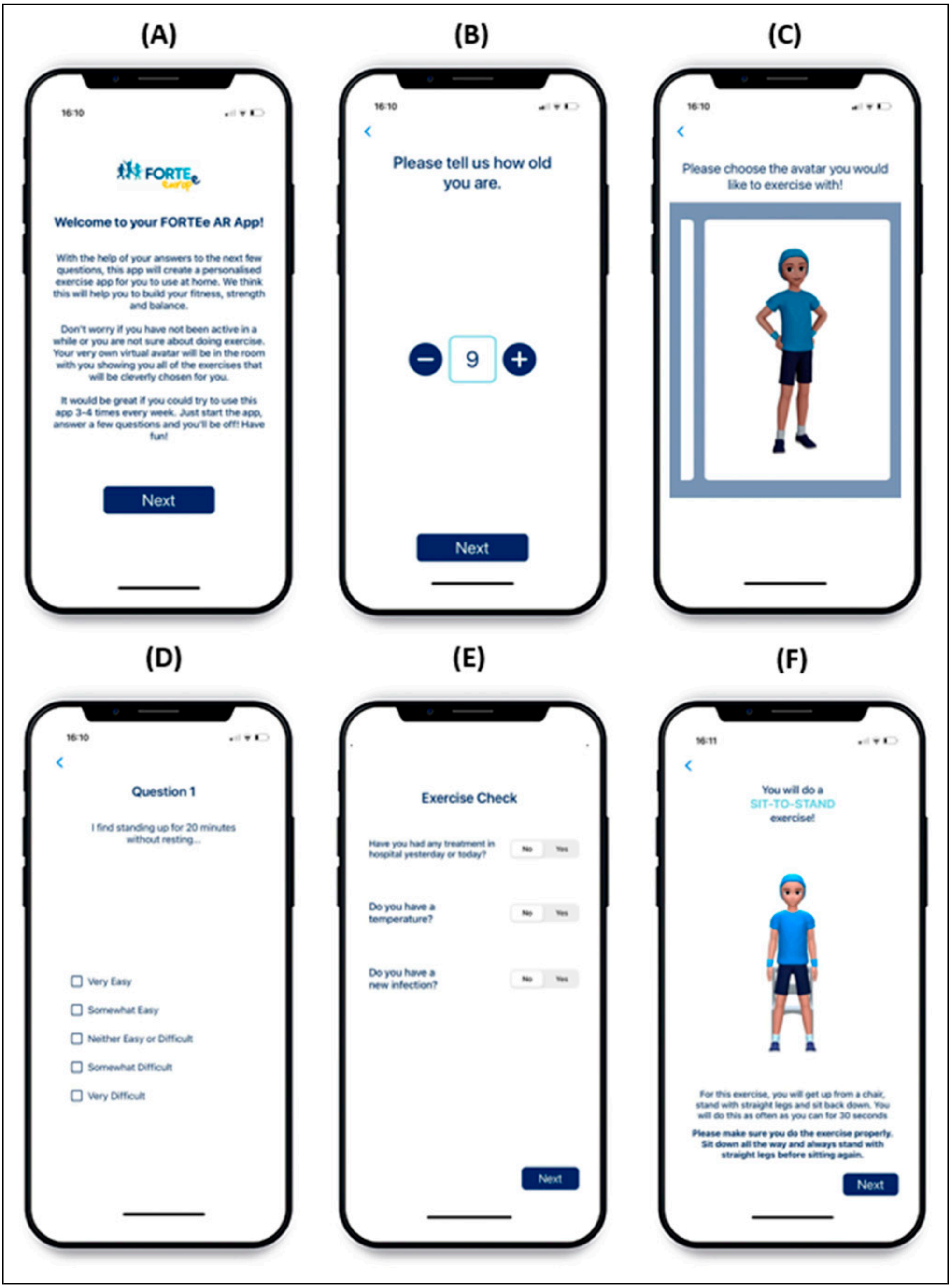


Figure 2. App onboarding example screens. (a) Welcome screen, (b) age selection, (c) avatar selection, (d) questionnaire example screen, (e) pre-exercise checklist, (f) fitness test.

secondary school (ages 16-18) or if they are year 1, two or three undergraduate students (ages 19-21). Participants also have to speak sufficient English to understand and engage with written and verbal instruction and will be able to take part in 30 min of low to moderate bodyweight exercises. All children and young people fulfilling the eligibility criteria and wishing to participate in the study, will be included. The eligibility criteria are gathered in Table 1.

The primary and secondary school have had previous contact with the research team, however had not previously been involved with any research projects. The University that will be used for the recruitment of young adults was the employing university of staff conducting this study. None of the recruited participants will have had any previous engagement with or experience of the augmented reality app. During the recruitment process for primary school age participants, the team will be in contact with the relevant school and teachers providing potential participants with study information. For secondary school age participants, visits to the school will take place in order to speak to potential participants about the study aims and process of taking part in the workshops and focus groups. During the recruitment of university students, the team will attend a sample of lectures from modules in which the identified cohort will be attending to provide study information. It will be reiterated that participation is voluntary and not a requirement of their academic course. One member of the team has been specifically selected for this role as they are not involved in any assessments, supervision or academic advising of students within the relevant cohort. Modules that are not currently led by any member of staff within the research team will be selected for student recruitment.

Potential participants will be handed information sheets, consent forms and data privacy notes to support their consideration of taking part in the study. For participants under the age of 16, participant assent and parent/guardian consent will be sought, with only direct participant consent sought for participants aged 16 and over. All participants will have at least 48 h to consider their participation and will be given contact details of one of the researchers in case they have any questions or concerns. Only participants/guardians that provided valid written consent participated in the study.

The table below contains an overview of the target participant numbers per recruited year group. The selection of an appropriate number of focus groups for qualitative studies has often been a topic for debate, with no clear and consistent guidance in place and varying explanations within the literature for justifying the specific number of groups used.[44] However, it has been proposed that the number of focus groups needed depends on a variety of factors, such as the purpose of the study, the type of expected findings, group stratification as well as type and degree of saturation.[45] In the present study, the purpose of the study will be to identify key elements for positive user experience and to highlight practical suggestions for incorporating user preferences. In addition, the type of codes herein will be more explicit, with a focus on code saturation over meaning saturation. Moreover, focus groups will be stratified by year groups within the individual recruitment

Table 1. Eligibility criteria.

Children and young people in
- Years 4, 5, 6, 7, 8, 9 of primary school and secondary school, aged 8-14 years old
- Sixth form in secondary school, aged 16-18 years old
- University, aged 19 to 21 years old
Proficient in the English language
Able to take part in a session up to 30 min of low-moderate intensity body weight exercises

institutions. Thus, a smaller number of focus groups is expected to be sufficient to address the study aims whilst also considering recruitment feasibility and reducing unnecessary participant burden (i.e., recruiting more participants than necessary to fulfil the study aims).[45] The target participant numbers per institution are shown in Table 2.

Data collection

To obtain user feedback on the functionality and design of the app as well as suggested improvements, workshops and focus group discussions will be conducted. During the workshops, participants will use the intensive phase functionality of the app. For the purpose of this explorative study of a novel app, healthy participants will be used. Research Assistants with comprehensive experience of working with children and young people and skilled in qualitative data collection, will facilitate all workshops and focus groups. For the workshops, both research assistants will complete the non-user facing onboarding process to ensure participants can engage with the main features of the app, regardless of their lack of cancer diagnosis. This will include pre-selecting the following: all body parts can be exercised; users will not exclusively exercise sitting down; users do not have a prosthetic limb; users do not suffer from peripheral neuropathy. The phone will then be passed on to the respective participants, who will click through the user-facing on-boarding process shown in Figure 1. Following this, participants will engage with the prescribed exercise session and subsequent follow-up questionnaire which includes a Rating of Perceived Exertion scale.

Workshops and focus groups will be scheduled to each last up to 30 min. This is to ensure the study can be conducted with minimal interruption to school and university teaching schedules. One research assistant will lead the workshop sessions, with his/her colleague present to facilitate. For the focus groups, a semi-structured interview guide will be used. The questions are included in Table 3. All discussions will be audio recorded using two devices: dictaphone and mobile phone. Participants will be informed of the purpose of this process.

At the beginning of the individual workshops, participants will be receiving information about what the app is designed to do and who the target group is as well as informed that both research assistants had contributed to the development of the AR app. Participants will be actively encouraged to provide honest reflections on their impressions of the AR app to reduce social desirability and acquiescence bias. Participants will be reassured by the researchers that all feedback is valuable and will be taken on board during the subsequent development of app updates. During the recruitment and data collection process, a rapport will be established with potential participants to facilitate their involvement. As the aims of this research rely upon honest and open feedback on the AR app, whilst limiting pressure to respond favourably, the study team will focus on an informal and collegiate report between both research assistants and all potential participants.

Table 2. Target participant numbers per institution.

Institution	N
Primary school (year groups 4-6, ages 8-11)	25
Secondary school (year groups 7-9, ages 12-14)	25
Sixth form of secondary school (year Group 12-13, ages 16-18)	25
University students (ages 18-21)	15
Total	90

N = target number of participants.

Table 3. Semi-structured interview guide for focus groups.

Topic	Guiding questions
Smartphone application perceptions	What are your thoughts on using a smartphone app to help you do exercise? How do you feel about using an augmented reality app to support you to be more active? Which part of the app do you feel would help you the most in doing more exercise?
Exercise selection and prescription	Which exercises do you remember from the app? What did you think about the exercises that were selected for you? What do you think children who are your age (or younger or older) would think about these exercises?
Augmented reality avatar experiences	What did you think about the avatar? How did you find the avatar's demonstrations? Were there any problems with the avatar whilst you were using the app?
App usability	How do you feel about the phone we gave you for using the app? How did you find using the tripod that held the phone whilst you were exercising? Do you feel that the equipment you were using affected your experience in any way? How did you find answering the questionnaire questions on the phone?
Suggestions for improvement	How do you think the app could be improved? How else do you think we could help you be more active and do more exercise?

Data analysis

As methodological orientation, a descriptive approach will be applied, with a focus on data collection that fosters an open environment allowing participants to honestly and authentically share their perceptions of using an app for PA, exercise selection and prescription, experiences of using an AR avatar, usability of the app, and suggestions for improvement. Firstly, audio recordings of all focus groups will be transcribed using edited transcription. Due to the participants' age, it is expected that some may re-start sentences multiple times as well as frequently use filler words and non-verbal communication. Non-verbal communication, gestures and facial expressions are not expected to significantly contribute to or influence the perception of the participants' responses in this study. Thus, edited transcription is expected to be most suitable to maintain full meaning, whilst simultaneously editing the transcripts to a degree that facilitates subsequent analysis. To ensure familiarisation with the content, all focus groups will be transcribed manually, without the use of an external transcription service or software. Transcripts will be read and re-read multiple times during the analysis process.

Edited transcriptions will be printed into paper format, with the researchers collaboratively conducting the coding process. In the present study, data will be explored and coded using qualitative content analysis with a combination of techniques adapted from two approaches[46–48]: (1) the deductive category application, which uses a prior formulated coding framework based on theory or empirical literature for analysis; and (2) the inductive category formation, which focuses on developing codes coming from the data material itself. Initially, data will be coded deductively deriving from the semi-structured interview guide: hardware user experience, app interface, app design, AR functionality, avatar design, exercise prescription, questionnaire completion, perceived benefits. In a second step, all remaining quotes will be reviewed and coded inductively. Inter-coder conversations will be held to discuss potential development of new categories from inductively coded comments or how these may fit within existing categories through establishing their explicit meaning.

For ensuring trustworthiness of the data collection and analysis processes, the study team will consider credibility, transferability, dependability and confirmability.[49] To ensure credibility, the present study will employ well-established methods for data collection and analysis, with specific protocols in place such as the use of consistent semi-structured interview guides, as well as use random sampling of participants from the respective institutions to ensure complete voluntary and un-coerced participation. Moreover, continued feedback and collaborative discussions will occur within the research team. Regarding transferability and dependability of data, the focus will be on providing thick descriptions and a comprehensive account of participant characteristics important for contextualising any resulting findings. This will allow other researchers to interpret data within its given context and transfer it to their own if applicable. To enhance confirmability of data, detailed descriptions of the applied methodology will be provided, its limitations, and their potential impact acknowledged.[49]

Discussion

This study will be among the first globally to explore user experiences, preferences and suggested improvements of a mobile AR app that uses algorithmic technology to prescribe exercise for childhood cancer patients and survivors. As healthcare systems are increasingly burdened, the use of mHealth to support digital health within clinical practice presents a unique opportunity for increasing access and cost savings,[50] while overcoming clinician time restraints and geographic barriers.[51] It is worth highlighting that the digitalisation of exercise interventions for long-term health conditions populations is a subject still little explored, however, digital interventions may provide an opportunity to supplement in-person interventions and act as a valuable adjunct to clinical care.[52] Digital interventions are scalable interventions that may increase accessibility for more individuals when compared to face-to-face interventions that are often limited by a reduced instructor to participant ratio.[53] The use of mHealth interventions may be of particular importance for a UK model of care as there is currently an overwhelming lack of PA provisions both within clinical and community settings for families affected by cancer.[1819] The development and implementation of such technologies is a promising prospect, however, there are significant complexities and challenges with regard to recruitment and engagement of patient groups and effective implementation.[54] A user-centred approach is recommended to ensure that preferences and needs are incorporated into mHealth tools.[16]

The availability of commercial mHealth apps has increased over recent years, with a peak during the COVID-19 pandemic in early 2021. Currently, there are 52,406 mHealth apps available in the Apple App Store[55] with 54,603 available in the Google Play Store.[56] Research has also increasingly focused on evaluating such apps, with 1712 papers published since 2000 focusing on mHealth and eHealth interventions related to PA, sedentary behaviour and diet.[57] Specifically, over 500 have been published exploring the use of gamification/games or mobile apps/smartphones.[57] Despite such apps being widely available and widely researched, gaps in the literature remain. It has been established that when evaluating mHealth tools such as apps, appropriate methodologies need to be chosen in line with the respective evaluation aims.[58] Existing research evaluating app interventions has mainly focused on assessing usage logs or employing questionnaires.[59] Few studies used interviews or focus groups, which are vital for obtaining in-depth qualitative data on user experiences and suggested improvements, especially during the early stages of development.[59]

Therefore, the current study will provide vital evidence to progress current trends in app development for clinical populations, such as cancer patients.

As the proposed study involves the evaluation of a novel app, it is crucial to perform usability testing in controlled laboratory conditions before assessing its commercial use and efficacy on a wider scale.[58] As part of this methodological approach, supervised use of the app (e.g., in the form of workshops) followed by gathering data exploring user experiences is deemed appropriate. It has been recognised that a variety of users from different population groups should be involved in the evaluation of user-centred mHealth tools.[60] It has also been recommended that applying methodologies focused on more controlled environments (i.e. testing an app in a laboratory setting) is a useful process, prior to allowing users to test the app in daily life.[60]

As this study involves children and young people, using qualitative methods to explore their views and preferences on the app interface and its functions will be crucial to obtain in-depth data as well as leave room for unintended or unexpected results to be discussed. Considering the young age of primary school children and their potentially limited experience of using a smartphone app, the current study methodology allows for some variation and flexibility that prioritises the collection of meaningful data over standardisation across the different age groups.[60] Data gathered as part of this study will be used to directly inform future development of the app and is also expected to contribute to advancing the empirical evidence base used for the design of future health-related apps, within both adult and paediatric care.

Limitations

In this formative study, age-matched, healthy participants will be used. This is, in part, due to the complexity of recruiting immunocompromised individuals in a group setting. While feedback on the app's functionality is expected to be comparable between cancer patients and healthy age matched peers, there may be differences in the usability of the app between these two populations. It is acknowledged that paediatric cancer patients will have a unique intention and motivation in regard to being physically active, whilst also having specific physical and cognitive performance needs and preferences. Whilst the app's onboarding process (see Figures 1 and 2) is specific to cancer patients, and its components thus more familiar to this population, the main aims of this study were to explore the functionality and usability of the app with a focus on the user experience of navigation, layout, instructions, and AR exercise demonstrations. It is expected that informing participants in this study of the discrepancy between their own experiences and the relevance of certain features for paediatric oncology patients will allow for meaningful insights into user experiences of children and young people. It has been suggested that it is particularly important to ensure current developments in digital health are relevant to the target user groups, such as cancer patients. Users who see the relevance of such tools within their treatment pathways are expected to be more likely to engage with these technologies, for example for self-management of their condition. Moreover, mHealth tools need to be applicable and relevant also within the daily life of its users,[59] further underlining the importance of future user testing with paediatric oncology patients in a real-world setting.[59]

Further, the app is designed for users to engage multiple times per week over the course of weeks or months, depending on their cancer treatment. Whilst the current study will not investigate the use of the app over a number of weeks and instead during a one-off workshop, it will provide foundational data to inform future work focusing on longer term use. Such studies will also allow exploring longer term adherence and barriers for regular participation, currently not included in the present study. To better understand the long-term effectiveness of AR apps, changes in behaviour (including exercise participation) and health outcomes (including cancer-related fatigue) should be more closely investigated.

Furthermore, it is also important to consider that user-centred design should extend to other interest groups, such as families, healthcare professionals and industry partners.[61] It is crucial to include those involved in the multidisciplinary approach within oncology care for optimal integration of technologies within clinical settings. It is for this reason that the involvement of wider interest groups should be strongly considered in the early stages of future research and technology development.

Another limitation is that the onboarding questions are not validated questionnaires, but are designed specifically for the app; their purpose is not to measure a specific outcome in a validated way, but rather to elicit answers to a limited number of basic 'check-up' questions. This enables the algorithm embedded within the application to automatically prescribe tailored exercises.

Conclusions

The findings of this study will provide invaluable information about user experiences, preferences and suggestions of healthy children and young people to improve an AR app prescribing exercise. User feedback gathered as part of the current research is important for informing the development of future mHealth tools such as apps and provides vital insights that can enhance the usability of and adherence to such tools. It is crucial to conduct user-centred, qualitative studies and use their findings to strengthen the current empirical evidence base on digital technology used within healthcare settings. The current study findings will influence future development of the AR app before this can be scaled up and employed during a longer-term randomised controlled trial involving childhood and young cancer patients.

Acknowledgements

We are grateful for the organisational support from Oxford Brookes University. Written informed consent and assent were required to participate in the project in accordance with the project approvals granted by the University Research Ethics Committee (registration number 211547).

Author contributions

All authors have made a substantial contribution to the article, read and approved the final version of the manuscript, and agree with the author's order of presentation.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 945153. This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

Ethical statement

Ethical approval

This research has received ethical approval from the Oxford Brookes University Faculty of Health and Life Sciences Research Ethics Committee (David E. Evans, Paul Hough, Robyn Curtis and Jo Brett) under the approval number of 211,547.

Informed consent

All participants and/or guardians provided written informed consent to participate in the study.

ORCID iDs

Kim Straun https://orcid.org/0000-0001-9776-9606
Alba Solera-Sanchez https://orcid.org/0000-0002-0683-0131

Supplemental Material

Supplemental material for this article is available online.

References

1. Barnes SJ, Pressey AD and Scornavacca E. Mobile ubiquity: Understanding the relationship between cognitive absorption, smartphone addiction and social network services. *Comput Human Behav* 2019; 90: 246–258.
2. Cook J, Pachler N and Bachmair B. Ubiquitous mobility with mobile phones: a cultural ecology for mobile learning. *E-Learn* 2011; 8(3): 181–195.
3. Mustafa AS, Ali N, Dhillon JS, et al. User engagement and abandonment of mHealth: a cross-sectional survey. *Healthcare (Basel)* 2022; 10(2): 221.
4. Inupakutika D, Kaghyan S, Akopian D, et al. Facilitating the development of cross-platform mHealth applications for chronic supportive care and a case study. *J Biomed Inform* 2020, Published online.
5. Ferrante G, Licari A, Marseglia GL, et al. Digital health interventions in children with asthma. *Clin Exp Allergy* 2021; 51(2): 212–220.
6. Jameel L, Valmaggia L, Barnes G, et al. mHealth technology to assess, monitor and treat daily functioning difficulties in people with severe mental illness: a systematic review. *J Psychiatr Res* 2021; 145: 35–49.
7. Lugones-Sánchez C, Recio-Rodríguez JI, Menéndez-Suárez M, et al. Effect of a Multicomponent mHealth intervention on the composition of diet in a population with overweight and obesity—Randomized clinical trial EVIDENT 3. *Nutrients* 2022; 14(2): 270.
8. Martin E, Di Meglio A, Charles C, et al. Use of mHealth to increase physical activity among breast cancer survivors with fatigue: qualitative exploration. *JMIR Cancer* 2021; 7(1): e23927.
9. Fedele DA, Cushing CC, Fritz A, et al. Mobile health interventions for improving health outcomes in youth: a meta-analysis. *JAMA Pediatr* 2017; 171(5): 461–469.
10. Lee JA, Choi M, Lee SA, et al. Effective behavioral intervention strategies using mobile health applications for chronic disease management: a systematic review. *BMC Med Inform Decis Mak* 2018; 18(1): 12.
11. Wickman K, Nordlund M and Holm C. The relationship between physical activity and self-efficacy in children with disabilities. *Sport Soc* 2018; 21(1): 50–63.
12. Tran C. The emerging role of mobile health in oncology. *J Target Ther Cancer* 2017; 6(3): 10.
13. Sanches EE, Aupers E, Sakran N, et al. Barriers and facilitators in rehabilitation in chronic diseases and after Surgery: is it a Matter of adherence? *Cureus* 2021; 13(12): e20173.

14. Cheung AT, Li WHC, Ho LLK, et al. Efficacy of mobile instant messaging–delivered brief motivational interviewing for parents to promote physical activity in pediatric cancer survivors: a randomized clinical trial. *JAMA Netw Open* 2022; 5(6): E2214600.
15. Mueller EL, Cochrane AR, Campbell ME, et al. An mHealth app to support Caregivers in the medical management of their child with cancer: Co-design and user testing study. *JMIR Cancer* 2022; 8(1): e33152.
16. Wiljén A, Chaplin JE, Crine V, et al. The development of an mHealth tool for children with long-term illness to enable person-centered communication: user-centered design approach. *JMIR Pediatr Parent* 2022; 5(1): e30364.
17. Rustler V, Hagerty M, Daeggelmann J, et al. Exercise interventions for patients with pediatric cancer during inpatient acute care: a systematic review of literature. *Pediatr Blood Cancer* 2017; 64(11): 50.
18. Viña CC, Wurz AJ and Culos-Reed SN. Promoting physical activity in pediatric oncology. Where do We Go from Here? *Front Oncol* 2013; 3: 3.
19. Yelton L and Forbis S. Influences and barriers on physical activity in pediatric oncology patients. *Front Pediatr* 2016; 4: 131.
20. Braam KI, Van Dijk-Lokkart EM, Kaspers GJL, et al. Cardiorespiratory fitness and physical activity in children with cancer. *Support Care Cancer* 2016; 24(5): 2259–2268. DOI: 10.1007/s00520-015-2993-1.
21. Kelly AKW. Physical activity prescription for childhood cancer survivors. *Curr Sports Med Rep* 2011; 10(6): 352–359. DOI: 10.1249/JSR.0B013E318237BE40.
22. Winter C, Müller C, Brandes M, et al. Level of activity in children undergoing cancer treatment. *Pediatr Blood Cancer* 2009; 53(3): 438–443.
23. Ross WL, Le A, Zheng DJ, et al. Physical activity barriers, preferences, and beliefs in childhood cancer patients. *Support Care Cancer* 2018; 26(7): 2177–2184.
24. Bonnechère B. Integration of exergaming in pediatric rehabilitation. *Belgian Journal of Paediatrics* 2021; 23(1): 23–25.
25. Sleurs C, Lemiere J, Vercruysse G, et al. Rehabilitation in pediatric oncology. *Belgian Journal of Paediatrics* 2021; 23(1): 35–38.
26. Okechukwu CE. Do oncology nurses have sufficient knowledge of exercise oncology? A mini narrative review. *Cancer Research Statistics and Treatment* 2021; 4(1): 88–92.
27. Rahimi K. Digital health and the elusive quest for cost savings. *Lancet Digit Health* 2019; 1(3): e108–e109.
28. Mears D and Hansen L. Technology in physical education article #5 in a 6-Part Series: active gaming: Definitions, options and implementation. *Strategies* 2009; 23(2): 26–29.
29. Owen N, Sparling PB, Healy GN, et al. Sedentary behavior: emerging evidence for a new health risk. *Mayo Clin Proc* 2010; 85(12): 1138–1141.
30. Trott M, Driscoll R, Irlado E, et al. Changes and correlates of screen time in adults and children during the COVID-19 pandemic: a systematic review and meta-analysis. *EClinicalMedicine* 2022; 48: 101452.
31. Von Bargen T, Zientz C and Haux R. Gamification for mHealth – a review of Playful mobile healthcare. *Stud Health Technol Inform* 2014; 202: 225–228.
32. Melillo A, Chirico A, De Pietro G, et al. Virtual reality rehabilitation systems for cancer survivors: a narrative review of the literature. *Cancers* 2022; 14(13): 3163.
33. Henshall C and Davey Z. Development of an app for lung cancer survivors (iEXHALE) to increase exercise activity and improve symptoms of fatigue, breathlessness and depression. *Psycho Oncol* 2020; 29(1): 139–147.
34. Bai S, Hew KF and Huang B. Does gamification improve student learning outcome? Evidence from a meta-analysis and synthesis of qualitative data in educational contexts. *Educ Res Rev* 2020; 30: 100322.

35. Deterding S, Dixon D, Khaled R, et al. From game design elements to gamefulness: Defining "gamification.". In Proceedings of the 15th International Academic MindTrek Conference. Envisioning Future Media Environments., 2011, pp. 9–15.
36. Manteghinejad A and Javanmard SH. Challenges and opportunities of digital health in a post-COVID19 world. *J Res Med Sci* 2021; 26(1): 11.
37. Mills N, Howsley P, Bartlett CM, et al. Overcoming challenges to develop technology for child health. *J Med Eng Technol* 2022; 46(6): 547–557.
38. Patenaude AF and Kupst MJ. Psychosocial functioning in pediatric cancer. *J Pediatr Psychol* 2005; 30(1): 9–27. DOI: 10.1093/JPEPSY/JSI012.
39. Noll RB, Leroy S, Bukowski WM, et al. Peer Relationships and Adjustment in children with cancer. *J Pediatr Psychol* 1991; 16(3): 307–326.
40. Noll RB, Bukowski WM, Davies WH, et al. Adjustment in the peer system of Adolescents with cancer: a two-year study. *J Pediatr Psychol* 1993; 18(3): 351–364.
41. Tong A, Sainsbury P and Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *Int J Qual Health Care* 2007; 19(6): 349–357.
42. Miah SJ, Gammack J and Najmul H. Design methodologies for M-health innovations: a content analysis. In Conference Proceedings: Australasian Conference on Information Systems, 2016.
43. Lopes A, Valentim N, Moraes B, et al. Applying user-centered techniques to analyze and design a mobile application. *J Softw Eng Res Dev* 2018; 6(1): 5.
44. Carlsen B and Glenton C. What about N? A methodological study of sample-size reporting in focus group studies. *BMC Med Res Methodol* 2011; 11(26): 26.
45. Hennink MM, Kaiser BN and Weber MB. What influences saturation? Estimating sample Sizes in focus group research. *Qual Health Res* 2019; 29(10): 1483–1496.
46. Kuckartz U. Qualitative Text analysis: a guide to methods, practice & using software. In: *Qualitative Text analysis: a guide to methods, practice & using software*. (Published online 25 February 2014).
47. Mayring P. Qualitative Inhaltsanalyse. In *Handbuch Qualitative Forschung in Der Psychologie*. VS Verlag für Sozialwissenschaften, 2010, pp. 601–613.
48. Proudfoot K. Inductive/deductive Hybrid Thematic analysis in Mixed methods research. *J Mix Methods Res* 2023; 17(3): 308–326.
49. Shenton AK. Strategies for ensuring trustworthiness in qualitative research projects. *Educ Inf* 2004; 22(2): 63–75.
50. Delemere E, Gitonga I and Maguire R. Utility, barriers and facilitators to the use of connected health to support families impacted by paediatric cancer: a qualitative analysis. *Support Care Cancer* 2022; 30(8): 6755–6766.
51. Moody L, Turner A, Osmond J, et al. Web-based self-management for young cancer survivors: consideration of user requirements and barriers to implementation. *J Cancer Surviv* 2015; 9(2): 188–200.
52. Ramsey RR, Plevinsky JM, Kollin SR, et al. Systematic review of digital interventions for pediatric asthma management. *J Allergy Clin Immunol Pract* 2020; 8(4): 1284–1293.
53. Marcu G, Ondersma SJ, Spiller AN, et al. The perceived Benefits of digital interventions for behavioral health: qualitative interview study. *J Med Internet Res* 2022; 24(3): e34300.
54. O'Connor S, Hanlon P, O'Donnell CA, et al. Understanding factors affecting patient and public engagement and recruitment to digital health interventions: a systematic review of qualitative studies. *BMC Med Inform Decis Mak* 2016; 16(1): 120.
55. Statista. *Number of mHealth apps available in the Google Play Store from 1st quarter 2015 to 2nd quarter 2022*. 2022.
56. Statista. *Number of mHealth apps available in the Apple App Store from 1st quarter 2015 to 2nd quarter 2022*. 2022. https://www.statista.com/statistics/779910/health-apps-available-ios-worldwide/ (Accessed 26 July 2023).

57. Müller AM, Maher CA, Vandelanotte C, et al. Physical activity, sedentary behavior, and diet-related ehealth and mhealth research: Bibliometric analysis. *J Med Internet Res* 2018; 20(4): e122.
58. Jake-Schoffman DE, Silfee VJ, Waring ME, et al. Methods for evaluating the content, usability, and efficacy of commercial mobile health apps. *JMIR Mhealth Uhealth* 2017; 5(12): e190.
59. Gejmzpjpjrphlåe BM. Methods and measures used to evaluate patient-operated mobile health interventions: Scoping literature review. *JMIR Mhealth Uhealth* 2020; 8(4): e16814.
60. Cornet VP, Toscos T, Bolchini D, et al. Untold Stories in user-centered design of mobile health: practical challenges and strategies learned from the design and evaluation of an app for older adults with heart failure. *JMIR Mhealth Uhealth* 2020; 8(7): e17703.
61. Dimitri P. Child health technology: Shaping the future of paediatrics and child health and improving NHS productivity. *Arch Dis Child* 2018; 104(2): 184–188.

Original Paper

Exploring User Experiences of an Augmented Reality Smartphone App Prescribing Exercise for Children and Young People With Cancer: Results From a Qualitative Study

Hayley Marriott[1*], MSc; Kim Straun[2*], PhD; Alba Solera-Sanchez[1], PhD; Eila Watson[3], Prof Dr; Stanley Windsor[1], PhD; Marie A Neu[4], Dr med; Elias Dreismickenbecker[4], MA; Joerg Faber[4], Prof Dr med; Peter Wright[1], Prof Dr

[1]School of Sport, Nutrition and Allied Health Professions, Oxford Brookes University, Oxford, United Kingdom

[2]School for Policy Studies, University of Bristol, Bristol, United Kingdom

[3]Oxford Institute of Applied Health Research, Oxford Brookes University, Oxford, United Kingdom

[4]Childhood Cancer Center Mainz, University Medical Center of the Johannes Gutenberg-University Mainz, Mainz, Germany

*these authors contributed equally

Corresponding Author:

Alba Solera-Sanchez, PhD
School of Sport, Nutrition and Allied Health Professions
Oxford Brookes University
Headington Road
Oxford OX3 0BP
United Kingdom
Phone: +44 01865484260
Email: asolera-sanchez@brookes.ac.uk

Abstract

Background: Mobile health (mHealth), and specifically smartphone apps, have grown exponentially in both functionality and accessibility and are becoming an important component of health care. Research exploring the use of mHealth for managing or treating chronic diseases, such as cancer, has shown promising effects. Yet, comparatively little work has examined how such technologies can enhance exercise interventions for young people with cancer. To optimize the effectiveness of mHealth in these contexts, it is essential to build a stronger evidence base on user experience.

Objective: This study aimed to investigate how healthy children and young people engaged with an augmented reality (AR) app developed specifically for children and young people undergoing cancer treatment, and to identify design features that may support engagement and behavior change in the intended clinical population.

Methods: School and university students, aged 8-21 years, were eligible to participate in the study. Practical workshops allowed participants to engage with the AR exercise app before taking part in focus groups to explore user experiences. Data were analyzed using qualitative content analysis, which also involved a critical friend approach using 2 researchers (HM and KS). Suggested improvements were mapped against the motivational affordances' taxonomy.

Results: A total of 39 participants aged 8-21 years took part in the focus group study. Participants found the demonstrations and varied exercises useful but expressed some concerns regarding data safety and functionality of the novel AR avatar. It was proposed that additional educational components, challenges, and rewards, as well as a customizable avatar, social support features, and audio instructions for a more inclusive design would be desirable and could enhance user experience. When mapped against the motivational affordances taxonomy, the suggested improvements aligned primarily with mechanisms of user education, challenges, feedback, cooperation, and comparison.

Conclusions: This study provides an understanding of how apps that prescribe exercise can be optimized to enhance motivation and user experience. By assessing feedback and suggestions for improvements, the findings highlight key design features that may support engagement. While this initial work focused on healthy, age-matched participants, further evidence specifically in children and young people with a childhood cancer diagnosis is needed.

International Registered Report Identifier (IRRID): RR2-10.1177/14604582241288784

JMIR Form Res 2026;10:e76855; doi: 10.2196/76855

Keywords: mHealth; AR; qualitative research; physical activity; exercise; childhood cancer; mobile health; augmented reality; mobile phone

Introduction

Over the past 50 years, chronic health conditions among children and young people have risen on a global scale [1]. Conditions such as cancer, type 2 diabetes, obesity, and mental health disorders are increasingly prevalent in this population, resulting in a substantial burden on health care systems [2]. Addressing this issue requires a comprehensive, multidisciplinary approach, incorporating preventive public health measures, early and targeted interventions, and health care systems that cater to the physical and psychological dimensions of chronic illnesses in children and young people [3]. The use of technologies within health care may offer an important role in the management of long-term conditions in pediatric populations [4].

Specific research in patients with cancer has reported that digital interventions have elicited positive outcomes, including improving adherence to medication [5], symptom management [6], physical activity levels [7], and mental well-being [8]. Digital tools can empower young patients to take an active role in their health management [9], as well as having the potential to alleviate some of the pressures (eg, staff shortages, limited capacity of services and facilities, and increased demand) on health care systems by supporting disease management outside of traditional clinical settings.

Children and young people undergoing treatment for cancer have some unique barriers to physical activity. These include (1) treatment-related side effects, such as fatigue and pain; (2) psychological barriers, such as fear of injury and low mood; and (3) organizational barriers, such as limited clinical space and lack of sports equipment during home stays [10].

Addressing these barriers requires accessible, personalized solutions. Digital interventions have grown exponentially in both functionality and accessibility, emerging as an increasingly important component of health care delivery [11]. Interventional evidence suggests that using mobile health (mHealth) tools can benefit those managing chronic conditions, such as cancer, by offering a more personalized approach to real-time health management [12]. mHealth tools have been shown to provide a medium for personalized care, continuous monitoring, and patient engagement, therefore improving clinical outcomes and enhancing quality of life for patients [13,14]. mHealth has opened doors for the development of innovative smartphone apps tailored to meet the health needs of specific populations, such as pediatric patients with cancer [15].

More specifically, the integration of augmented reality (AR) in mHealth tools has gained traction in recent years [16]. AR technology overlays digital information on places or objects in the real world [17], as seen in apps, such as Pokémon Go (Niantic Inc). It is expected that incorporating AR within existing tools could enhance user satisfaction and facilitate long-term engagement by using more graphic-focused screen design and multimedia message presentation, as well as clear demonstrations and instructions by an AR avatar [18]. There is a previous systematic review [19] exploring the effectiveness of AR interventions for physical activity promotion and improving health outcomes. This evidence in children and young people reported that AR helped participants increase their physical activity levels as well as their engagement and motivation toward physical activity. Additionally, social interactions and psychological distress were also improved [19]. However, there is a lack of research on the user experience of AR apps specifically designed for promoting exercise participation during cancer rehabilitation.

Development and implementation of mHealth tools and specifically AR apps, in pediatric populations, especially for long-term, maintained engagement, presents significant challenges, emphasizing the need to use theoretical frameworks as well as evidence-based and user-centered approaches [20,21]. In recent years, there has been an increased acknowledgment of behavior change techniques, such as goal setting, motivational messaging, and outcome feedback, in the design of mHealth tools and programs [21]. Current guidance for designing and evaluating mHealth tools has specified that it is of particular importance that behavior change techniques are used as a basis for development to ensure content is theory-driven and follows evidence of best practice [22]. The app that was designed and evaluated as part of the research outlined here contains features based on behavior change techniques, such as feedback on behavior, instruction on how to perform the behavior, and demonstration of the behavior [23]. While these techniques are promising for integration in interventions promoting physical activity, there is limited evidence on their application in more complex mHealth tools, such as apps using AR. To address this gap, additional strategies, including motivational affordances, should be considered.

Motivational affordances are defined as design features, such as gamification and personalized feedback, that focus on increasing user engagement, distinguishing them from the internal cognitive processes emphasized in behavior change techniques [24,25]. The success of apps relies on user engagement, which is based on the user's motivation. Satisfaction, efficiency, and engagement define the overall user experience; however, apps do not always provide the expected results and rarely investigate user engagement [26]. For this purpose, the integration of disciplines of usability and motivational psychology could be achieved through research in motivational affordances [27]. Motivational affordance mechanisms and design elements could be used to satisfy the user's motivational requirements (ie, psychological, cognitive, social, and emotional); thus, there have been calls for motivational affordances to be applied in mHealth design. Theory-based approaches for the evaluation of apps are particularly useful due to their specific technology designs, which seek to tap into users' motivations, so they are captivated by them and really seek to use them [28].

However, there is a particular lack of evidence evaluating the usefulness of and user preferences for motivational affordances in exercise prescription apps for children and young people with cancer [29,30]. It is vital to specifically assess the potential for integrating motivational affordances in exercise prescription apps, since their adequacy and specificity are key in populations with chronic diseases [31].

Due to the novel nature of this app, there is a need for extensive evaluation of the app's functionality and usability, particularly regarding the navigation, layout, instructions, and AR demonstrations, before testing with children and young adults with cancer. The findings of this study provide valuable insights, which are more appropriately assessed in a more controlled setting, such as schools and healthy peers [32]. Participants of this study were age-matched to the target population for which the app was being developed.

Thus, the aim of this study was to explore the experiences of school pupils and university students of an AR smartphone app designed to prescribe exercise for children and young people with cancer. The study also aims to map participants' suggestions for improvement onto motivational affordance mechanisms and design elements. Understanding user preferences allows developers to refine features, improve accessibility, and create more engaging and effective mHealth tools for exercise prescription [32].

Methods

Overview

The methods (including app design, recruitment, data collection, and data analysis) have been comprehensively described in a previous publication [32]. In reporting of methods, the 32-item COREQ (Consolidated Criteria for Reporting Qualitative Research) checklist has been used (Checklist 1) [33].

AR App Development

The AR app was developed to support an individualized exercise program for children and young people undergoing cancer treatment, particularly when face-to-face provision was not possible, the child was at home, or they were immunocompromised. Its design was guided by an interdisciplinary team of software developers, digital health researchers, and pediatric oncology exercise professionals. Key features were implemented with the needs of children with cancer in mind, including professional input during onboarding to record diagnosis and contraindications, child-reported fatigue and activity levels, and a pre-session questionnaire to screen for new symptoms. The app offers upper body, lower body, and core exercises with seated and standing options, and a rate of perceived exertion scale that automatically adjusts exercise volume if intensity is inappropriate.

Recruitment and Setting

Participants were recruited through schools and universities. Eligibility criteria are presented in Textbox 1.

Textbox 1. Participant eligibility criteria.

Children and young people in
- Years 4, 5, 6, 7, 8, and 9 of primary school and secondary school, aged 8-14 years old
- Sixth form in secondary school, aged 16-18 years old
- University, aged 19-21 years old

Proficient in the English language
- Able to take part in a session up to 30 min of low-moderate intensity body weight exercises

Participants were recruited through convenience sampling of age-matched children and young people, representing a mix of rural and urban schools, along with 1 university group. During the recruitment of primary school children, the research team liaised with the school and its teachers, who passed on information about the study to potential participants and legal guardians. Participants were told why the research was being conducted and that the app had been developed for children with cancer in mind. For secondary school pupils, members of the team visited the school to explain the purpose of the study and outline what involvement in the workshops and focus groups would entail. For university students, the team provided details about the study by attending a selection of lectures.

Ethical Considerations

This research has received ethical approval from the Oxford Brookes University Faculty of Health and Life Sciences Research Ethics Committee (David E. Evans, Paul Hough, Robyn Curtis, and Jo Brett; approval 211547). Written informed consent and assent, including parental consent where applicable, were required to participate in the project in accordance with the project approvals granted by Oxford Brookes University Faculty of Health and Life Sciences Research Ethics Committee (registration 211547). All data were fully anonymized before analysis, with any identifying information removed to ensure participant confidentiality. Participation was voluntary, and individuals could withdraw at any time without penalty. Participants did not receive any compensation for their involvement.

Before the workshops, non–user-facing onboarding steps were completed to ensure that participants could access the main functions of the app, even though they did not have a cancer diagnosis. This setup involved selecting the following default options: all body areas were eligible for exercise, activities were not limited to seated movements, participants did not use a prosthetic limb, and they did not experience peripheral neuropathy. At the beginning of each workshop, participants were told why the research was being conducted and that the app had been developed for children with cancer in mind. None of the individuals invited to take part had used or interacted with the AR app.

Participants were given a phone and then progressed through the user-facing onboarding sequence. Once this was completed, participants completed an individualized exercise session, following the AR avatar demonstrations (Figure 1). Each workout consisted of 6 exercises, with the number of repetitions (1-6) and sets (1-3) automatically adjusted by the app's algorithm based on responses provided during the onboarding process. Following the session, participants completed a postsession questionnaire, which included a rating of perceived exertion measure (Figure 2).

Figure 1. App screen during exercise.

Figure 2. Rate of perceived exertion scale.

Subsequently, participants took part in focus group discussions to explore the user experience of using the AR app and had the opportunity to share suggested improvements. For the focus groups, a semistructured interview guide was used (Table 1).

Table 1. Semistructured interview guide for focus groups.

Topic and guiding questions	Prompts
Smartphone app perceptions	
What are your thoughts on using a smartphone app to help you do exercise?	• What kind of app are you thinking of? • How have your thoughts changed from before the workshop to now? • How would you use an app to be more active and do exercise?
How do you feel about using an augmented reality app to support you to be more active?	• Why would you use one? Why would you not?
Which part of the app do you feel would help you the most in doing more exercise?	• Which features did you enjoy the most? • Which features do you think you wouldn't need?
Exercise selection and prescription	
Which exercises do you remember from the app?	—[a]
What did you think about the exercises that were selected for you?	• Did you find the exercises easy or difficult? • Have you done any of these exercises before?
What do you think children who are your age (or younger or older) would think about these exercises?	—
Augmented reality avatar experiences	
What did you think about the avatar?	• What did you like about the avatar? • What kind of avatar would you prefer?
How did you find the avatar's demonstrations?	• Were you able to follow the reps and rounds? Was this made clear enough on the screen?
Were there any problems with the avatar whilst you were using the app?	• Did the avatar appear properly on the screen? Was the avatar the wrong size? • Were there any problems with the avatar's demonstrations?
App usability	
How do you feel about the phone we gave you for using the app?	• Did you find it easy or difficult to use? • What do you think about the size and display? • How did you find pressing different buttons on the phone?
How did you find using the tripod that held the phone whilst you were exercising?	—
Do you feel that the equipment you were using affected your experience in any way?	• Did the phone make it easy or hard to follow the demonstrations? • Was the tripod getting in the way of how well you could follow the demonstrations? • What do you think about the space you used for doing the exercises?
How did you find answering the questionnaire questions on the phone?	• What do you think about the amount of questions? • What do you think about how the questions were worded? • What do you think about answering questions on an app, compared to, for example, a piece of paper?
Suggestions for improvement	
How do you think the app could be improved?	• What do you think would make the avatar more useful? • What do you feel we should change about the exercises?
How else do you think we could help you be more active and do more exercise?	• What other technologies or equipment would you find useful?

[a]Not applicable.

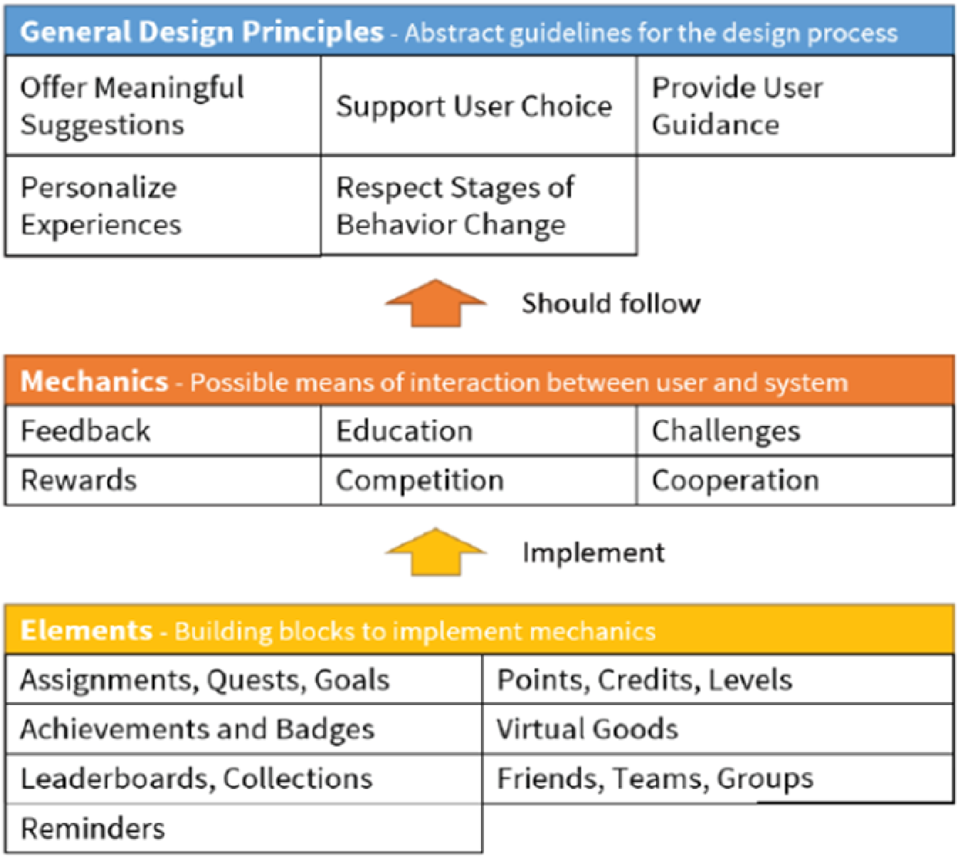
Workshops were conducted by KS (PhD, postdoctoral research assistant, female) and HM (MSc [Res], postgraduate research assistant, female), and SW (PhD, postdoctoral researcher and senior lecturer, male, qualitative research and technology expert), and focus groups were conducted by KS and HM. The research team had previous experience in conducting mixed method and qualitative research and specific training as part of their academic qualifications. Focus groups were audio-recorded and transcribed.

Data Analysis

Edited transcriptions were printed and reviewed in paper format, with 3 researchers (KS, SW, and HM) collaboratively conducting a coding process. Analysis combined deductive and inductive approaches [34-36]. The deductive component applied a pre-established framework based on key topics—hardware user experience, app interface, app design, AR functionality, avatar design, and exercise prescription. User experiences and suggested improvements were considered separately. Any remaining data from the discussion were inductively coded through intercoder conversations [32].

Features mentioned as suggested improvements were mapped onto the mechanisms and design elements outlined in the taxonomy of motivational affordances (Figure 3) [24]. Applying the taxonomy ensured relevant features were mapped onto evidence-based strategies and a unified terminology was used, which will aid the development and evaluation of future tools.

Figure 3. Taxonomy of motivational affordances (reproduced from Weiser et al [24], which is published under Creative Commons Attribution-Non-Commercial 4.0 International [CC BY-NC 4.0 37]).



Moreover, 2 coders (HM and KS) independently mapped the features to the taxonomy to enhance the validity of the coding process. Subsequently, "critical friend" discussions were held to explore the suitability of the respective selections and to encourage reflexivity and enhance the dependability and credibility of data [38]. This approach also encouraged KS and HM to reflect upon their coding and provided room for considering alternative interpretations [38].

Results

Overview

In total, 19 primary school pupils, 28 secondary school pupils, and 3 undergraduate (UG) university students took part in the practical workshops, with 39 providing consent to take part in the subsequent gender-mixed focus groups. These were conducted in the respective educational facilities (eg, school classroom). There were 8 focus groups in total—3 with primary school students, 4 with secondary school students, and 1 with university students. Workshops and focus groups were conducted between June and December 2021 at one primary school in Gloucestershire, one secondary school in Oxfordshire, and one university in Oxfordshire (United Kingdom). Participant ages and year groups are presented in Table 2.

Participants were able to test the app for 20-30 minutes before taking part in semistructured focus groups, which lasted between 16 and 28 minutes.

Table 2. Demographic characteristics of focus group participants.

Stages of education	Total participants, N	Sex, n
Primary school (year group 4-6, ages 8-11 y)	8	4 male, 4 female
Secondary school (year group 7-9, ages 12-14 y)	19	4 male, 15 female
Sixth form of secondary school (year group 12, ages 16-17 y)	9	6 male, 3 female
Undergraduate university students (ages 18-21 y)	3	2 male, 1 female
Total	39	16 male, 23 female

User Experience

Overview

Overall, most participants reported that they enjoyed using the app and described it as "fun" (Y9, UG). One participant explained they enjoyed using an app as it "was fun to do exercise that you don't usually do" (Y9). They also mentioned they would likely use it if it were available and suitable for their needs. Moreover, they felt the app could be a useful tool for promoting physical activity more broadly, and most agreed that it would help users engage more specifically with exercise. In particular, participants pointed out that the app "could build confidence" and "basic strength" (UG) to enable users to subsequently engage in more comprehensive physical activity provisions (such as group exercise classes). When comparing face-to-face exercise provisions, a participant shared that

> *sometimes it's nice to not have a scheduled time to go and see someone to do it in person. [...] If you feel insecure or feel weak, you can literally just set up the phone and do it alone [...]. It feels a lot easier.* [UG]

When asked about long-term use, some participants mentioned they would likely use it for a long time, whereas others stated they would likely use it for the shorter term only, with one describing they would engage with it for "two weeks and then get bored with it" (Y8). In contrast, other participants highlighted that the app could be helpful as a "prompt" to exercise, and it is "easy to follow and to pick up and make a habit of" (UG).

AR Functionality

During the focus groups, participants specifically discussed their experiences of using the app with regard to the AR functionality, app design, onboarding processes, accessibility, and safety. In addition to the iPhones (model 12, screen size 6.06 inches; Apple Inc), participants in this study were given a tripod to ensure they could execute the exercises without holding the phone. Participants generally found it useful to have a digital exercise demonstration, compared with paper-based drawings or text. Participants shared that using the AR app makes accessing exercise "quick" and "easy" (UG). Participants shared that the AR avatar felt like a "training partner" who provided a bit more motivation and "[made] the exercise more fun" and "might make […] someone feel like one of their friends is doing the same" (UG). Furthermore, participants felt that for clinical users who may wish to do activities without face-to-face supervision, the AR functionality could be useful to provide demonstrations and maintain a sense of personalization and care. Participants liked being able to watch the demonstration for as long as they needed to and "didn't feel rushed" (UG), as there was no specific time allocation per exercise. Participants agreed that having a virtual exercise demonstration is useful, especially if users had insufficient knowledge to execute specific exercises.

In comparison, there was no consensus among participants with regard to the use of AR compared with more traditional (2D) video demonstrations. One participant mentioned that "there are more problems presented by the AR than solved by the AR" (Y12), hinting at technical difficulties that occurred when scanning the room to allow the avatar to appear. Participants mentioned that they had to scan the surroundings with the phone for the AR avatar to appear before each exercise, which some stated was "frustrating" (Y8, UG), and others felt like they should not have to physically move the phone each time to make the avatar appear. It should be noted that this was not an issue for everyone, with some participants saying that "it worked quite quickly" (Y8). It also transpired that at times, the avatar would appear in a different location to the one scanned, or appear too large or too small. Moreover, some participants mentioned that it was difficult to follow exercises that required them to be seated or lying down on the floor, as they could no longer see the phone screen. It was suggested that using videos would allow users to move the phone without impacting the exercise demonstration. On the other hand, some participants stated that the use of an avatar was unique to this app and generated a more enjoyable experience compared with traditional apps (ie, those using videos), as it made the exercises feel more like a game. One participant said that,

> *[...] it was really fun and enjoyable because while I was doing it, I didn't really notice I was doing exercise.* [Y5/6]

App Design

Most participants stated that they merely focused on the avatar, without reading the other information presented on the screen, whereas some read the text before looking at the avatar. Among users who indicated they read the instructions, some found it difficult to decipher whether they were asked to perform 1 round, 1 set, or multiple sets. It was evident that text presented in bold was perceived as important and was prioritized by some participants before beginning the exercise.

Onboarding Process

Some participants questioned the relevance of some of the questions, for example, with regard to the ability to keep their balance on a slippery surface, and also mentioned that some of the questions felt repetitive. Others appreciated that the individual questions were needed for the subsequent exercise prescription, and older users mentioned they liked that there would be scope for progression.

Participants stated that an option to skip a question they felt uncomfortable answering would be beneficial as "someone might be worried that if [...] they find it hard to do something, they might not like people knowing that" (Y5/6). Participants appreciated that the questionnaires did not ask them for any input on their height and weight, as they perceived this may be potentially uncomfortable for some users. Moreover, questions that enabled more tailored exercises were welcomed as they would "feel more motivated because it's actually targeted [...] personally, instead of just a generic app" (UG).

Regarding the number of questions, there was no consensus among participants. Some felt the questionnaires were too long, and they would potentially skip questions, respond randomly, or cease use of the app. Others stated the questionnaires were "quite short" (Y4) and not "too long or bothersome" (UG). One participant appreciated that "[...] for the people who actually need it, [they] would pay attention to what is actually going on because they want to get better" (Y9), hinting that intended users (ie, children with cancer) would also be more likely to appreciate the need for onboarding questions.

It was also discussed that most felt the questions were easy to read; however, others stated they might need to be shortened for younger users. One participant (Y5/6) mentioned that the questions should be as specific as possible, as they struggled to select an answer when the question was not clear (eg, asking about their ability to carry a heavy book, with confusion on what "heavy" would entail).

In regard to the answer options, most participants felt that 5 options were sufficient, and the wording should be clearer to effectively distinguish between options (eg, "sometimes" vs "almost never").

Exercise Prescription

Most participants stated that the prescribed exercise intensity was achievable, although a few participants reported that some of the exercises were too easy. The selected exercises were deemed to be suitable, with a "good range" and appropriate provision of exercises done in a lying, sitting, and standing position. One participant felt this made it "interesting" and "fun" (Y9).

Participants felt that a gradual intensity progression is helpful in regard to a decrease or increase in intensity or repetitions based on previous performance or feedback input from users. The rate of perceived exertion scale (Figure 2) was well-received, and participants found it easy to select the relevant score.

Accessibility

Some participants stated that they found it beneficial not to need specific equipment (ie, other than a chair), whereas others mentioned they would prefer exercise sessions that require no equipment at all. One participant added that the app was also beneficial for those with limited access to appropriate outdoor space for exercising as "you don't need a big field to do exercise, so even if you live in a flat […] you can still do it" (Y5/6). It was also recognized that paying for exercise apps, such as this one, could be a barrier for some users, as expressed by one, "it's really good to have it free" (Y7).

Safety

A couple of participants also discussed their experiences with data and usage safety, including concerns regarding how much, and what type of information was collected, as well as how this would be shared. One participant hinted that the length of the onboarding questionnaires may "[make them] a bit suspicious of what is happening so [would] delete it" (Y9). One participant mentioned their parents may share these concerns and would encourage them not to provide personal information, such as their real age.

Avatar Design

Participants generally agreed that the avatar design was appropriate for a variety of ages, with no suggestions made on specific features that should be changed as a default. Participants commented that the avatar was "cute and funny" (Y9), and the design allowed for easy interpretation of the exercise demonstrations. Older participants highlighted that they appreciated the semirealistic design and felt that the avatar's body shape was helpful not to "feel pressure of 'you have to look like this'" (UG) but rather encouraged them to focus on being physically active for enjoyment.

Suggested Improvements

Throughout the focus groups, participants voiced suggestions for future improvements of the app. Table 3 contains an overview of suggested improvements linked to the following motivational affordance mechanisms: user education, challenges, feedback, cooperation, and comparison.

Table 3. Summary of suggested improvements by motivational affordance mechanisms.

Category	Participant quote	Recommendation	Motivational affordance design elements
User education			
Exercise instructions	• "I think if it explains to you what it does or [help with], […] that would be more educational" (UG)[a] • "[...] I didn't actually know how long I was doing it for." (Y4) [b]"[...] It didn't [...] say per leg or all together." (Y12)[g] • "[...] It could say [...] you need a chair [...]." (Y12)	Provide detailed (written or audio) instructions explaining purpose, repetitions, and equipment	Assignments

Category	Participant quote	Recommendation	Motivational affordance design elements
	• "[…] I would prefer more text or description of what we're going to do" (UG) • "I think it would definitely help especially when you are doing an exercise when you can't […] directly see the screen, the audio telling you the next exercise is about to start would definitely help someone notice when to move onto the next one" (Y12)		
Visual demonstration aids	• "It would be better if it had arrows of [...] where to move." (Y9)[f]	Implement additional visual guidance to support movement execution	Assignments
Duration	• "[...] there [could] be a timer in front of you so you could see [...] how long there is to do this exercise." (Y12) • "[...] There should maybe be an option to do a countdown [...]." (Y7)[d]	Consider use of countdowns or timers	Assignments and goals
Order	• "I would try [to] space out the chair exercises [...]. [...] So maybe do a sitting down one, a lying down [one] and then a standing up [one]." (Y5/6)[c]	Ensure sitting, lying, and standing exercises are included and interspersed	Assignments
Exercise type and variety	• "I guess it would be good to have more variety [...]" (Y12) • "[...] There should be options on what you want to work on, like if you want to work on your legs [...], on your arms, or you want to do your whole body." (Y9)	Give a variety of exercises and allow user choice for type of exercises (including strength and mobility)	Assignments, quests, and goals
Rest	• "I think [...] there should be a rest time." (Y9) • "[...] If it was as long as you like, then I would give up. I would lay down and forget about it." (Y9)	Implement specific durations for rest	Assignments
Equipment options	• "[...] You could do an option so people that aren't used to exercising [...] can have a chair with them [...]." (Y5/6)	Provide exercises using equipment to facilitate safe and appropriate exercise performance	Assignments and quests
Challenges			
Setup	• "[...] There should be [...] a few different levels, so an easy, a medium and a hard [...]." (Y4) • "I think it would be nice [...] before you go to the exercise you can type in how much you want to do [...]." (Y12)	Provide different levels of intensity to account for previous experience and current capabilities and allow users to select their own	Levels, quests, and goals
Intensity progression	• "[...] It [should be] updated [...] every two weeks [...]. The exercise levels could change, [...] get harder." (Y8)[e] • "[…] If you found it too hard, it can make the exercises a bit easier next time" (Y9) • "[...] Whenever you finish an activity, you can write down what was easy or hard for you [...]." (Y7)	Allow intensity progression or regression and user input to gain feedback on perceived exercise intensity	Assignments, quests, goals, and levels
Progress overview	• "A form of motivation would be a progress bar, [...] and over time you can see [how] well you improve." (Y12)	Provide progress overview graphs, bars, or charts as motivational tool	Points, achievements, and badges
Feedback			
Compliance	• "[…] There could be a sensor, it could make sure, seeing what you are doing, like saying out of 10, it knows what you are doing" (Y5/6)	Consider sensor technology to track movements and give feedback on execution	Points and achievements
Encouragement	• "I thought it was a bit quiet, so "you can do this," or like "you've done great" or something" (Y9)	Provide audio encouragement during or between exercises	Achievements
Cooperation and comparison			
Group exercise	• "Maybe you could choose how many people do the workout, so if you want to do it as a family then you	Give options for group exercise with invited users	Friends, teams, and groups

Category	Participant quote	Recommendation	Motivational affordance design elements
	could say partner round or how many people are playing with and then you could have three different avatars […]" (Y5/6) • "It would be a good idea if, […] you could FaceTime a friend whilst you're doing the exercise or you could have like a split screen thing where you both do it and you can see what each other are doing and like talk to them whilst doing it" (Y7)		
Social support	• "Because your friends would probably encourage you if you say this is hard, they would encourage you" (Y7)	Allow users to interact with others via call or chat feature	Friends, teams, and groups
Performance comparison	• "Like a scoreboard with other people's scores on it." (Y5/6)	Allow comparison between users via visual aids	Leaderboards

[a]Undergraduate (UG) focus group.
[b]Y4: Year 4 focus group.
[c]Y5/6: Combined Year 5/6 focus group.
[d]Y7: Year 7 focus group.
[e]Y8: Year 8 focus group.
[f]Y9: Year 9 focus group.
[g]Y12: Year 12 focus group.

In addition to these improvements, participants discussed options for incorporating gamification within the app, which was mentioned to hold potential to attract users who usually do not enjoy exercise. One participant added that "[...] rather than playing games [...], [they] would be doing exercise" (Y7). They felt it could be useful to use young people's interest in computer gaming or other activities and amalgamate this with the exercise-related features of an app. Table 4 contains an overview of gamified features proposed by participants, linked to challenges and rewards as per the motivational affordance mechanisms.

Table 4. Overview of suggested improvements for gamification by motivational affordance mechanisms.

Category	Participant quote	Recommendation	Motivational affordance design elements
Challenges			
Exercise tasks	• "[...] If you are jumping on the spot, [...] you can try and beat your high score [...]." (Y4)[a]	Give personalized activity tasks	Quests and challenges
Cognition	• "[...] You can add games that could teach them about Maths and English [...]." (Y7)[b] • "You could [...] match the [...] name of the exercise to the actual exercise." (Y8)[c]	Integrate games related to school subjects or logical thinking	Quests
Special interest	• "[...] It might be good to teach them activities, [like] how to shoot a basketball, how to dribble a football." (Y7) • "[...] There could be [...] vocal exercises for people who like singing." (Y7)	Incorporate activities to train special interests	Quests
Virtual world	• "[...] You could make the avatar do games, like football or basketball [...]." (Y4) • "[...] The avatar could do stuff at home, like as if it's them but in the game, [...] like going to school and things [...]." (Y7)	Create virtual world for the avatar to complete tasks	Quests
Rewards			
Virtual rewards	• "[...] If you reach your [...] target for one day of exercise you then [...] unlock the points and then you can get something to customize your avatar a bit more [...]." (Y9)[d] • "[...] At the start of the app you could have the yellow one and blue one but then when you complete [...] 10 exercises, you can unlock other [...] [colors]." (Y9)	Provide rewards (eg, via avatar customization) for exercise achievements	Credits, achievements, and badges

Category	Participant quote	Recommendation	Motivational affordance design elements
	• "[...] If you do [the exercise] amazingly, you could get [...] stars and you could trade it in for [...] a little fun game play." (Y5/6)[e]		

[a]Y4: Year 4 pupils focus group.
[b]Y7: Year 7 focus group.
[c]Y8: Year 8 focus group.
[d]Y9: Year 9 focus group.
[e]Y5/6: Combined Year 5/6 pupils focus group.

In addition to the suggested improvements shown in Tables 3 and 4, and outside of the scope of features related to motivational affordances, participants highlighted that equipment for using the app should be user-friendly. For example, phone screens should be of sufficient size (>6 inches), and tripods should be sturdy and easy to adjust. Moreover, customization of the app interface (eg, by giving options to change background colors), or of the avatar (eg, by allowing users to change its features, such as age, gender, skin color, hair, body composition, and clothes, or giving nonhuman options, such as, animals or fantasy characters) would be useful and could enhance engagement with the exercise. It was also suggested that allowing users to play their own music or select from a choice of songs could be motivating.

Discussion

Principal Findings

This study explored user experiences of an AR exercise app and mapped users' suggested improvements against motivational affordance mechanisms and design elements [24]. Most participants reported that they enjoyed using the app. Participants found the demonstrations and varied exercises useful but expressed some concerns regarding data safety and functionality of the AR avatar. Suggestions included improvements, such as additional educational components, incorporating challenges and rewards, as well as a customizable avatar and a social support feature, such as the possibility of exercising with family or friends. Additionally, some suggestions, such as the integration of audio instructions for a greater inclusive design, were made. Finally, users also expressed concerns about personal data safety. When mapped against the motivational affordances taxonomy, the suggested improvements aligned with mechanisms of user education, challenges, feedback, cooperation, and comparison. This study underlines the importance of incorporating a variety of motivational affordances to account for different user needs and preferences.

Motivational Affordances

Within this study, participants' suggestions frequently mapped against the taxonomy of motivational affordances [24]. It is promising that motivational affordances incorporated within the current app, such as user education on how to perform exercise, seem to be particularly effective in improving physical activity levels among patients with cancer in other research [39]. Participants in our study also suggested new features, such as audio instructions, visual progress bars, and the ability to connect with other users, highlighting the need to further develop design features, such as achievements, credits, and friends [24].

While current studies may assess the general usefulness of mobile apps, a deeper exploration is needed to determine how specific features drive engagement and thus encourage long-term physical activity, especially in populations, such as pediatric oncology, which we know face additional barriers to exercise. Currently, we may only understand the usefulness of motivational affordances, and further research should delve deeper into the mechanisms through which the features work, for example, via belief in capabilities and intentions [40]. Investigating these underlying mechanisms could help optimize app design and ensure that interventions are effectively promoting behavior change, and not only short-term app use. Long-term engagement is particularly important for survivors of children with cancer as physical activity levels are often lower than noncancer controls [41], and observational studies have identified associations between sedentary behavior and adverse effects on cardiometabolic and bone health [42].

Gamification

For end users to use and positively benefit from an app, they must actively engage with it. Our findings indicated that incorporating challenges and rewards is preferred, which is in line with other app research [43]. However, it has to be considered that when using the app within clinical populations, there may be contraindications (eg, treatment-related side effects) that prohibit users from engaging with the app, or some of its features, for a period of time. When programming the app to provide challenges and rewards, such as continuous usage streaks or increases in exercise prescriptions, it is crucial to also incorporate rewards for the performance of tasks achievable by all users. Additionally, if participation is affected by a reason outside of the users' control (eg, treatment), they should not be negatively affected (eg, losing a daily streak or points). The approach of personalized gamification has been highlighted by Mahmoudi et al [44], with the addition of customization, where users can select elements they wish to use. Customization of the app interface and avatar was a frequent suggestion within this study. Avatar-based interventions, and specifically customizable avatars, have been shown to promote health-related behavior change, including exercise [45]. Within the motivational affordance taxonomy, there is no clearly defined mechanism dedicated to "customization" [24]. While customization as a reward or as a transactional element involving earned coins may be conceptually aligned with the motivational affordances design features of credits or achievements, there is no explicit mechanism pointing toward users customizing features (eg, interface or avatar) without first fulfilling certain criteria or earning that capability. While customization may be a popular demand, future research should explore whether being able to personalize apps is motivating in itself or whether the motivation is attached to the act of "earning" the reward in order to do so.

Social Support

The results showed that having a social support feature, such as being able to exercise with family members or friends, may be beneficial for app engagement and links well to friends, teams, and group mechanisms within the taxonomy of motivational affordances [24].

Family apps have been seen to have promising effects on physical activity levels and psychosocial outcomes by promoting child-parent exercise [46]. Including social features in exercise apps for children with cancer may enhance engagement and motivation. One study [47] found that physical and social activities merged when ambassadors (ie, peers or siblings) participated alongside survivors of childhood cancer, supporting enjoyment and adherence. Integrating peer interactions into digital platforms could replicate these benefits, promoting physical activity and well-being. While the current app does not have this feature due to the restrictions of data protection and safety, this concept may be of interest when considering the isolation and reduced opportunities for social interaction often experienced by children with cancer [48].

Interestingly, 1 participant revealed a different perspective and highlighted that the app could be a useful tool for those who do not have family members or friends who exercise. It was mentioned that the AR avatar could serve as a form of "digital friend" who could positively influence exercise participation, which was in line with findings from a study conducted by Thorsteinsson et al [47]. There is some initial research on a sense of belonging and digital support received from apps that can positively influence physical activity levels [49]; however, the findings of this study underline the importance of exploring this concept more comprehensively.

Accessibility

The results highlight a need to enhance accessibility within mHealth applications, particularly through the extension of existing motivational affordance mechanisms, such as assignments, to better accommodate diverse user needs and promote inclusive design. For instance, the inclusion of a text-to-speech function was recommended, which would provide meaningful support for users with reading difficulties or visual impairments. This recommendation aligns with existing research emphasizing the importance of designing inclusive digital experiences [50]. The evidence highlights the importance of accessibility features, such as voice control, voice over, color contrast, and easy access controls, to ensure apps are usable for individuals with disabilities [50]. These features are particularly relevant in physical activity apps, where ease of use and clear instructions are essential for safe engagement. For example, individuals with visual impairments may rely on voice commands and audio feedback to navigate exercise programs, while those with motor disabilities may benefit from customizable controls that allow for seamless interaction. Therefore, app developers should consider the inclusion of such features to ensure inclusivity and enhance user satisfaction across diverse populations.

Data Safety

Results highlight concerns regarding the appropriateness of the app collecting and potentially sharing personal data (eg, age). It is important to recognize that the use of an app that requires any user input should be accompanied by relevant training and information for users. It is expected that, by providing extensive information to users and their parents or guardians, concerns may be mitigated effectively, with users satisfied and subsequently willing to provide accurate information. It has been widely acknowledged that the increased volume of data available through the use of mHealth tools, such as apps, can indeed be used to provide better services if current data protection and sharing regulations are adhered to [22]. Looking ahead, due to the frequent multicomponent treatment approach for children and young people with cancer, it would be crucial to explore how user data within apps (eg, rate of perceived exertion and exercise duration and intensity) can be integrated within digital health records for a more comprehensive treatment approach. As part of such evaluations, specific mHealth reporting and assessment guidelines, such as the mHealth Evidence Reporting and Assessment checklist, should be used [51].

Strengths and Limitations

This study provides a rich and in-depth understanding of user experiences when using the app, allowing researchers to study potential unexpected patterns in how users interact with the different app features. Mapping results with motivational affordances allows for a better understanding of certain features that might be more motivating and support app engagement within this population. Our findings can inform the development of effective mHealth tools that support behavior change in the field of exercise and physical activity as well as guide future interventions, including more personalized, user-centered approaches to digital health technology.

Despite our study's strengths, it is important to acknowledge limitations. First, this study recruited healthy participants. While some perceptions of the app's functionality are expected to be comparable between patients with cancer and healthy age-matched peers, there may be differences in the usability of the app between these 2 populations. Some pediatric patients with cancer may have a unique motivation with regards to exercise and physical activity, as well as different physical and cognitive needs and preferences; user experiences of some features could differ. Currently, the AR app is at technology readiness level 5. Future studies with the intended clinical population would progress the app to technology readiness level 6.

Second, the study targeted a broad age range (8-21 y), while the app itself remained largely static across all ages. While differences in cognitive ability, physical capability, accessibility, and design preferences may mean that some features are less engaging for certain age groups, given the lack of existing AR apps for this population. This approach is also pragmatic, considering the high costs associated with technology development, allowing initial feedback to inform improvements before investing in age-specific customizations.

Third, this study focused on short-term app interaction. Given that the app is designed to support exercise prescriptions over several weeks, the brief duration prevented the assessment of features influencing longer-term adherence. Although the controlled setting allowed for the collection of immediate feedback, it did not capture the evolving experiences users may have during extended use. Future studies should incorporate longitudinal testing to better understand long-term engagement and identify which features support ongoing use.

Finally, there was also the potential of researcher bias in the study, as the investigators had a background in sport and exercise science, which may have influenced how data were interpreted or which themes were prioritized.

Despite these limitations, the study provides valuable foundational evidence to guide improvements to the app and inform future research on implementing mHealth tools within pediatric exercise interventions.

Conclusion

Theory-driven evidence for best practice on mHealth apps is often inconsistent or not focused on the overall user experience. This study explored young people’s experiences of an AR exercise app and mapped suggested improvements onto the motivational affordance mechanisms and design elements. Users identified several ways the app could be strengthened, including the addition of educational content, challenges and rewards, a customizable avatar, and social features that enable exercising with family or friends. Suggestions also highlighted the need for greater inclusivity through features, such as audio instructions, and clear safeguards around the security of personal data. Mapping these recommendations onto the motivational affordance taxonomy revealed alignment with mechanisms, such as assignments, achievements, friends, groups, and credits, underscoring the diversity of motivational pathways that can support engagement. Further research directly involving children and young people with a childhood cancer diagnosis is planned to further explore the preferences of those facing unique barriers to physical activity and exercise. Such work will also be crucial for advancing the technology readiness level of the intervention by testing the app with the intended population in real-world settings.

Acknowledgments

We are grateful for the organizational support from Oxford Brookes University and thank the children, young people, and teachers for their engagement in the project.

The authors would like to acknowledge the FORTEe consortium for their support and contributions to the development of this work. Generative artificial intelligence was not used in the writing of this manuscript.

Funding

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 945153. This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

Data Availability

The data will be available from the corresponding author upon reasonable request.

Authors’ Contributions

Conceptualization: HM, KS, SW, MAN, ED, JF, PW
Data curation and formal analysis: HM, KS, SW, PW
Investigation: HM, KS, ASS, SW, PW
Methodology: HM, KS, ASS, SW, MAN, ED, EW, JF, PW
Project administration: HM, KS, ASS, SW, EW, PW
Resources: EW, PW
Supervision: EW, PW
Writing – original draft: HM, KS, ASS, EW, PW
Writing – review and editing: HM, KS, ASS, SW, MAN, ED, JF, EW, PW
Co-first authors – HM, KS

Conflicts of Interest

None declared.

Checklist 1

COREQ checklist.

[DOCX File (Microsoft Word File), 3769 KB-Checklist 1]

References

1. Perrin JM, Anderson LE, Van Cleave J. The rise in chronic conditions among infants, children, and youth can be met with continued health system innovations. Health Aff (Millwood). Dec 2014;33(12):2099-2105. [doi: 10.1377/hlthaff.2014.0832] [Medline: 25489027]
2. Guthold R, White Johansson E, Mathers CD, Ross DA. Global and regional levels and trends of child and adolescent morbidity from 2000 to 2016: an analysis of years lost due to disability (YLDs). BMJ Glob Health. Mar 2021;6(3):e004996. [doi: 10.1136/bmjgh-2021-004996] [Medline: 33731441]
3. Bonnie RJ, Stroud C, Breiner H, editors. Investing in the Health and Well-Being of Young Adults. National Academies Press; 2015. [doi: 10.17226/18869] [Medline: 25855847] ISBN: 978-0-309-30995-0
4. Edwards J, Waite-Jones J, Schwarz T, Swallow V. Digital technologies for children and parents sharing self-management in childhood chronic or long-term conditions: a scoping review. Children (Basel). Dec 18, 2021;8(12):1203. [doi: 10.3390/children8121203] [Medline: 34943399]
5. Dayer L, Heldenbrand S, Anderson P, Gubbins PO, Martin BC. Smartphone medication adherence apps: potential benefits to patients and providers. J Am Pharm Assoc (2003). 2013;53(2):172-181. [doi: 10.1331/JAPhA.2013.12202] [Medline: 23571625]
6. Mehdizadeh H, Asadi F, Emami H, Mehrvar A, Nazemi E. An mHealth self-management system for support children with acute lymphocytic leukemia and their caregivers: qualitative co-design study. JMIR Form Res. Apr 15, 2022;6(4):e36721. [doi: 10.2196/36721] [Medline: 35228195]
7. Huang JS, Dillon L, Terrones L, et al. Fit4Life: a weight loss intervention for children who have survived childhood leukemia. Pediatr Blood Cancer. May 2014;61(5):894-900. [doi: 10.1002/pbc.24937] [Medline: 24436138]
8. Ozturk CS, Toruner EK. Effectiveness of technology-based psychosocial interventions for child, adolescents and young adults undergoing cancer treatment: a meta-analysis of randomised controlled trials. European J Cancer Care. Jan 2022;31(1). URL: https://onlinelibrary.wiley.com/toc/13652354/31/1 [Accessed 2026-02-04] [doi: 10.1111/ecc.13515]
9. Wesley KM, Fizur PJ. A review of mobile applications to help adolescent and young adult cancer patients. Adolesc Health Med Ther. 2015;6:141-148. [doi: 10.2147/AHMT.S69209] [Medline: 26316835]
10. Götte M, Kesting S, Winter C, Rosenbaum D, Boos J. Experience of barriers and motivations for physical activities and exercise during treatment of pediatric patients with cancer. Pediatr Blood Cancer. Sep 2014;61(9):1632-1637. [doi: 10.1002/pbc.25071] [Medline: 24753116]
11. Okolo CA, Babawarun O, Arowoogun JO, Adeniyi AO, Chidi R. The role of mobile health applications in improving patient engagement and health outcomes: a critical review. Int J Sci Res Arch. 2024;11(1):2566-2574. URL: https://ijsra.net/ArchiveIssue-2024-Vol11-Issue1 [Accessed 2026-02-04] [doi: 10.30574/ijsra.2024.11.1.0334]
12. Lim DSC, Kwok B, Williams P, Koczwara B. The impact of digital technology on self-management in cancer: systematic review. JMIR Cancer. Nov 22, 2023;9(1):e45145. [doi: 10.2196/45145] [Medline: 37991831]
13. Quazi S, Malik JA. RETRACTED: A systematic review of personalized health applications through human-computer interactions (HCI) on cardiovascular health optimization. J Cardiovasc Dev Dis. Aug 16, 2022;9(8):273. [doi: 10.3390/jcdd9080273] [Medline: 36005437]
14. Pappot H, Assam Taarnhøj G, Elsbernd A, et al. Health-related quality of life before and after use of a smartphone app for adolescents and young adults with cancer: pre-post interventional study. JMIR Mhealth Uhealth. Oct 3, 2019;7(10):e13829. [doi: 10.2196/13829] [Medline: 31584008]
15. Fedele DA, Cushing CC, Fritz A, Amaro CM, Ortega A. Mobile health interventions for improving health outcomes in youth: a meta-analysis. JAMA Pediatr. May 1, 2017;171(5):461-469. [doi: 10.1001/jamapediatrics.2017.0042] [Medline: 28319239]
16. Istepanian RSH. Mobile health (m-Health) in retrospect: the known unknowns. Int J Environ Res Public Health. Mar 22, 2022;19(7):3747. [doi: 10.3390/ijerph19073747] [Medline: 35409431]
17. Berryman DR. Augmented reality: a review. Med Ref Serv Q. 2012;31(2):212-218. [doi: 10.1080/02763869.2012.670604] [Medline: 22559183]
18. Wei X, Yang G, Zhang K, Li Z. Research on mobile ar language learning environment based on virtual avatar. Presented at: 2020 Ninth International Conference of Educational Innovation through Technology (EITT); 229-234; Porto, Portugal. 2020.URL: https://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=9320621 [Accessed 2026-04-02] [doi: 10.1109/EITT50754.2020.00047]

19. Piqueras-Sola B, Cortés-Martín J, Rodríguez-Blanque R, et al. Systematic review on the impact of mobile applications with augmented reality to improve health. Bioengineering (Basel). Jun 18, 2024;11(6):622. [doi: 10.3390/bioengineering11060622] [Medline: 38927858]
20. Wiljén A, Chaplin JE, Crine V, et al. The development of an mHealth tool for children with long-term illness to enable person-centered communication: user-centered design approach. JMIR Pediatr Parent. Mar 8, 2022;5(1):e30364. [doi: 10.2196/30364] [Medline: 35258466]
21. Vollmer Dahlke D, Fair K, Hong YA, Beaudoin CE, Pulczinski J, Ory MG. Apps seeking theories: results of a study on the use of health behavior change theories in cancer survivorship mobile apps. JMIR Mhealth Uhealth. Mar 27, 2015;3(1):e31. [doi: 10.2196/mhealth.3861] [Medline: 25830810]
22. Michie S, Yardley L, West R, Patrick K, Greaves F. Developing and evaluating digital interventions to promote behavior change in health and health care: recommendations resulting from an international workshop. J Med Internet Res. Jun 29, 2017;19(6):e232. [doi: 10.2196/jmir.7126] [Medline: 28663162]
23. Michie S, Richardson M, Johnston M, et al. The Behavior Change Technique Taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. Ann Behav Med. Aug 2013;46(1):81-95. [doi: 10.1007/s12160-013-9486-6] [Medline: 23512568]
24. Weiser P, Bucher D, Cellina F, De Luca V. A taxonomy of motivational affordances for meaningful gamified and persuasive technologies. Presented at: EnviroInfo and ICT for Sustainability 2015; Copenhagen, Denmark. 2015.[doi: 10.2991/ict4s-env-15.2015.31]
25. Aguiar M, Trujillo M, Chaves D, Álvarez R, Epelde G. mHealth apps using behavior change techniques to self-report data: systematic review. JMIR Mhealth Uhealth. Sep 9, 2022;10(9):e33247. [doi: 10.2196/33247] [Medline: 36083606]
26. Ho MHW, Chung HFL. Customer engagement, customer equity and repurchase intention in mobile apps. J Bus Res. Dec 2020;121:13-21. [doi: 10.1016/j.jbusres.2020.07.046]
27. Durmaz TB, Fuertes JL, Imbert R. Toward usability testing of motivational affordances through gamification. International Journal of Human–Computer Interaction. May 2, 2024;40(9):2398-2414. [doi: 10.1080/10447318.2022.2162277]
28. Zhang P. Motivational affordances: fundamental reasons for ICT design and use. Commun ACM. 2008;51(11). URL: https://papers.ssrn.com/abstract=2352593 [Accessed 2025-04-10] [doi: 10.1145/1400214.1400244]
29. Harris J, Cheevers K, Armes J. The emerging role of digital health in monitoring and supporting people living with cancer and the consequences of its treatments. Curr Opin Support Palliat Care. Sep 2018;12(3):268-275. [doi: 10.1097/SPC.0000000000000362] [Medline: 29927756]
30. Yang CH, Maher JP, Conroy DE. Implementation of behavior change techniques in mobile applications for physical activity. Am J Prev Med. Apr 2015;48(4):452-455. [doi: 10.1016/j.amepre.2014.10.010] [Medline: 25576494]
31. Duscha BD, Piner LW, Patel MP, et al. Effects of a 12-week mHealth program on functional capacity and physical activity in patients with peripheral artery disease. Am J Cardiol. Sep 1, 2018;122(5):879-884. [doi: 10.1016/j.amjcard.2018.05.018] [Medline: 30049464]
32. Straun K, Marriott H, Solera-Sanchez A, et al. The development of an augmented reality application for exercise prescription within paediatric oncology: app design and protocol of a pilot study. Health Informatics J. 2024;30(4):14604582241288784. [doi: 10.1177/14604582241288784] [Medline: 39447216]
33. Tong A, Sainsbury P, Craig J. Consolidated Criteria for Rreporting Qualitative Research (COREQ): a 32-item checklist for interviews and focus groups. Int J Qual Health Care. Dec 2007;19(6):349-357. [doi: 10.1093/intqhc/mzm042] [Medline: 17872937]
34. Kuckartz U. Qualitative Text Analysis: A Guide to Methods, Practice & Using Software. 2014. URL: https://www.academia.edu/89311675/Qualitative_Text_Analysis_A_Guide_to_Methods_Practice_and_Using_Software ISBN: 978-1-4462-6774-5
35. Mayring P. Mey G, Mruck K, editors. Handbuch Qualitative Forschung in Der Psychologie Wiesbaden: VS Verlag Für Sozialwissenschaften. 2010:601-613. [doi: 10.1007/978-3-531-92052-8_42] ISBN: 978-3-531-92052-8
36. Proudfoot K. Inductive/deductive hybrid thematic analysis in mixed methods research. J Mix Methods Res. Jul 2023;17(3):308-326. [doi: 10.1177/15586898221126816]
37. Attribution-noncommercial 4.0 international CC BY-NC 4.0. Creative Commons. URL: https://creativecommons.org/licenses/by-nc/4.0/ [Accessed 2026-04-13]
38. Smith B, McGannon KR. Developing rigor in qualitative research: problems and opportunities within sport and exercise psychology. Int Rev Sport Exerc Psychol. Jan 2018;11(1):101-121. [doi: 10.1080/1750984X.2017.1317357]
39. Samadbeik M, Garavand A, Aslani N, Sajedimehr N, Fatehi F. Mobile health interventions for cancer patient education: a scoping review. Int J Med Inform. Nov 2023;179:105214. [doi: 10.1016/j.ijmedinf.2023.105214] [Medline: 37729837]

40. Carey RN, Connell LE, Johnston M, et al. Behavior change techniques and their mechanisms of action: a synthesis of links described in published intervention literature. Ann Behav Med. Oct 10, 2018;53(8). [doi: 10.1093/abm/kay078]
41. Antwi GO, Jayawardene W, Lohrmann DK, Mueller EL. Physical activity and fitness among pediatric cancer survivors: a meta-analysis of observational studies. Support Care Cancer. Sep 2019;27(9):3183-3194. [doi: 10.1007/s00520-019-04788-z] [Medline: 30993451]
42. Ivory BJ, Moore K, Dinalo JE, et al. Sedentary behavior in children, adolescents, and young adults treated for cancer: a scoping review of health outcomes and interventions. J Cancer Surviv. Nov 11, 2025. [doi: 10.1007/s11764-025-01908-z] [Medline: 41217621]
43. Lee J, Su Z, Chen Y. Mobile apps for children's health and wellbeing: design features and future opportunities. AMIA Annu Symp Proc. 2023;2023:1027-1036. [Medline: 38222362]
44. Mahmoudi E, Yejong Yoo P, Chandra A, et al. Gamification in mobile apps for children with disabilities: scoping review. JMIR Serious Games. Sep 6, 2024;12:e49029. [doi: 10.2196/49029] [Medline: 39240675]
45. Cragun DL, Hunt PP, Dean M, et al. Applying the framework for developing and evaluating complex interventions to increase family communication about hereditary cancer. PEC Innov. Dec 2023;2:100133. [doi: 10.1016/j.pecinn.2023.100133] [Medline: 37214492]
46. Wong RSM, Yu EYT, Wong TWL, et al. Development and pilot evaluation of a mobile app on parent-child exercises to improve physical activity and psychosocial outcomes of Hong Kong Chinese children. BMC Public Health. Oct 14, 2020;20(1):1544. [doi: 10.1186/s12889-020-09655-9] [Medline: 33054753]
47. Thorsteinsson T, Schmiegelow K, Thing LF, et al. Classmates motivate childhood cancer patients to participate in physical activity during treatment: a qualitative study. Eur J Cancer Care. Sep 2019;28(5). URL: https://onlinelibrary.wiley.com/toc/13652354/28/5 [Accessed 2026-04-02] [doi: 10.1111/ecc.13121]
48. Pahl DA, Wieder MS, Steinberg DM. Social isolation and connection in adolescents with cancer and survivors of childhood cancer: a systematic review. J Adolesc. Feb 2021;87:15-27. [doi: 10.1016/j.adolescence.2020.12.010] [Medline: 33450464]
49. Akca Sumengen A, Savas EH, Ay A, Ercan Koyuncu İ, Erkul M, Semerci R. Impact of technology on physical activity levels of childhood cancer survivors: a systematic review. Semin Oncol Nurs. Dec 2024;40(6):151757. [doi: 10.1016/j.soncn.2024.151757] [Medline: 39547836]
50. Shikako K, Mogo ERI, Grand-Maison V, et al. Designing user-centered mobile health initiatives to promote healthy behaviors for children with disabilities: development and usability study. JMIR Form Res. Sep 16, 2021;5(9):e23877. [doi: 10.2196/23877] [Medline: 34528886]
51. Agarwal S, LeFevre AE, Lee J, et al. Guidelines for reporting of health interventions using mobile phones: mobile health (mHealth) evidence reporting and assessment (mERA) checklist. BMJ. Mar 17, 2016;352:i1174. [doi: 10.1136/bmj.i1174] [Medline: 26988021]

Abbreviations

AR: augmented reality
COREQ: Consolidated Criteria for Reporting Qualitative Research
mHealth : mobile health
UG: undergraduate

Edited by Alicia Stone; peer-reviewed by Lisa McCann, Saniya Singh; submitted 14.May.2025; final revised version received 10.Feb.2026; accepted 12.Feb.2026; published 22.Apr.2026

Please cite as:
Marriott H, Straun K, Solera-Sanchez A, Watson E, Windsor S, Neu MA, Dreismickenbecker E, Faber J, Wright P
Exploring User Experiences of an Augmented Reality Smartphone App Prescribing Exercise for Children and Young People With Cancer: Results From a Qualitative Study
JMIR Form Res 2026;10:e76855
URL: https://formative.jmir.org/2026/1/e76855
doi: 10.2196/76855