Developing a virtual reality exergame to engage adolescents in physical activity: description of the formative intervention development process

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ABSTRACT

Background: Early adolescence (13-17 years) is a key developmental stage for physical activity (PA) promotion. Virtual reality (VR) exergaming is a promising intervention strategy to engage adolescents in PA.

Objective: The vEngage project aimed to develop a PA intervention for adolescents involving VR exergaming. This paper describes the formative intervention development work and process of the academic-industry collaboration.

Methods: The formative development was guided by Medical Research Council (MRC) Framework and included recruiting an adolescent user group to provide iterative feedback, a literature review, a quantitative survey of adolescents, qualitative interviews with adolescents and parents, inductive thematic analysis of public reviews of VR exergames, a quantitative survey and qualitative interviews with users of augmented reality (AR) running app Zombies, Run! (ZR) and building and testing a prototype with our adolescent user group.

Results: VR exergaming was appealing to adolescents and acceptable to parents. We identified behavior change techniques (BCTS) that users would engage with and features that should be incorporated into a VR exergame, including realistic body movements, accurate graphics, stepped levels of game-play difficulty, new challenges, in-game rewards, multi-player options and potential to link with 'real-world' aspects like PA trackers; and some potential barriers to use like cost, perceived discomfort of VR headsets and concerns about motion sickness. A prototype game was developed and user-tested with generally positive feedback.

Conclusions: This was a world-first attempt to develop a VR exergame designed to engage adolescents in PA developed within a public health intervention development framework. Our formative work suggests this is a very promising avenue. The benefit of the design process was collaborative parallel work between academics and game designers, and involvement of the target population in the game (intervention) design from the outset. Developing the game within an intervention framework allowed us to consider factors that would be important for future implementation (like parental support). This paper also serves as a call to action for potential collaborators who may wish to join this endeavor for future phases and an example of how academic-industry collaboration can be successful and beneficial.

KEYWORDS

Adolescent; adult; exercise; health; leisure activities; obesity; sports; video games; virtual reality; motivation.

INTRODUCTION

The benefits of performing sufficient physical activity (PA) are well established and include prevention of non-communicable disease and better mental health [1,2]. Early adolescence (12-17 years) [3] is particularly important because there is substantial age-related decline in activity levels from childhood into adolescence [4] and active adolescents are more likely to become active adults [5]. In addition, sustained moderate-to-vigorous PA (MVPA) in adolescence is positively associated with multiple markers of metabolic health, such as blood-pressure levels, insulin, C-reactive protein and lipoprotein cholesterol and triglycerides among others [6]. There is also some evidence that rates of depression and anxiety are lower in more active adolescents [7] and PA reduces depressive symptoms in this group [8]. However, the majority of adolescents are insufficiently active. Engaging adolescent girls in PA is particularly important since the age-related decline is greater for girls [9]. Objectively measured data from the Health Survey for England in 2016 showed less than 15% of UK adolescents were meeting the government's PA recommendations of at least 60 minutes MVPA per day [10]. Similarly, the US Department of Health and Human Services estimates that over 80% of American adolescents do not meet guidelines [11] and low levels are observed worldwide [12,13]. Leisure-time PA throughout adolescence is increasingly replaced by sedentary behaviors like screen-time [14], highlighting screen-time as a potential intervention target.

Challenge Engaging Adolescents in Physical Activity

While it is clear that intervention is required, how to change adolescent PA behavior at a population level remains unknown. A 2012 meta-analysis of 30 randomized controlled trials (RCTs) in children and adolescents up to 16 years using objective measures found that they only increased MVPA by an average of 4 minutes per week. Only two of these interventions specifically targeted adolescents [15]. A 2019 meta-analysis of 17 school-based interventions including children and adolescents found no increase in objectively measured daily MVPA in intervention compared to control groups [16]. These authors suggested that interventions were failing at the implementation stage, and the paper was a call to action for careful description of the intervention development and process evaluation [16]. A multimodal approach may be required, targeting the school/home environments, policy and parents [17,18]. However, multicomponent interventions are labor-intensive and it remains unclear how feasible they are for wide-scale implementation. Digital interventions have been proposed as a solution, but their efficacy for promoting PA in adolescents is not clear. A systematic review identified 17 digital intervention for adolescents designed to promote PA and diet, but studies were generally small and findings mixed [19]. In addition, the majority were web-based, which may not reflect current volitional adolescent technology behavior [19].

Gaming to Engage Adolescents in Physical Activity

There are industries that have been very successful in engaging adolescents, particularly the gaming industry. Gaming is a recreational activity regularly performed by over 90% of adolescents, popular across socio-economic groups and with girls as well as boys [20]. Gaming was recently highlighted as a promising avenue for health promotion [21]. Games requiring bodily movement – exergames – can encourage PA. A meta-analysis of 35 trials in children and adolescents found that previous generation exergames like Wii Fit and Dance Dance Revolution had similar physiological benefit to 'active' controls (running or field-based PA) [22]. Exergames also enhanced self-efficacy, liking/enjoyment and intrinsic motivation for PA [22]. In a three-arm RCT of obese 15-19 year olds, those encouraged to play Wii Fit for 40-60 minutes per day cooperatively (working with a peer to expend calories) lost significantly more weight and had increased self-efficacy compared to competitive (competing against each other) or control conditions (regular daily activities) [23]. In another small trial by the same researchers, percentage body fat was reduced in girls who adhered to a dance exergame [24]. Although most exergames were not designed in a research context, McBain et al. (2018) developed a High-Intensity Training (HIT) exergame for adult males in deprived communities and found that the game delivered sustained progressive HIT training over a 6-week pilot [25]. A mobile app-based game 'Pokémon Go', which has activity as a by-product of the gaming and fun element, has had huge commercial success with over 800 million downloads, and has resulted in short-term increases in step count in users [26]. A longitudinal survey found that exergaming may be effective at engaging adolescent girls in sustained PA, and that gender and motivation may be particularly important to consider when designing exergames [27].

The gaming industry has been commercially successful in building engaging products, but these were not developed as public health interventions or evaluated using traditional academic approaches. Collaboration between sectors offers a solution, but can pose challenges, with industry and academia having different skills, goals, timeframes, epistemic cultures and definitions of success [28]. The challenges of cross-sectoral collaboration between industry and academia, and health services, have long been recognized as a barrier to innovation adoption in healthcare [20]. There are also differences within academia between researchers from a health background and those from a computing background. Blandford and colleagues (2018) note the contrast between the former having a focus on summative evaluation and the latter on formative evaluation, as well as differences in epistemology and the culture of reporting [29]. Academic computer science research is closer to software industry practice in a number of ways, such as the nature of filling the gaps in research (summative vs formative reviews), the accepted evidence and the way research is reported [29].

Potential of VR

As part of a previous small industry-partnered innovation grant designed to explore the potential of VR to educate young people about benefits of PA 'Innerselfie' [30], we conducted technology workshops with 13-17 year old allowing them to try top range virtual and AR, and observed how engaging they found immersive virtual reality (VR). VR has potential to enhance the impact of an exergaming experience, since VR creates presence and allows the user to be fully immersed in the virtual environment [31]. VR headsets are increasingly portable, and wireless headsets and tracking allow for whole body movement. Statista reported projected worldwide shipments of VR headsets to reach 15 million in 2022 [32]. There is early evidence from laboratory studies in adults that immersive VR exergaming is more engaging than standard exercise. For example, in 88 university staff and students, heart rate was higher in a VR versus a standard exercise condition, ratings of fatigue lower and enjoyment higher in VR [33]. A pre-post study including 9 children found that playing an older generation VR exergame 'Astrojumper' for 15 minutes enhanced self-reported motivation to exercise, but this study had no follow-up to test whether behavior changed [34]. However, to the best of our knowledge, when we began this work, there were no VR exergaming interventions designed to promote PA in adolescents, and none where substantial formative development work had been conducted to inform content.

For the work presented in this paper we followed the Medical Research Council (MRC) Framework for developing and evaluating complex interventions published in 2000 and updated in 2019 [35]. MRC guidance consists of five steps: i) developing, ii) piloting, iii) evaluation, iv) reporting and v) implementation, specific to epidemiology, public health and even social policy [35]. In line with the MRC framework of developing interventions and other coherent approaches to intervention development [35], substantial formative development work is recommended to understand the target behavior and the views of the end users. While it is likely that to achieve sustained PA change interventions will need to target multiple social and environmental determinants of PA [36], we hypothesized that VR exergaming could be a platform to engage and motivate adolescents to be physically active, and could ultimately form the core of a multidimensional intervention. However, it was recognized that to make a high-quality appealing VR exergame that adolescents would want to play, industry experts would have to lead the development. Here we describe the steps involved in the early intervention development process of a true industry-academic partnership aimed at designing a VR exergaming intervention for adolescents.

OBJECTIVES

The overarching objective of the vEngage project was to develop then test a PA intervention for younger adolescents involving VR exergaming. The of this paper was to describe the process of the academic-industry partnership the formative development studies that fed into game development and development and user testing of the protype VR game. Future phases (subject to funding) will involve developing the game to full specification and identifying additional components (including 'real-world' activity partners) to encourage sustained behavior change.

Funding was awarded by the UK MRC Public Health Intervention Development scheme (MRC PHIND) to conduct the formative stages of intervention development outlined in Table 1. The project was a true academic-industry partnership whereby the industry partner Six to Start (led by AH) was a co-investigator on the grant and involved since project's inception and the grant gave structure to the collaboration. The collaboration was only possible because of the prior "problematisation" [38] based on Six to Start's prior experience with the National Health Service (NHS), interest in promotion of PA and the prior establishment of relationships across the research team (AH had been on the Innerselfie steering committee as the industry expert).

The academic team was led by AF, a behavioral scientist with background in promotion of PA for prevention and treatment of chronic disease. Other academic partners have expertise in sport science and epidemiology (LS), health informatics and statistics (HP), psychology and epidemiology (AS), risk-perception and health behavior (KN) and psychology (NF). The industry partners (led by AH) are Six to Start [37], commercial game designers who developed the world's most successful mobile app AR narrative (audio) based exergame ZR.

Table 1. Steps in the Phase I v-Engage intervention development work

Completed steps: Phase I		
Academic team	**Update meeting**	**Industry team**
MRC STEP 1: DEVELOPING		
1. Literature review to identify determinants of PA and mechanisms of change	x[a]	Scoping and finalizing suitable technologies
MRC STEP 2: PILOTING		
2. Recruit user group	x	Set up development environment and toolchain

3. Pilot quantitative survey with 695 adolescents	x	Pre-concepting / technology feasibility
4. Qualitative interviews with adolescents and parents	x	Pre-concepting / technology feasibility
5. Thematic analysis of public reviews of VR exergames	x	Pre-concepting
6. Survey of Zombies, Run! users with qualitative interviews	x	Develop and iterate prototype game using real hardware and exercise integration
Future steps: Phase II		
MRC STEPS 3: EVALUATION; AND 4: REPORTING		
MRC STEP 5: IMPLEMENTATION		
7. User / steering committee testing	x	Prototype released to the research team
8. Pre-post study		Not applicable for the industry team
9. Outline components for community PA link up and parental support		Outline necessary iterations to prototype game and possible link up technologies to integrate into game (eg, smartphone tracking)

[a]x denotes which steps have been completed by both teams

METHODS

Process for the academic-industry collaboration

An important aspect of our intervention development was managing the academic-industry collaboration. It was essential to establish a process that could balance the need for formative development work using traditional research processes, with the speed of working of game designers in a fast-moving technology-based industry and within the period of grant funding for Phase I (12 months). Ideally formative work would have been conducted prior to game development, but this was not feasible within the funding period, so work had to be conducted in parallel, with an ongoing dialogue and regular meetings involving presentations of research findings (academic team) and game demonstrations (industry partners). Key steps and timings of meetings are shown in Table 1. The industry partner was always aware of the need for flexibility to be built into in the game design in case new evidence arose from our work, or from the work of other researchers.

Literature reviewing: identifying theoretical and behavioral constructs

A key 'first step' in the research process was to identify which determinants may influence younger adolescent's PA and therefore which theory may inform the intervention. NF extensively reviewed the literature and identified potentially modifiable targets (summarized in Table 2). The determinants identified most closely aligned with Self-Determination Theory (SDT) of motivation [39] and it has been posited that the appeal of gaming may be grounded in their ability to satisfy basic psychological needs for competence, autonomy, and relatedness, core constructs of SDT [40]. The identified determinants and SDT were presented to the industry partners in our first formal meeting, then the group discussed which would be feasible to target using the exergame component. As highlighted in the introduction there is meta-analytic evidence that older generation exergaming can enhance PA self-efficacy, intrinsic motivation and enjoyment in children and adolescents [22,41], and a pre-post VR exergame study in 9 children suggested VR exergaming may enhance motivation and enjoyment of PA [34]. Therefore, it was determined that a VR exergame could target PA self-efficacy, motivation and identity, by allowing young people to experience movement in an immersive and fun environment (Table 2). Determining the wider intervention components (Table 2) is a key part of phase II (future work, subject to funding).

Behavior change techniques

The intervention required specific behavioral targets. It was not entirely possible to determine these from adolescent literature, since (as highlighted in the introduction) there are a lack of effective interventions to draw from. However, retrospective coding of more than 200 trials of PA interventions in more than 12,000 participants using the Behavior Change Taxonomy (BCT) [42] found that behavior change techniques (BCTs) such as goal-setting, self-monitoring and feedback on behavior were consistently associated with successful PA change [43,44]. The aforementioned review of digital interventions for adolescents also suggested these BCTs may be particularly important [45]. However, part of the work within this grant (user group visits, quantitative survey with adolescents) aimed to determine which BCTs they would engage with in a digital intervention. Table 2 includes proposed BCTs that could be linked to specific elements of the intervention.

Table 2. Behavioral determinants of adolescent PA from literature reviews and hypothesized method of inclusion in the intervention

Potentially modifiable targets	**Description**	**Proposed intervention components**	**Proposed BCTs [43]**
VR exergame [a]			
Self-efficacy	Individuals own beliefs about capability to carry out a task	Game features that encourage feedback on performance, small in-game rewards, multiplayer elements for social support/feedback on performance of others	Feedback on performance Goal-setting Rewards (in-game) Social support Time management
Motivation	Particularly intrinsic motivation, driven by internal reward	Delivery of PA using platform that is highly appealing to target users, perform PA in a fun and visually appealing immersive environment, specific game targets to access next levels	Goal-setting Self-reward Incentive
PA identity	Individuals view of themselves as someone who is physically active (or not)	PA as a by-product of fun and enjoyment, immersion distracting from negative physiological effects of exertion, shifting negative perceptions of PA	Framing/reframing Identity associated with changed behaviour
Wider intervention			
Parental support	Identify ways to reduce concerns about gaming and garner parental support for intervention	Design a non-violent game Displace sedentary with active screen time	Social support Monitoring of behavior by others without feedback (awareness) Time management

Community/external PA opportunities	Link up with PA partners that appeal to target users	User group suggestions were online influencers, trampoline or skate parks, climbing walls,	Restructuring the physical/social environment Behavioral practice/rehearsal
Link up with wearables and trackers	Synch game with wearables / PA trackers to feed into the game	Most common / preferred by target group smartphone app	Self-monitoring of behavior Feedback on behavior
Habits		Encourage game play at same time, same context to develop a PA habit Displacing sedentary behaviors with active gaming	Habit formation Planning

[a] focus of the current phase (although some aspects like multiplayer could not be built into the prototype)

[b] future work, subject to funding

Establishing and working with a user group

A key part of our formative work was to establish a group of adolescent users to get iterative feedback on ideas, help us design questions for empirical research and try technologies. It was important to ensure representation from girls, as well as boys. Thirty-six 13-16-year-old (19 boys and 17 girls) from three London schools were recruited. The user group were separate from the research participants. A number of visits to schools were conducted to i) discuss initial ideas to shape the grant application ii) discuss experiences of gaming and VR and rank BCTs in order of preference iii) try our prototype game and consider what the wider intervention might contain.

Quantitative survey with adolescents

A cross-sectional quantitative survey of adolescents was conducted through two London-based schools and online platforms (girls schools were recruited in the hope of understanding more about the views of girls, but the online version was open to anyone aged 13-24 years). The aims of the survey were to understand adolescent PA behavior, beliefs about and desire to change PA and identify which BCTs they would like to see in a digital intervention. To help understand which companion technologies might accompany a VR exergame (to allow self-monitoring) the survey also asked them to report which platforms they used/preferred. Full analyses are in progress but the summary findings using descriptive statistics (that were provided to the industry partner to incorporate into the game) are described in this paper.

Qualitative interviews with adolescents and parents

Semi-structured interviews were conducted with target users (adolescents aged 13-17) to explore their interest in VR, views about VR as a way to encourage activity, potential barriers and which features they would like to see in a VR game. Interviews were conducted by two graduate psychology researchers. Data were analyzed using thematic analyses conducted by the academic team (AF, NF, KN). In order to incorporate findings into game development NF presented results as they emerged and created a table of desired game features. Full thematic analyses were performed [46,47] in parallel fulfilling sufficient sample size requirements [48], and findings published (including the table of recommendations provided to the industry partner) in JMIR Serious Games in 2019 [49].

A separate qualitative study aimed understand how parents of adolescents felt about VR as way to encourage adolescent PA, and how best to gain their support for this type of intervention. Summary findings necessary for game development were presented to the industry partners in a meeting, and full findings published in JMIR Serious Games [50].

Inductive thematic analysis of public reviews of VR exergames

In order to investigate game features that were particularly enjoyed or disliked in VR exergames reported players themselves, we thematically analyzed 498 publicly available reviews of exergames from the top 3 VR marketplaces Steam (Valve Corporation), Viveport (Valve Corporation), and Oculus (Oculus VR). To share findings to feed into our game development table of key recommendations was generated for the industry partner as soon as was possible, and the full study (including the table) has been published in JMIR [51].

Survey and interviews with ZR users

The exergame developed by our industry partner (ZR) is an immersive audio AR mobile application (app) released in 2012 [52]. The app became the highest grossing health application on Apple's App Store (Apple Inc.) two weeks post-release. Since 2012, ZR has accrued 5.5 million downloads, with approximately 200,000 monthly active users [53]. ZR combines exercise and a post-apocalyptic radio story, a narrative-based game delivered via the smartphone app. To understand what appealed to the users of popular and widely used exergame and potential impact on PA behaviour, we surveyed ZR users between November to January 2019. The survey was cross-sectional and included 36 questions around experiences of using ZR, likes and dislikes of app features and engagement with BCTs. Users were also asked to report their PA levels (number of days and length of sessions of MVPA using the items from Coleman et al. [54]) prior to and since using ZR. The survey also aimed to explore interest in VR exergaming, and perceived benefits and barriers to this. The users were reached via in-app notification, ZR social media and ZR newsletter. The survey asked ZR users if they were willing to be interviewed qualitatively in order to tell us more about their experiences, and 30 ZR users were interviewed.

Building the prototype

At the conception of the project the industry partners developed gameplay concepts for the VR prototype based on some key findings that emerged from our research (summarized in Table 3). Six to Start then established some basic principles in order to widen the potential game audience in terms of technology and appeal:

- The game should not require any special equipment other than a standard Vive/Oculus VR setup; ie, no weights, additional Vive trackers, exercise bikes, pull-up bars (because this would limit future implementation)
- Gameplay should not be overtly about fitness or exercise (because our user group almost universally reported they would prefer a game that was fun with physical movement as a by-product)
- The game must work in a standard household environment such as a living room with normal height ceilings

Six to Start reviewed a wide set of basic gameplay types, such as Simon Says (similar to Dance Dance Revolution), Dodgeball, Point and Shoot, Building, Plate-spinning (maintenance of a chaotic system, eg, Diner Dash), and Photography. They also established some desirable principles such as quick sessions, peaks and troughs in physical exertion, and quick start-up, all which are common with very popular "casual" and "hypercasual" games that tend to reach a very wide audience. Finally, both teams discussed the content of the game, and how it might be scaled – whether the game's levels should be all human-authored or randomized, or semi-randomized. Two broad concepts were arrived at with working titles "action photography" and "hole in the wall". These were discussed with our user group and ultimately to develop solely the latter concept to have more time for iteration and graphical polish. Development took place on the Unity platform and Steam VR for ease of cross-platform deployment to different VR hardware. The prototype was designed for room scale use and tested on HTC Vive hardware with the standard two hand controllers, to allow for full body movement tracking. Gameplay was iterated during development, adding music and developed levels that increased in difficulty, as well as built level design tools for non-programmers.

Intellectual property: game code

Establishing intellectual property (IP) agreements with multiple partners can be complex and establishing an IP contract that satisfied all collaborators took a number of months. A funder requirement was that, at the end the project, the code for our game would be made available open source under the Open Source License GPL v3 and available on our website. Open-source code is beneficial for future software development and the academic community. A benefit of acquiring external funding for a research endeavor meant that Six to Start were also involved in an exploratory research capacity, rather than for financial gain. If other partnerships requiring similar IP contracts wish to see the content of the agreement in order to expedite their own process they are welcome contact the corresponding author for sharing.

RESULTS

Quantitative survey of adolescents

695 adolescents (13-18 years: 86%, 19-24 years: 14%; 96% girls) completed the survey. Analyses are ongoing and we plan to explore differences in preferred BCTs and technology features by gender and age, but overall 77% were interested in advice to increase their PA and were most likely to go online or use a tablet/mobile app to find information about PA. 50% used some kind of health tracker. Preliminary data on preferred BCTs suggest that goal-setting, personalized feedback on behavior, instructions of how to perform a behavior, self-monitoring and rewards were strongly desired. Features that were less desired were information about health consequences of not performing sufficient PA, and features that include social networks/forums, or photo feedback.

Qualitative interviews with adolescents and parents

Qualitative interviews were conducted with 31 adolescents (58% female, 62% from non-white ethnicities). Boys and girls were equally positive about the use of VR for PA promotion. Both highlighted fun or enjoyment as fundamental. Rewards, increasing challenges, including a social/multiplayer and real-world aspects were all identified by participants as important game features. Barriers included the cost of high-end systems and the need for parental approval [49]. Exercising at home was perceived as very appealing and a way to overcome social and cultural barriers to PA, particularly for girls. 18 parents of adolescents took part in interviews and believed that VR exergaming would engage their adolescents with PA, and although they would prefer real-world PA they were very supportive of an intervention that harnessed gaming for a positive outcome (promotion of PA). In addition, that they consistently reported that to garner their support a game must be non-violent and that mental health was their most salient reason for encouraging PA in their adolescents, so a game would ideally be calming or relaxing rather than aggressive. For more detail on results of the studies see [49,50].

Thematic analysis of public reviews of VR exergames

The results of the review found that VR exergaming was a way to engage with PA in a fun, enjoyable and playful way, without PA being the focus of the activity. Promisingly users reported feeling that VR exergaming had provided exertion comparable with 'real world' PA. However, some notable drawback were also identified, such as those pertaining to the technology itself (e.g. the mechanics of the games and unintuitive controls) as well as lack of real-world feeling while playing the games. The full details of this study are available in [51].

Survey of ZR users

This work was in progress at the time of writing and we plan to explore findings by age and gender, but summary findings are presented here. 6423 participants opened the link. 5343 completed the survey. Participants ranged from 16 to 71 years (mean=33.1, SD=10.1). 59% identified as female, 38% male and 3% as other. The majority were white (84%) and approximately half were from the United States (46%). The most common education category was Bachelors' Degree educated (37%). ZR app usage was associated with a reported mean increase of 84 minutes of PA (95 % confidence interval 82, 87). 40% of participants experienced a positive identity shift (from not a runner to a runner). The BCTs or game features with strongest perceived impact on the PA behavior were positive outcomes of PA, goal-setting and obtaining intrinsic reward (through fun); while the least important were obtaining a reward-money and social comparison. The most popular game features of ZR included simulation, customization, self-monitoring, role-play and obtaining a within-game reward. 65% hadn't tried VR exergaming but would like to, 23% hadn't tried it and didn't want to, 8% had tried and liked it, 2% had tried and didn't like it and 2% didn't know what it was. By far the most appealing perceived positive aspects of VR were immersion and fun/enjoyment. The perceived negative aspects were cost and discomfort (heavy or bulky headset).

Preliminary thematic analysis of 30 interviews revealed that people became immersed in PA through the narrative of the story and this motivated them to keep going and distracted them from negative associations with PA. The app wasn't solely used for running by all participants, but also for walking, gardening or cycling. 70% of interviewed sample reported positive effects on mental health. The qualitative and quantitative work are being written for publication by NF as part of her PhD work.

The prototype

The key findings of the formative research that fed into the prototype game are described briefly in Table 3. The game was given the working title 'Walls' (see Figure 1) (although we subsequently asked the user group to suggest appealing names). In the game, the player needs to use the VR controllers to complete complex patterns which appear on walls by moving their arms and body to be as accurate as possible. An image of a player trying the prototype is presented in Figure 2. The accuracy and speed of completion earn players high scores. The game includes PA movements such as stretching, fast and slow arm motions and dodging. The idea is that if game were developed further, additional levels would become more and more physically challenging. However, the virtual environment was also designed to be calming (based on parental views).

Figure 1. ‘Walls’ exergame developed and evaluated as part of the project.

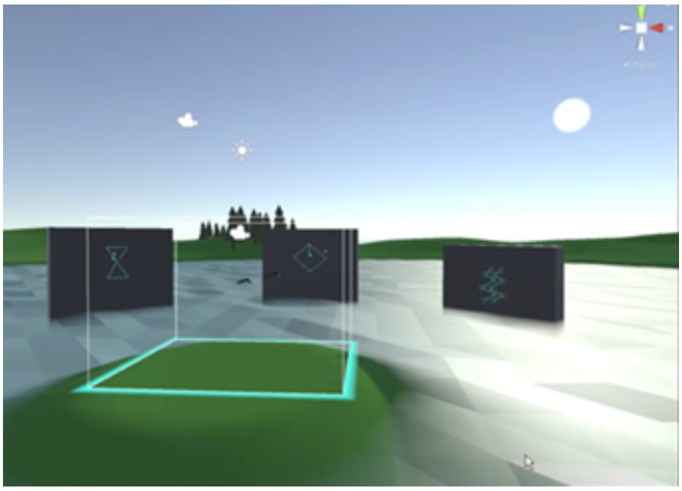

Figure 2. A player during ‘Walls’ gameplay.

Table 3. Key features of research that fed into game design

Study	Key findings that fed into game design	Reference
Review of literature	See Table 2	See Table 2
User group	Preferences for game types, preferred BCTs; Iterative feedback on prototype ideas	N/A
Adolescent survey	Strong desire to increase PA; Preferred BCTs such as goal-setting, feedback on performance	In preparation
Adolescent qualitative interviews	Desired VR exergame features: Being able to exercise at home; Rewards; Increasing challenges; Social or multi-player aspects; Using own Music; Barriers: High cost; Need for parental buy-in	Published in [49]
Parent qualitative interviews	Approval of harnessing gaming for something positive; Intervention must be non-violent; Mental health most salient reason for encouraging PA and a calming virtual environment preferred	Published in [50]
Thematic review of VR exergame reviews	Desired VR exergame features: Removing motion sickness due to immersive quality and accurate graphics; Gradual acquisition of skill and multiplayer options with music; Disliked features: Motion sickness, poor graphics, unresponsive developers	Published in [51]
ZR survey	Global appeal to those who identified as gamers and non-gamers and all ages; Main use of ZR was running but also walking, gardening and cycling and training for weight and fitness control, even to run marathons	In preparation
ZR interviews	Narrative and interactive storyline the reason for engagement, not the actual game-play; Distraction from negative and mundane aspects of running; Community feel; More than half used ZR to improve mental health (improved mood)	In preparation

User testing of the prototype

Before trying our prototype 89% (n=17/19) of the boys and 59% (n=10/17) of girls had tried some form of VR. This was almost always a smartphone-based headset, rather than a fully immersive experience. All-but one who had tried it reported enjoying it, with the exception of one reporting motion sickness. When asked which features they'd like to see in our game goal-setting, rewards, social aspects, choosing own music, custom levels or custom storyline, player creation and progressive game challenges were reported as most important features they wanted to see in the VR exergame. The majority of students (but not all) enjoyed the prototype game play (n=23/31; 74%). Issues were lack of instructions at the set-up to practice, confusing controller functions and not seeing the overview of other people's scores at the end to compare their performance. Almost all students reported feeling excited about the potential of the VR game once it had been further developed and provided additional feedback ranging from alternative names, features that would make the game even more appealing and ideas for the wider intervention.

Other important outcomes: training of researchers and engaging adolescents with science

The formative development work described here has facilitated substantial post-graduate training. In a short funding time-frame, when a large proportion of the grant has to necessarily go towards game development, in order to conduct and disseminate work it has been invaluable to involve graduate psychology researchers. Four UCL MSc students (listed in acknowledgements in this paper and authors on the relevant papers) conducted their dissertations on this work and the data will contribute to the PhD of NF (who was employed as a research assistant during the funding period). The novelty of this project, and the opportunity to spend time in a research center and a gaming lab made the projects appealing, and extremely enjoyable and valuable for students. In addition, teachers from the schools where the user groups were recruited informed us that an unanticipated benefit was engagement of their young people in the scientific process, with a number of their girls and boys wishing feeling motivated to pursue careers in scientific research or computer science/game development.

DISCUSSION

This paper described the formative intervention development work that resulted in the development of a prototype VR exergame, designed to engage adolescents with PA. The results of the vEngage formative development phases demonstrate that our target population, younger adolescents 13-17 years, see great potential in VR technology as means to engage in PA and this enthusiasm was reflected by users of another population exergame (ZR). We identified a number of desired features of VR exergames include realistic body movements, removing motion sickness and accurate graphics, gradual acquisition of skill and multiplayer options with music. However, notable perceived drawbacks to a VR exergaming intervention were affordability and accessibility and potential discomfort. Additionally, our study using inductive thematic analysis of public VR exergames reviews suggested that although VR exergaming can elicit levels of exertion that users equate with other forms of MVPA, and distract participants from the negative perception of performing PA, the affordability of high-end VR equipment, the graphics and motion sickness are still drawback to VR becoming more mainstream [51].

The benefit of the applied design was that the academics used traditional academic methods of inquiry to study the target population and in turn informed the game developers. Feedback on our prototype was encouraging and future work (subject to funding) will seek to further develop the prototype and wider intervention components. The academic-industry collaboration was successful due to the iterative nature of collaboration and frequent meetings where goals were set and work was performed in parallel and shared in real time. We hope describing our process can serve as a guide to researchers who wish to design an intervention together with their target population and an industry partner. We established ways of distilling top-line academic findings quickly to provide to the industry partner. In addition, we utilized ways of accessing information quickly, like analyzing existing publicly available reviews of VR exergames [51] or collecting data from the existing ZR user base, along with more traditional recruitment processes.

Study strengths and limitations

This work has a number of strengths and limitations. The collaborative approach and involvement of end users throughout were strengths. However, within the limits of early phase funding it was only possible to develop the game to a standard that would facilitate user input, meaning that we could not assess the potential of the game for impact on PA. We have an ongoing experimental study exploring the potential exertion (heart rate and perceived exertion) that can be achieved playing some of the popular commercially available VR games.

The mix-methods were a strength; we employed a number of different methods including thematically analyzing player reviews, in app surveys and well as standard surveys and qualitative interviews. However, the formative studies had limitations. The quantitative surveys were cross-sectional self-report (although questions about interest and engagement can't be assessed objectively) and a future aim would be to test the fully developed game and use accelerometers to measure PA. The school-based survey was completed as a class activity following opt-out consent. However, it is very likely that the ZR users survey was completed by people who felt most positive about ZR, introducing some selection bias. Our user group and those we interviewed qualitatively were recruited from schools in and around the research center in London, which may not reflect the views of others in different geographical locations (although the sample of interviewed ZR users was worldwide). The vast majority of our those we surveyed or interviewed did not own or use VR frequently, which meant that barriers and benefits were generally perceived rather than based on experience. Longer and more frequent exposure in the context of a trial would allow us to explore how these factors influence their PA behavior and user experience. It is likely that multimodal intervention would be required, targeting multiple influences on adolescent PA [17,18] and the current work only focused on VR exergaming (which we hypothesized may enhance motivation for PA). In line with frameworks like the COM-B model and Behavior Change wheel, it is important that intervention considers the wider influences on behavior and not just individual motivation [43].

Long-term and sustained behavior change

It is worth considering the wider application of our findings including steps towards implementation of VR (and AR) exergaming interventions. Implementation of VR games to sustain behavior change would be made easier if VR gyms or fitness centers utilizing VR existed in the UK, but at present (August 2020) there are none and the cost of an average head mounted VR is still relatively high (average £400). The somewhat virtual gyms (eg, Digme) that do exist, are not allowing full-immersion via head mounted pieces, but modify the user's experience by similar means as theatre performances and AR (eg, use of music and lights) and displaying certain features on the screens in front of users [55]. The availability and accessibility of VR for PA is still tied to cost, the technological market and PA competitors (eg, gyms, fitness clubs, sports centers, apps, outdoors etc). VR exergaming would have to offer people a distinct and accessible PA experience. However, it has been predicted that VR console home ownership will continue to rise home [32]. The COVID-19 pandemic and the need for social distancing or restrictions placed on exercise facilities mean that tools that can facilitate home-based exercise have never been more important.

Future work

There are a number of challenges in the next steps for the project. Firstly, funding must be acquired for future phases. The funding was awarded for the formative development work and we believe that we have established that VR exergaming is promising for engagement with PA in our target group. However, significant development work is required for the game to be at the stage that it is ready to trial. As highlighted in the introduction, it is likely that multimodal intervention would be required to facilitate sustained PA change [17,18]. We have always acknowledged that the game alone is unlikely to be sufficient for long-term change, and working with our user group identified that linking with ‘real-world’ technologies (e.g. trackers) and real-world activity partners (e.g. vouchers to try a range of real-world activities like climbing wall, boxing class, trampoline park, etc). However, these options will have to consider the post COVID-19 pandemic world and the need for socially-distanced exercise, which our vEngage project did not directly address. Implementation also requires the game to be promoted in order that it gain a sufficient user base to support further testing and to warrant further development. To be successful as more than a testbed, the game needs a funding mechanism beyond the initial research funding.

Future intervention development steps (Phase II) include developing the VR game to a high specification, identifying components that can link PA to the game (eg, smartphone phone tracking), linking with real world PA partners (eg, schools and community or leisure centers, gaming conferences), linking with vloggers. Ultimately, we would like to empirically test the potential of our intervention to enhance motivation and change behavior (Phase II).

Ethical consideration and dissemination

Ethical approval has been provided from the UCL ethics committee for all relevant steps above, and participants or parents provided informed consent (Project IDs: 10213/001, 12669/001, 3777/004). The results of each stage of this work have been or will be disseminated to academic audiences through presentations at national and international conferences in PA, public health and gaming and through peer-reviewed publications in relevant journals. Results have been/will be disseminated to the public, policy makers, and game designers through seminars and press releases coordinated through the UCL Press Office.

CONCLUSIONS

This vEngage project is a world first attempt to develop a VR exergame designed to engage adolescents with PA utilizing academic-industry collaboration. Our findings suggest that VR exergaming has potential as a public health intervention designed to engage adolescents in PA. We plan to take this work forward and invite collaboration for future stages.

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CONFLICTS OF INTEREST

As outlined in the paper this is a true academic and industry collaboration which was funded by the UK MRC industry partnership grant and leads to the development of a VR game licensed by Six to Start. There is no legal, financial, or commercial conflict with our industry partner company, Six to Start.

ABBREVIATIONS

AR: Augmented reality

BCT: Behavior change taxonomy

BCTs: Behavior change techniques

HIT: High-intensity training

MRC: Medical Research Council

MVPA: Moderate-to-vigorous PA

NHS: National Health Service

PA: PA

RCT: Randomized Controlled Trial

SDT: Self-determination theory

VR: Virtual reality

ZR: Zombies, Run!

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