



# A Review of Serious Gaming as an Intervention for HIV Prevention

Ariel U. Smith<sup>1</sup> · Gabriella M. Khawly<sup>2</sup> · Janna Jann<sup>1</sup> · Ana Paola Mata Zetina<sup>3</sup> · Janeth Padilla<sup>3</sup> · Rebecca Schnall<sup>2</sup>

Accepted: 8 May 2023 / Published online: 22 May 2023

© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2023

## Abstract

**Purpose of Review** Young people face the highest number of new HIV infections globally. With today's increasing access to smartphones, serious games have been viewed as an effective means of improving knowledge and behavioral outcomes. This systematic review describes current HIV prevention serious games and their relationship with HIV-related knowledge and behavioral outcomes.

**Recent Findings** A search of HIV prevention serious games was conducted using PubMed, CINAL, IEEE, Web of Science, and Google Scholar. A total of 31 papers were identified, which consist of 20 studies and 11 protocols. Results for knowledge, attitudes, intentions, and behaviors were mixed. Two interventions reported improvement in PrEP usage and optimal dosing.

**Summary** Gaming appears to be a viable and engaging method to improve knowledge, attitudes, and behavioral outcomes to promote HIV prevention among diverse groups of adolescents and young adults globally. However, additional research is needed to understand how to implement this modality effectively.

**Keywords** HIV · AIDs · Gaming · Intervention · Serious games

## Introduction

Despite the increase in treatment and testing, the HIV epidemic continues to impact approximately 1.2 million people in the USA and an additional 38.4 million people globally [1]. There are notable disparities in the epidemic, with specific geographic regions in the USA highlighting the need for culturally targeted intervention [2]. Moreover, disparities occurring at the intersection of race/ethnicity, gender, and sexual orientation warrant further attention [3]. Given the negative health outcomes associated with the acquisition of HIV [4], innovative interventions are needed to engage various communities that are underserved, under-resourced, or under-engaged in prevention efforts.

Gaming is one such tool that has emerged as a potential adjunct for clinical treatment and targeting a variety of health

conditions [5•]. Gaming refers to the engagement of interactive play through consoles, computers, mobile phones, face-to-face interactions, and other mediums for fun or high stakes [6] (<https://www.merriam-webster.com/dictionary/gaming>). Additionally, phrases such as “game-based learning,” “serious games,” “serious learning games,” or gamification have been employed to describe gaming applications. For instance, game-based learning is an umbrella term used to describe the achievement of learning outcomes through game context, such as fun and play, to reach a specific skill or achieve a certain outcome [7]. Within the umbrella of game-based learning is “serious learning games,” also referred to as “serious games.” These include applications or modules that encompass active, problem-solving, and rapid feedback, which promotes learning in the context of industry training or simulation [8, 9]. Serious games are classified as full-fledged games to promote learning [9]. On the other hand, gamification refers to applying gaming mechanics such as points, badges, trophies, and other incentives that are applied in non-game contexts [8–10]. Although gamification is a broader concept that focuses more on the components of games and their application to real environments, each of the three terms (gamification, game-based learning, serious games) share the idea of using gaming and fun for the purpose of education or behavioral change rather than mere entertainment [11].

✉ Ariel U. Smith  
asmit37@uic.edu

<sup>1</sup> College of Nursing – Population Health Systems Science, University of Illinois at Chicago, Chicago, IL, USA

<sup>2</sup> Department of Epidemiology, Mailman School of Public Health, Columbia University, New York, NY, USA

<sup>3</sup> Division of Scholarship and Research, Columbia University School of Nursing, New York, NY, USA

Terms such as eHealth (electronic health), mHealth (mobile health), and computer-based games have been used to describe the medium in which gaming interventions have been implemented in health practice [12]. These terms do not necessarily describe the type of gaming mechanisms employed to facilitate change but have been used interchangeably to describe various interventions that employ gaming via electronic or digital mediums [13]. For this paper, the phrase “serious games” will be employed to describe all gaming interventions (regardless of medium) used to improve health or behavioral outcomes.

Serious games are designed for educational and training purposes, not solely for entertainment. They empower participants by engaging them in realistic scenarios that encourage them to make decisions to increase health promotion [9, 10, 14, 15]. The employment of serious games to improve health is a scalable innovation that can provide participants with a risk-free environment to freely navigate different conflicts and identify healthy choices to improve health outcomes [16]. Studies have shown its established utility in improving critical thinking skills such as problem-solving, coping, and emotional management as participants are able to reassess and reflect on prior decisions [16, 17, 18, 19]. Virtual environments provide an accessible platform that can be used to educate and empower participants through social skill training and deep learning [17].

Serious games have been shown to improve health behavior motivation with positive results in health interventions addressing sex education, nutrition, asthma, diabetes, and cancer [14, 18]. Many serious games incorporate “gamification” elements such as setting challenges, goals, and rewards for a player to converge extrinsic motivation into intrinsic motivation for behavioral change [11]. A systematic review found that serious games employed in randomized control trials improved the outcomes of psychotherapy (69%), physical therapy (59%), physical activity (50%), clinician skills (46%), health education (42%), pain distraction (42%), and disease self-management (37%) among diverse populations [20]. Participants enjoyed engaging in serious games due to the game’s ability to fulfill psychosocial needs (i.e., control, autonomy, and sense of achievement) [21]. Given that about 95% of teens and adults have access to a smartphone, digital interventions, such as serious games, may be an accessible means of engagement [22].

Given the evidence of serious games in health, the purpose of this descriptive review is twofold. The first objective is to describe serious games employed for HIV prevention interventions that are currently available and examine the approach employed within serious games. Next, this review will explore the relationships between serious gaming interventions with attitudes, knowledge, and behavioral outcomes.

## Methods

We conducted a comprehensive search of serious gaming HIV prevention interventions using PubMed, CINAL, IEEE, Web of Science, and Google in the summer of 2022. This search was based on the best match. Given the scope of our resources, we were limited and could not search more comprehensively than the first ten pages, which was approximately 500 articles per search engine. We acknowledge this limitation and have included this in our limitations section. The search was limited to English articles. The final list of search terms included: (HIV or AIDS or PREP) AND (Intervention or eHealth or mHealth or program or “clinical trial” or pilot or prevent\*) OR (Gaming or game or gam\*). We included studies that assessed feasibility, usability, or outcomes such as knowledge, attitudes, or behaviors of game-based HIV prevention interventions. Pilot, usability, and feasibility studies were included. Studies were excluded based on the following criteria: (1) did not assess a game-based intervention; (2) articles that were systematic reviews or did not have full text; and (3) articles not published in English.

We define HIV prevention as the focus of reducing the risk and protecting against HIV infection by altering knowledge, attitude, and/or behaviors [23, 24]. Hence, these interventions typically included populations that are HIV-negative. Outcomes of interest include HIV testing, attitudes about HIV testing, PrEP adherence, contraceptive use, sexual health knowledge, and sexual health activity. This review will include game-based interventions focused specifically on *HIV prevention*.

The authors divided the online reference databases and conducted the initial title/abstract review. Each title/abstract was reviewed by one reviewer. Next, two reviewers independently reviewed and extracted data from eligible articles. Following title/abstract review, the remaining articles ( $n = 54$ ) were assessed to determine if they further met eligibility criteria. Articles were excluded due to focusing on HIV management instead of prevention ( $n = 16$ ), not assessing or describing the protocol for a serious game ( $n = 7$ ), being a systematic or scoping review ( $n = 2$ ), or if the full text was not available in English ( $n = 1$ ).

Additionally, all authors were instructed to examine the references of each eligible full-text article to determine if any additional articles would meet the inclusion criteria for review. If additional articles were identified from examining the references, the title/abstracts of these articles were assessed by one reviewer. If the article met inclusion criteria, the full text was independently reviewed by two authors. Any discrepancy was discussed and reconciled. All articles recommended for full-text review ( $N = 31$ ) were analyzed (see Fig. 1). The Garrard matrix method was employed to evaluate articles critically, extract study components, and compare, contrast, and

synthesize findings [25]. The following was extracted from each article: sample characteristics, research design, methodological quality, theoretical or conceptual framework used, intervention description, measurement approaches, and intervention outcomes. Data from each eligible article were organized in an Excel spreadsheet, appraised independently, and reviewed by a second author. Discrepancies were discussed between reviewers until a consensus was reached.

## Result

A total of 31 articles were included in this study. We identified 20 studies that evaluated and reported the impact of serious gaming HIV prevention interventions on knowledge, attitudes, and behavioral outcomes (see Table 1). Additionally, 11 study protocols were included (see Table 2). About 65% of studies included in this review ( $n = 20$ , including protocols) were published within the past 5 years.

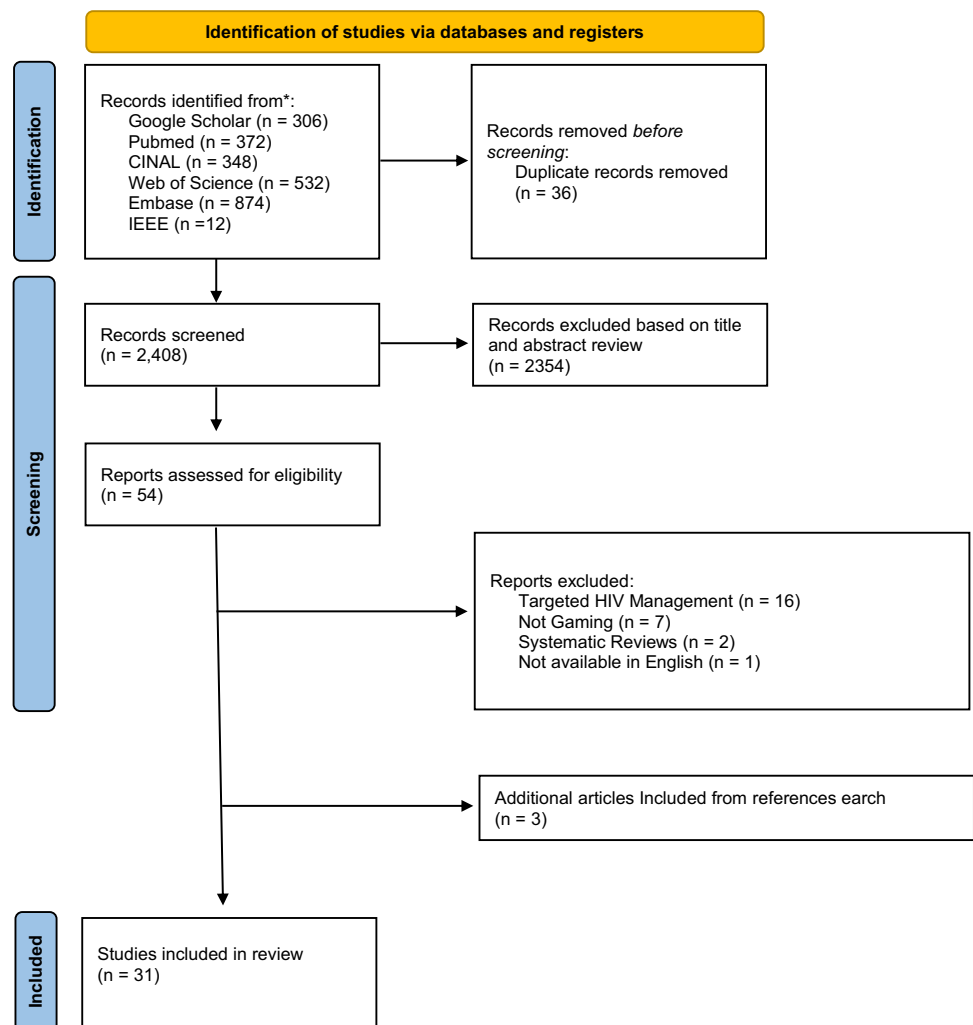
The target populations for the studies included within this review included non-sexual/gender minority adolescents ages 11–18 years old ( $n = 12$ ) and non-sexual/gender minority adults ages 18 and up ( $n = 3$ ). There is also one protocol that targets both adolescents and young adults ages 13–24. Additionally, studies tailored for sexual and/or gender minority populations, which included both adolescents and adults, were included ( $n = 15$ ). The age range across all studies is age 11–59.

The remainder of this section will describe HIV prevention interventions that utilize serious games and related outcomes. Existing protocols describing HIV prevention interventions that utilize serious games will also be discussed.

## HIV Prevention Gaming Interventions

Interventions are arranged based on three populations: adolescents, adults, and sexual and gender minority individuals.

**Fig. 1** PRISMA model flow-chart for the keywords used in the review of serious gaming as an intervention for HIV prevention



**Table 1** Description of HIV prevention games and outcomes

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
<b>Adolescents</b>								
Fiellin [26●●]	PlayForward: Elm City Stories	Ages: 11–14 USA racial/ethnic minority adolescents <i>N</i> = 333	We hypothesized that an engaging theory-based digital health intervention in the form of an interactive video game would improve sexual health outcomes in adolescents	RCT	Yes	Total: 6 weeks 2 sessions per week, 1 h per session	Immediate post 3 months 6 months 12 months	No differences in rates of initiating sexual intercourse ( $P = 0.77$ ) Improvement in attitudes about sexual health compared to control ( $P = 0.03$ ) Increased sexual health knowledge compared to control ( $P < .001$ ) Intentions to delay intercourse: no differences ( $P = 0.56$ ) Significant changes in intentions and knowledge ( $p = 0.037$ ) ( $p = 0.025$ ) related to HIV testing and counseling at follow-up No change in perceived susceptibility to HIV ( $p = 0.390$ ) No significant changes in HIV testing ( $p = 0.135$ )
Pendergrass [27●●]	+PlayTest: modified videogame	Ages: 14–17 Male and female adolescents <i>N</i> = 13	Modify an original serious game targeting risk reduction and HIV prevention developed and create a new serious game that focuses on HTC; (II) evaluate its feasibility and acceptability; (III) pilot test the assessment measures that are subsequently being used in a large trial	Pilot test Feasibility Acceptability	No	Total: 3 weeks Twice weekly for approximately 6 h	3 weeks 6 weeks	

**Table 1** (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Winskell [28●●●]	Tumaini	Ages: 11–14 Male and female preadolescents Kisumu, Western Kenya N=60	To pilot test a theory-based, empirically grounded smartphone game for young Kenyans designed to increase age and condom use at first sex, aiming to establish the directionality of effects on behavior change	Pilot RCT	Yes	Total: 16 days 1 h/day-16 days	Immediate post 6 weeks	Significant changes in behavioral intentions for risk avoidance and reduction ( $p=0.006$ ) Increases in self-efficacy scores ( $p= <0.001$ ) Increases in knowledge, attitudes, risk assessment, self-efficacy, and behavioral intentions in the thematic areas of puberty ( $p=0.001$ ), and pressure from adults and peers ( $p=0.02$ ) Significant gains in sexual health-related knowledge and self-efficacy (both $P < .001$ ), sexual risk communication ( $P = .006$ ), No differences in assessment of risk, attitudinal measures, or perceived social norm

Table 1 (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Shegog [31●●]	It's Your Game (IYG)	Ages: 12–14 Middle school youth Houston, TX N=14	Evaluate the multi-media component of IYG on student attitudes of importance of the curriculum content, self-efficacy regarding refusal skills, and usability parameters	Usability	No	Total: four 35-min computer sessions * Only multimedia components were tested	N/A	Ease of use: 78–100% Content trustworthy and correct: 92.9% Program language understandable: 100% Interface strategies and program activities fun: 71–100% Content helped student make health choices: 92.9–100% Two participants suggested more media elements
Shegog [32●●]	*It's Your Game (IYG)-Tech	<i>Usability test</i> Ages: 12–14 N=33 <i>Feasibility test</i> Ages: 13–15 N=22 Southeast Texas	Evaluate usability parameters and immediate impact on selected psychosocial factors related to sexual behavior	Feasibility pilot test	No	Total: 3 weeks Once per week (length of time undefined, but stated lessons are 35 min and complete 8/day)	Immediate post	Positive beliefs about waiting to have sex ( $p < .01$ ) Greater self-efficacy to use condoms ( $p < .05$ ) Greater intentions to abstain from sex until marriage ( $p < .01$ ) Youth rated IYG-Tech favorably compared to other learning channels (> 76.2% agreement) Higher perceptions of friends' beliefs to wait to have sex ( $p < .05$ ) Negotiating with others to protect personal rules ( $p < .05$ ) Improved knowledge about what constitutes healthy relationships ( $p < .05$ )

**Table 1** (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Peskin [33●●]	It's Your Game (IYG)-Tech	Ages: 13–15 (8th grade students) Urban school district southeast Texas (20 schools) N= 1374	Investigated the efficacy of It's Your Game (IYG)-Tech on middle school youth	RCT	Yes	Total: 13 lessons, 35–45 min each	12 months	No difference in delay of sexual activity or any other sexual behavior Ninth graders improvements in STI/condom knowledge, positive beliefs about waiting until marriage for sex, perceived friends had more positive beliefs about abstinence, self-efficacy to use condoms
Javidi [34●●]	HEART—Health Education and Relationship Training	Ages: 9th–11th grade Students from a school district in southeastern USA N= 457	Describe the process of adapting, reprogramming, and evaluating program, which may serve as a guide for investigators seeking to adapt behavioral interventions onto digital platforms	Feasibility	No	Total: 90 min 45 min completing HEART program	Immediate post	No significant differences in any of the program acceptability findings by gender or sexual activity status

Table 1 (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Haruna [35•]	N/A	Ages: 11–15 Dar El Salaam, Tanzania N= 120	Investigates extent to which game-based learning (GBL) and gamification could improve sexual health education	RCT	Yes	Total: 5 weeks 40-min sessions per week and 30-min orientation to learn game	Within 1 week post-intervention	Knowledge: mean increase in scores for Adolescent Sexual Health Literacy Test (ASHLT) Motivation: higher attention, relevance, confidence, and satisfaction (ARCS) components of motivation for GBL and gamification conditions ( $p = 0.001$ ) Attitude: higher self-ratings for cognitive and affective attitudes ( $p = 0.001$ ) Engagement: higher emotional and cognitive engagement ( $p = 0.001$ )



Table 1 (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Roberto [36••]	Choose Your Adventure–CD ROM	Age: Not specified, $\mu$ : 15.50, high school Adolescents Rural Appalachia -2 public high schools N= 326	Determine whether a computer-based and Internet-based intervention influenced several variables related to the prevention of pregnancy, sexually transmitted diseases (STDs), and HIV in rural adolescents	RCT	Yes	Total: 7 weeks 6 activities, ~ 15 min/ activity	10 weeks	Knowledge: increased among intervention group ( $p < 0.001$ ) Condom negotiation self-efficacy: increased among intervention group ( $p < 0.05$ ) Condom self-efficacy: no significant difference Attitudes toward waiting to have sex: increased among intervention group ( $p < 0.05$ ) Situational self-efficacy: increased among intervention group ( $p < 0.05$ ) Refusal self-efficacy: no significant difference Perceived susceptibility: increased among intervention group ( $p < 0.01$ ) Treatment group significantly more likely to answer questions related to the relationship between HIV risk and age correctly ( $P < 0.07$ ) Those in the treatment group answered 1.65 times as many questions correctly
Datta [37••]	Unnamed	Ages: 15–19 Adolescents Cape Town, South Africa N= 151	Determine whether a simple, computer-based “HIV risk game” leads to a better understanding of HIV risk and age than a version of the traditional “brochure approach” to dispensing information	RCT	Yes	Total: nine sessions over the course of 4 days	Immediate post 3 months	

Table 1 (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
<b>Adults</b> Card [38•]	SAHARA (SISTAS Accessing HIV/AIDS Resources At-a-click)	Ages: 18–29 African American women Atlanta, GA, USA N= 135	Describing translation of an HIV prevention group-level intervention called SISTA into a computer-delivered intervention called SAHARA. Describe the impact of a computer-based intervention on knowledge and behavioral outcomes	RCT	Yes	Total: 140 min 2 1-h computer sessions and 20-min wrap-up with health educator	3 months	STI prevention knowledge increase ( $P < 0.001$ ) Higher condom use self-efficacy ( $P < 0.012$ ) Higher percentage of condom-protected sex acts ( $P < 0.03$ ) More likely to use condoms consistently for vaginal sex ( $P < 0.039$ )
Astutya [39•]	Simulation game intervention—snake ladder game	Unloading workers at the Soekarno Hatta Port of Makassar (active employees, productive age TKBM 18–50 years) Makassar City, South Sulawesi Province	Determine the effect of social media method intervention (WhatsApp) with the simulation game method (snake ladder) on increasing literacy in the form of knowledge and attitudes about HIV and AIDS	A quasi-experimental design with a randomized group	Details unknown	Details unknown	Unknown	Differences in the mean for each measurement of changes in the level of knowledge categories about HIV and AIDS literacy ( $p < 0.05$ )

**Sexual and gender minority populations**

**Table 1** (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Schnall [40●●]	MyPEEPS	Ages: 13–18 YMSM Birmingham, Alabama; New York City, New York; Seattle, Washington; Chicago, Illinois N = 763	To determine the efficacy of a mobile-delivered HIV prevention intervention, to reduce sexual risk behavior in same-sex attracted young males	RCT via block randomization	Yes	Total: 3 months	3 months 6 months 9 months	Reduction in condomless anal sex acts compared to delayed intervention group at 3 months, but no difference at 6 or 9 months No difference in change in number of sex partners, number of condomless anal sex partners, number of sex acts under the influence, PrEP use, HIV testing, or STI testing Overall, highly acceptable to both groups
Wilbourn [42●●]	My Life	Ages: 13–24 Predominantly LGBTQ+ youth Washington, D.C N = 46	Determine whether a life-and-dating simulation game to increase HIV testing would be acceptable among AYAs	Qualitative Acceptability	No	N/A	N/A	
Mustanski [43●●]	Keep It Up!	Ages: 18–24 Young MSM Chicago N = 102	Evaluated the feasibility, acceptability, and preliminary efficacy	Feasibility RCT	Yes	Total: 2 h 7 modules completed across three sessions	6 weeks 12 weeks	Participant felt program valuable and acceptable KIU! participants 44% less unprotected anal sex at 12-week follow-up ( $p < .05$ ) Significantly less condom failure in KIU! Group No between group difference in HIV knowledge, intentions to use condoms

Table 1 (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Mustanski [44••]	Keep it Up!	Ages: 18–29 HIV-negative MSM Atlanta, Chicago, New York N=901	Determine if it significantly reduced condom-less anal sex and sexually transmitted infections compared with an HIV knowledge condition	RCT	Yes	Total: 3 h 3 sessions each 1 h, ≥24 h apart	3 months 6 months 12 months	STIs at month 12 were 40% lower for intervention participants ( $p < .01$ ) Reduced condom-less anal sex with a casual male partner at month 12 for both the control (44%) and intervention (37%) groups ( $p = .04$ ) No differences in self-reported incident HIV diagnoses between groups
Christensen [46•]	SOLVE—Socially Optimized Learning in Virtual Environments	Ages: 18–24 MSM, African American, Latino, or White N=921	Determine whether SOLVE interventions reduce shame as intended and unprotected anal intercourse	RCT	Yes	Not specified	3 months	Shame (re: sexual stigma) reduction among SOLVE intervention group ( $p < .001$ ) Mediation analysis: shame change predicted risky behavior (unprotected anal intercourse (UAI)) change, whereby intervention participants reported lower UAI. Indirect effect of reduced stigma on UAI statistically different from zero

**Table 1** (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Muessig [47●●]	HealthMpowerment (HMP)	Ages: 20–30 Black assigned male at birth: MSM TWSM North Carolina, USA N= 15	Assess participant responses to how HMP components led to behavior changes	Pilot trial	No	Total: 4 weeks At least 1 h per week	4 weeks	A trend toward higher dose received and more advanced stages of behavior change: high users most proportionately represented in action stage Medium users not proportionally represented in preparation stage Low users most proportionally represented in contemplation stage No changes in condom use self-efficacy, attitudes toward condom use, or safe sex norms ( $p = .05$ ) Significant improvements were seen in social support ( $p = .012$ ), social isolation ( $p = .050$ ), and depressive symptoms ( $p = .045$ ) Participants provided positive feedback for the website overall
Hightow-Weidman [48●●]	HealthMpowerment (HMP)	Ages: 20–30 Black assigned male at birth: MSM TWSM North Carolina, USA	To assess the feasibility, acceptability, and preliminary outcomes	Pilot trial	No	Total: 4 weeks At least 1 h per week	4 weeks	

Table 1 (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Control group	Duration of dose	Follow-up	Outcomes
Whiteley [50•••]	Viral Combat	Ages 18–35 Cisgender MSM initiating PrEP Jackson, Missis- sippi, USA N = 81	Determine the impact of Viral Combat on medi- cation adherence, PrEP-related knowledge, motivation, social support, and self- efficacy	RCT	Yes	Not specified	12 weeks 24 weeks	12-week follow-up: intervention group taking PrEP more days per week ( $p = .04$ ) No significant dif- ference in optimal prep dosing, TFV-DP levels, no difference in psy- chosocial factors Only 11.5% of par- ticipants completed the game 24-week follow-up: intervention group 3.75 times more likely to have opti- mal PrEP dosing No difference in TFV-DP levels, no differences in behavioral or psy- chosocial outcomes 20% completed the game

**Table 2** Description of HIV prevention game protocols

Citation	Intervention name	Sample population and location	Study purpose	Research design	Proposed outcomes
**Sabben [29●●]	Tumaini	Ages: 11–14 Kisumu Town, western Kenya N = 60	Pilot tests the game, focusing on the data needed to inform a future randomized controlled efficacy trial, including assessments of study feasibility and safety	Pilot RCT	Findings indicate that it is feasible and safe to test a smartphone-based HIV prevention intervention for very young adolescents in urban and peri-urban sub-Saharan Africa
**Mudhune [30●●]	Tumaini	Ages: 13–14 African adolescents N = 1004 Kisumu County, West Kenya	The objective of our protocol is to determine (1) if Tumaini delays sexual debut and increases condom use at first sex and (2) whether it influences behavioral mediators of early and unprotected sex	RCT	Biological testing of HIV and Herpes simplex type 2
**Kuhns [41●●]	MyPEEPs	Ages: 13–18 Sexual minority cisgender young men USA N = 700	Protocol for a randomized controlled trial of an mHealth-based HIV prevention intervention,	RCT	Proposed knowledge outcomes include managing minority stress, HIV/STIs, and condom usage Proposed behavioral outcomes include emotional regulation and negotiating interpersonal and substance-related risk
**Muessig [49●●]	HealthMpowerment (HMP)	Ages: 15–29 Black and Latinx young men and transgender women who have sex with men N = 1050 *n = 300 HIV-negative	Determine whether participants engaged HMP 2.0 report improvement in HIV prevention and care continuum outcomes	RCT protocol	Increased HIV testing among HIV-negative participants. Stable viral load among youth living with HIV
**Mustanski [48●●]	Keep It Up!	Ages: 18–29 Young MSM Atlanta, Chicago, New York N = 901	Determine the efficacy of the KIU! via a randomized controlled trial (RCT)	RCT protocol	Knowledge, motivation, partner sexual communication, correct condom use, number of condom-less anal sexual act, condom errors
**Whiteley [50●●]	Viral Combat	Ages: 18–35 MSM initiating PrEP N = 20	Aimed to improve PrEP adherence and HIV preventative behaviors in young MSM. Engaging young MSM in learning information, practicing behavior, and improving motivation for increased adherence to PrEP has the potential to decrease HIV seroconversion	RCT protocol	Proposed knowledge outcomes such as HIV/STI sexual risk knowledge, and perceived vulnerability to HIV/STIs Proposed behavioral outcomes such as medical adherence, reduced substance use, and self-efficacy

Table 2 (continued)

Citation	Intervention name	Sample population and location	Study purpose	Research design	Proposed outcomes
Castel [52●●]	Life-Simulation Game Prototype	Ages: 13–24 LGBTQ + or African American adolescents Washington, DC N = 10	Aim to increase HIV testing and PrEP access among adolescents in the DC area. In this intervention, players can enact real-life behaviors and receive their HIV risk profile to promote HIV testing and PrEP seeking	RCT protocol	Proposed behavioral outcomes such as motivation and self-efficacy related to HIV testing and PrEP use
Tang [53●●]	AIDS Fighter–Health Defense	Ages: 15–24 Adolescent students China N = 145	A protocol for conducting a randomized controlled trial to evaluate the “AIDS Fighter · Health Defense,” a game-based AIDS education project aimed at improving the ability of adolescents to prevent AIDS	RCT protocol	Proposed knowledge outcomes include AIDS prevention, diagnosis, antiretroviral treatment, and pre-exposure prophylaxis Proposed behavioral outcomes include encouraging condom usage and substance-related risk
Rawat [54●●]	No specified name mHealth HIV prevention for Indian MSM	Ages: 18 and up MSM/intersex in Mumbai with male sex partners found via the Internet Mumbai, India N = 24	Determine if an mHealth intervention was acceptable to men having sex with men (MS) and hijras living in Mumbai. Describe what features would be useful in targeting the prevention of HIV acquisition and to increase the quality of life among persons living with HIV/AIDS	Qualitative study	Proposed content to include in an mHealth intervention included HIV/STI awareness, proper condom use, and condom negotiation skills Proposed behavioral outcomes include intent to engage social support, overcoming stigma regarding HIV positive lifestyles
Lukhele [55●●]	Swazi Yolo	Ages: 18–29 Swaziland residents with a smartphone Swaziland, Southern Africa N = 380	Test whether a serious game intervention delivered on mobile phones to increase HIV risk perception, increase intention to reduce sexual partnerships, and increase intention to know own and partners HIV status will be more effective compared with current prevention efforts	Two-arm RCT trial protocol	Primary outcomes: decrease in HIV risk perception score compared to control and increase in HIV risk perception Secondary outcomes: condom usage, intent to test for HIV and know partners’ HIV status, and intent to reduce multiple concurrent partnerships
LeGrand [56●●]	P3: Prepared, Protected, empowered	Ages 16–24 YMSM and YTW	Develop an app-based intervention to increase PrEP adherence and outline an RCT to test its efficacy	RCT protocol	This paper outlines the usability and feasibility study as well as the RCT targeting adolescents and young adults



## Adolescents

**PlayForward: Elm City Stories** PlayForward, the parent intervention, is an evidence-based video game that targets HIV prevention and risk reduction among youth [26••]. Players engage customized, aspirational avatars to travel through life, facing challenges and exploring how specific choices impact their short and long-term goals. Skill-building storylines and topics include sex, drugs, and positive decision-making. This intervention comprises 16 h of unique gameplay conducted over 6 weeks.

Fiellin and colleagues [26••] conducted a randomized control trial with adolescents ages 11–14 ( $N=333$ ) to determine whether engaging in this serious game would improve sexual health outcomes. Participants were administered an immediate post-survey and 3-month, 6-month, and 12-month follow-up surveys. Key findings revealed improvements in attitudes about sexual health and increased sexual health knowledge as compared to the control group. There were no differences in initiation of sexual intercourse or intentions to delay intercourse.

PlayTest! was modified from PlayForward [21]. Although HIV content was incorporated into the storylines and mini-games of PlayForward, HIV testing and counseling were not the primary focus. The PlayTest! modified game allowed the storylines and mini-games to focus specifically on HIV testing and counseling and specific topics, including behaviors associated with increased likelihood of contracting HIV, stigma and misperceptions, HIV testing and counseling process and confidentiality, barriers, and facilitators to getting tested. There are eight unique main storylines and five mini-games. This game includes 6 h of original content as compared to the PlayForward parent game. PlayTest was administered twice weekly over 3 weeks.

Pendergrass [27••] conducted a feasibility pilot study with adolescents ages 14–17 years ( $N=13$ ). Follow-up surveys were administered 3 weeks and 6 weeks post-intervention. Key findings included significant changes in intentions and knowledge related to HIV testing and counseling at follow-up. However, there were no changes in perceived susceptibility to HIV or HIV testing.

**Tumaini** This intervention consists of 3 intersecting components designed for android smartphones [28••, 29••, 30••]. The first component employs a “choose-your-own-adventure” role playing game that allows participants to make decisions for six diverse characters. Three boy and three girl characters are included in the game. Participants walk each of the six characters through adolescence as they face challenges similar to the ones that impact their personal lives. Topics include peer pressure, puberty, violence, smoking, alcohol, drugs, and sex. Second, mini-games are employed to reinforce knowledge and skills relating to puberty, HIV and STIs, pregnancy, and other sexual situations. Mini-games

include quizzes, jigsaws, and role playing with feedback. Last, *My Story* employs customizable avatars and allows participants to engage in goal setting. Tumaini consists of approximately 12 h of gameplay.

Winskell and colleagues [28••] conducted this pilot randomized control with adolescents ages 11–14 years ( $N=60$ ) in Kenya to determine whether the serious game increased age and condom use used at first sex. Follow-up surveys were administered immediately following the intervention and 6 weeks post. Key findings included significant improvement in behavioral intentions for risk avoidance and reduction, increased self-efficacy, significant improvements in sexual health knowledge, and sexual risk communication. There were no differences in the assessment of risk or perceived social norms.

**It’s Your Game (IYG)** This game serves as a sexual health education intervention [31••]. Twelve lessons in 7th grade and 12 lessons in 8th grade were administered. Program content includes group-based activities (e.g., role plays, discussions), individual journaling, and the IYG multimedia intervention completed on laptop computers. The multimedia component consists of a 3D virtual world interface, educational activities (e.g., quizzes, animations, video, fact sheet), and “real-world” online group chats occurring in real time. Certain activities are tailored by gender, sexual experiences, and intent to create a more personalized experience. Participants completed four 35-min sessions.

Shegog [31••] conducted this usability survey with adolescents ages 12–14 to evaluate usability and students’ attitudes on the importance of content included within the serious game and their self-efficacy regarding refusal skills. Outcome measures were administered immediately following the intervention. Youth reported that the content was trustworthy and correct, program language was understandable, program activities were fun, and that the content helped [the] student make healthier choices.

**It’s Your Game (IYG)-Tech** This intervention was adapted from the *It’s Your Game!* (IYG) program. IYG-Tech consists of 13 lessons, 35–45 min each [32••, 33••]. Students are guided by two animated narrators introducing them to targeted scenarios in a mall-like environment. The intervention integrates life skills that encourage youth to select their behavioral limits before engaging in sexual behavior, detect signs and circumstances that could challenge those limits, and protect their rules with refusal skills. Activities include animated skill practice and modeling, peer modeling videos, quizzes, fact sheets, personalized reflection, and virtual role play with real-world situations. The intervention was administered once weekly (35 min per session) for 3 weeks.

Shegog [32••] conducted another usability ( $N=33$ ) and feasibility test ( $N=22$ ) with youth ages 12–14 and 13–15,

respectively. A post-evaluation survey was administered immediately following the intervention. Key findings included an increase in positive beliefs about waiting to have sex, greater self-efficacy to use condoms, greater intentions to abstain from sex until marriage, higher perceptions of friends' beliefs to wait to have sex, and negotiating with others to protect personal rules.

Additionally, Peskin and colleagues [33••] conducted a randomized control trial with youth ages 13–15 ( $N = 1374$ ) to investigate the efficacy of IYG-Tech on middle school youth. During this RCT, participants completed 13 lessons ranging from 35 to 45 min each. Youth completed a follow-up survey 12 months post-intervention. Key findings were that 9th graders reported improvements in STI/condom knowledge, positive beliefs about waiting until sex for marriage, positive beliefs about marriage, and self-efficacy to use condoms. However, there was no difference in the delay of sexual activity or any sexual behavior.

**Health Education and Relationship Training (HEART)** This sexual health education intervention comprises digital interventions, presentations, and interactive classroom components designed to encourage healthy relationships and provide tools regarding boundaries and physical intimacy [34••]. Topics include the impact of STDs, gender-related differences, primary protection by delaying sex, and the role of the immune system in preventing STDs. The total intervention was 90 min, with 45 min allocated to completing the HEART program.

Javidi and colleagues [34••] conducted a feasibility test with youth in grades 9–11 ( $N = 457$ ) to describe adapting, reprogramming, and evaluating the HEART serious game. A post-test survey was administered immediately following the intervention. The majority of participants reported that they liked the program (85%), learned new things (89%), stated the program kept their attention (85%), and that they will use the information in the future (91%). However, no significant differences existed in any of the program's acceptability outcome measures.

**Unnamed Intervention [35]** Haruna and colleagues examined the difference between three educational styles of sexual health education. These groups included gamification, game-based learning, and traditional teaching. Students assigned to the gamification arm of the study engaged in a sexual health education program that included gamified mechanics (i.e., badges, leaderboards, and a point system). Each topic included ten relevant questions, and students received awards for correct answers and lost points for incorrect answers. Badges were awarded to students with the highest scores [35•]. The intervention consisted of a 30-min orientation to learning the game and five 40-min sessions, one completed each week.

The game-based learning intervention developed an intervention consisting of digital stories embedded in interactive content [35•]. For the game-based learning arm, students individually engage in the intervention and perform activities such as quizzes and other activities to increase learning. Students were asked to view the game story and complete a series of questions for each topic. Students must correctly answer six out of ten questions to move to the next topic. The traditional teaching (control group) included a didactic course completed 40 min per week. The post-survey was administered 1 week following the intervention. Key findings included increased knowledge and motivation, higher self-rating for cognitive and affective attitudes, and higher emotional and cognitive engagement.

Choose Your Own Adventure is one component of a six-module intervention developed to prevent pregnancy, STDs, and HIV [36••]. The computer-based intervention was largely text-based, incorporating colorful graphics and relevant images to improve appeal. The program included content on impulse decision-making, sexual behavior risk, and refusal skills. During Choose Your Own Adventure—CD ROM component, students went on a virtual date and made choices that encouraged them to navigate sexual behaviors. The game finishes by describing positive or negative outcomes resulting from the decisions made during the game. Each of the six modules was about 15 min and was administered over 7 weeks.

Roberto and colleagues [36••] conducted a randomized control trial with high school sophomores ( $N = 326$ ) to determine whether the serious gaming intervention influenced variables related to pregnancy prevention, STDs, and HIV. The post-intervention was administered 10 weeks following intervention completion. Key findings include increased knowledge, condom negotiation, attitudes toward waiting to have sex, self-efficacy (situational and refusal), and perceived susceptibility. There was no difference in condom self-efficacy.

**HIV Risk Game** Datta and colleagues developed a game to improve youth's knowledge and understanding of HIV risk and age [37••]. Participants engaged in an interactive game in which they were presented with two individuals with varying characteristics. The game aimed to identify which individual was more likely to have HIV based on the risk factors presented. The purpose of this approach was to enable participants to update their preconceived notions about HIV risk. Participants played ten rounds of the game and received information on HIV and risk. Nine sessions were administered over 4 days.

Datta [37••] conducted a randomized control trial with you ages 15–19 in Cape Town, South Africa ( $N = 151$ ) to determine whether this serious game led to a better understanding of HIV risk. Post-assessments were administered

immediately following the intervention and 3 months post-intervention. Key findings included that the treatment group was significantly more likely to answer questions related to the relationship between HIV risk and age correctly. Additionally, those in the treatment group correctly answered 1.65 times more questions than the control group.

## Adult Sample

**SISTAS Accessing HIV/AIDS Resources At-a-click (SAHARA)** was developed from the intervention Sisters Informing Sisters on topics About AIDS (SISTAS) [38•]. The parent intervention SISTA is a group-level, gender, and culturally targeted intervention for African American women ages 19–29. The purpose was to increase condom use to help prevent HIV/AIDS. SAHARA was developed as a computerized version of the parent intervention that could employ computer sessions and be implemented in a quarter of the time. The intervention consisted of two 1-h computer sessions and a 20-min wrap-up session. The intervention employs combinations of video clips featuring group discussions and modeling appropriate sexual and contraceptive behavior, interactive cognitive rehearsals, games, quizzes, and role play. Core concepts include (1) enhancing ethnic/gender pride and awareness of HIV risk and (2) enhancing communication, condom use, and healthy relationship skills.

Card and colleagues [38•] conducted a randomized control trial with individuals ages 18–29 to describe the SISTA intervention's translation and the impact of this serious game on knowledge and behavioral outcomes. A post-assessment was administered 3 months following the interventions. Key findings include increases in STI prevention knowledge, condom use self-efficacy, percentage of condom-protected sex acts, and the likelihood of using condoms consistently for vaginal sex.

**Snake Game** Astutya and colleagues [39•] conducted a study to determine the effect of social media method intervention (WhatsApp) and a serious game (snake ladder) on knowledge and attitudes about HIV and AIDs. Limited details regarding the study design and approach are available. However, key findings included improvements in HIV knowledge and health literacy.

## Sexual and Gender Minority Populations

MyPEEPS provides educational info about HIV and STIs among YMSM, raises awareness about minority stress, and builds skills for condom use, emotional regulation, and negotiating interpersonal substance-related risk [40••,

41••]. Learning processes are facilitated through storytelling, games, scenarios, and role plays within 21 mobile activities divided into four sequential modules. The intervention was administered over 3 months.

Schnall and colleagues [40••] conducted a randomized control trial and enrolled cisgender, nonbinary, and genderqueer adolescents assigned male sex at birth (ages 13–18). This study aimed to determine MyPEEPS mobile's efficacy in reducing sexual risk behavior ( $N=763$ ). Post-surveys were administered 3, 6, and 9 months post-intervention. Key findings included a reduction in condomless anal sex acts compared control group at 3 months post-intervention. However, there were no differences reported at 6 or 9 months. There was no difference in the number of sex partners, sex acts under the influence, PrEP use, or testing.

My Life is a life-and-dating simulation game that allows participants to engage in relationship scenarios tailored to same-sex and opposite-sex couples [42••]. Wilbourn engaged health care providers, adolescents, and young adults. Participants completed focus groups and surveys assessing the acceptability of the digital gaming intervention. The My Life prototype was designed to be modified following user feedback. Additionally, providers suggested the game not force youth to define their sexual orientation and not refer to youth as “high risk.”

Wilbourn and colleagues [42••] conducted a qualitative acceptability study with LGBTQ+ participants ages 13–18 ( $N=46$ ). This study aimed to determine whether the life and dating serious game would be acceptable among the target populations. Both adolescents and young adults included in the study reported the serious game was “highly acceptable.”

Keep It Up! is an eHealth HIV prevention program that is completed online. The game aims to reduce STIs among men who have sex with men [43••, 44••, 45••]. The intervention consists of seven modules completed across three sessions. Content is presented in videos, interactive animation, and games. The main gaining component is called “The Club Game,” which uses real-life scenarios to explore decision-making around condom use, steps to proper condom use, and the effects of excessive alcohol, drug use, and sexual arousal. The player goes through 5 rooms and interacts with the environment while completing activities related to the aforementioned topics. Activities include videos, animation, and games to improve HIV knowledge, safe behaviors, and self-efficacy. The Keep It Up! 2.0 intervention included seven modules completed across three sessions  $\geq 24$  h apart (i.e., > 3 days) and totaling about 1 h.

Mustanski and colleagues [43••] conducted a randomized control feasibility pilot test among young MSM ages 18–24 to evaluate the Keep It Up! intervention's feasibility, acceptability, and preliminary efficacy ( $N=102$ ). Post-surveys were administered 6 and 12 weeks following the intervention. Participants felt the program was valuable and

acceptable. Additionally, intervention participants reported 44% less unprotected anal sex at the 12-week follow-up. There was also significantly less condom failure among participants in the intervention group. There were no differences in HIV knowledge or intentions to use condoms.

Additionally, Mustanski and colleagues [44••] conducted a randomized control trial with HIV-negative men who have sex with men ( $N=901$ ) to determine if the Keep It Up! intervention reduced condomless anal sex and STIs as compared to the control group. Post-surveys were administered 3, 6, and 12 months post-intervention. Key findings included that STIs at month 12 were 40% lower for intervention participants, reduced condomless anal sex at 12 months for both intervention and control groups, and no differences in the self-reported incidence of HIV diagnosis between groups.

Socially Optimized Learning in Virtual Environments (SOLVE) is a 3D dating simulation game designed for MSM, ages 18–24, who have recently engaged in unprotected anal intercourse [46•]. Players navigate realistic scenarios and encounter choice points where they make decisions surrounding alcohol, casual sex, and other self-regulatory topic areas. Through rehearsal and feedback, players practice decision-making skills.

Christensen [46•] conducted a randomized control trial with Black, White, and Latinx MSM ( $N=921$ ) to determine whether the SOLVE intervention reduced shame and unprotected anal intercourse. A post-survey was administered 3 months following the intervention. Key findings included a reduction in shame, represented as sexual stigma, among the intervention group. Mediation analyses revealed that shame significantly predicted sexual behavior risks such as condomless anal intercourse. Moreover, the indirect effect of reduced stigma on condomless anal sex was significant.

HealthMpowerment (HMP) is a mobile phone-optimized online (web-based) intervention with a gaming component [47••, 48••]. This intervention promotes user-generated content and social support to reduce stigma, promote health and wellness, and improve HIV-related outcomes among young Black men who have sex with men and transgender women who have sex with men. This multi-feature intervention allows each user to create a profile and avatar. HMP includes resources and supportive forums. Health and HIV/STI information is provided through quizzes, “Know Your Risk” (behavioral assessments), Ask Dr. W, and “The Scene,” which is a “choose your own adventure” decisional balance game. The intervention was administered for at least 1 h per week for 4 weeks.

Muessig and colleagues [47••] conduct a pilot trial with Black, cisgender, MSM, and transgender women who have sex with men ( $N=15$ ). The study assessed participants’ responses to how HMP components led to behavior changes. A post-survey was administered during the last visit and 4 weeks following the intervention. Key findings

included a trend toward higher doses received and more advanced stages of behavior change. High users were most proportionately represented in the action stage. Medium users were most represented in the preparation state, and low users were most represented in the contemplation stage of behavioral change.

Hightow-Weidman and colleagues [48••] published additional findings regarding feasibility, acceptability, and preliminary outcomes from the same pilot trial mentioned above. Key findings included significant improvements were seen in social support ( $p=0.012$ ), social isolation ( $p=0.050$ ), and depressive symptoms ( $p=0.045$ ). Additionally, there were no changes in condom use self-efficacy, attitudes toward condom use, or safe sex norms ( $p>.05$ ), and participants provided positive feedback for the website overall.

Viral Combat is an interactive game developed to promote PrEP adherence [50••, 51••]. This game targeted cisgender MSM between 18 and 35 years old. The game takes place inside and on the body. Participants fight off HIV and keep it from entering the body. Points are earned by swallowing pills (PrEP) that increase health, strength, and artillery. The game includes multiple tailored messages from doctors, clinicians, and friends to encourage participants to use PrEP, schedule appointments, and ask questions about HIV prevention. During the game, levels become progressively more difficult. The dose of the intervention was not specified.

Whiteley and colleagues [50••] conducted a randomized control trial with cisgender MSM initiating PrEP ( $N=81$ ). This study aimed to determine the impact of viral combat on medication adherence, PrEP-related knowledge, motivation, social support, and self-efficacy. Post-surveys were administered at 12 and 24 weeks following the intervention. Participants in the intervention group reported taking PrEP more days per week than the control group. At 12 weeks, there were no significant differences in optimal PrEP dosing, TFV-DP levels, and no difference in psychosocial factors. Additionally, only 11.5% of participants completed the game. At 24 weeks, participants in the intervention group were 3.75 times more likely to have optimal PrEP dosing. However, there were no differences in TFV-DP levels or behavioral or psychosocial outcomes. Results indicated that 40% of intervention participants reported playing Viral Combat for > 1 h in the last 3 months, and 20% completed the game.

## HIV Prevention Intervention Study Protocols

Our search identified 11 study protocols that outlined game-based HIV prevention interventions. Six of the 11 protocols describe the procedures for games included within this review—Tumaini [29••, 30••], MyPEEPs [41••], Keep It



Up! [45••], HealthMpowerment (HMP) [49••], and Viral Combat [51••]. There were two separate protocols written detailing Tumaini (see Table 2). The remaining five protocols outlined unique interventions that will be discussed below.

**Life-Simulation Game Prototype** The life-simulation game prototype displayed an adolescent’s HIV risk based on their sexual choices throughout the game [52••]. Participants navigate various social environments and make choices that influence their health. This intervention was developed for smartphones (iOS and Android), tablets, and the web.

**AIDS Fighter Health Defense** AIDS Fighter Health Defense, a 4-week game experience that includes components designed to increase AIDS-related knowledge, improves AIDS prevention motivation, and strengthens AIDS prevention behaviors among adolescents [53••]. The core storyline is that “HIV” launched an attack on the human body, and the goal is to fight “HIV” to eradicate its existence. The participant (the hero) must obtain antiretroviral medication and refuse behaviors such as condomless alcohol, drugs, and sex to fight off HIV. There are seven levels in the game representing different systems within the body.

Rawat and colleagues conducted four focus groups with MSM and interviews with four hijras, ten health service providers, and eight mHealth developers to determine the acceptability of mHealth interventions to address HIV in India [54••]. During focus groups and interviews, participants were asked about the content they’d like to see included within an ideal intervention for sex education.

SwaziYolo interactive is an interactive, educational smartphone game that puts the player in the role of a young adult looking for love in Mbabane [55••]. This intervention aims to increase HIV risk perception, increase intention to reduce sexual partnerships, and increase intention to know own and partner’s HIV status. SwaziYolo mimics a social media network similar to Facebook and WhatsApp to engage individuals in interactive role playing. Participants make important choices about relationships and sexual health. This study included individuals ages 18–29 that reside in Swaziland.

**P3 (Prepared, Protected, emPowered)** A theory-based, comprehensive social networking PrEP adherence app designed for young men who have sex with men (YMSM) and transwomen (YTW) includes game-based elements to encourage engagement via in-app messaging [56••]. The app uses game-based mechanics to help deliver information regarding “best practices” for PrEP adherence and retention in clinical care. Topics ranged from using contraceptives, STI education, and the importance of adhering to appointments. Each participant received a virtual tour upon downloading the app

and a reminder card with the researcher’s contact information for any issues with the gameplay or questions regarding content. The P3 + intervention also includes adherence counseling delivered via two-way text messaging through the app [56••].

## Study Design Considerations

Most of the studies reported in this review were pilot studies focused on the interventions’ usability, feasibility, and acceptability. Despite the small sample sizes, lack of randomization, and short follow-up time, these studies provide evidence about the usability, feasibility, and acceptability of serious games for HIV prevention, but not evidence regarding effectiveness or efficacy. In the few large RCTs described in the review, there was mixed evidence on the effect of behavioral outcomes. The Fiellin RCT study (Play-Forward) [26••] had mixed findings, with improvements in attitudes about sexual health but no improvements in sexual risk behavior. The Peskin (It’s Your Game-Tech) [33••] and Javidi (HEART) [34••] RCTs showed no significant improvements in outcomes. On the other hand, the Schnell (MyPEEPs) [40••], Mustanski (Keep It Up!) [44••], and Christensen (SOLVE) [46•] RCTs all demonstrated significant improvements in sexual risk behavior in the intervention groups as compared to the control group. Regarding behavioral outcomes, findings were mixed in terms of condom use self-efficacy—with one study reporting improvements (SAHARA) [38•] and another study reporting no significant difference (Choose Your Own Adventure) [36••]. Two studies assessed PrEP use. One study reported no differences in PrEP usage (MyPEEPs) [40••], while the other reported a significant improvement in uptake (Viral Combat) [50••].

## Discussion

This paper reviewed HIV prevention, serious games, and their impact on HIV-related knowledge, attitudes, and behavioral outcomes. Serious games have shown the potential to be innovative and effective by creating an interactive experience with realistic scenarios, establishing agency in a virtual and safe environment, and enabling individuals to practice and develop skills without stigma [33••, 34••, 35•, 36••, 37••, 38•, 39•, 40••, 41••, 42••, 43••, 44••]. Although several usability and feasibility studies have assessed the use of serious games for HIV prevention, fewer studies have rigorously evaluated the effect of gaming on HIV prevention, as evidenced by our search results.

There were 24 discrete serious gaming interventions identified in this review, with differences noted in the target population, duration, and dose of gaming implemented. Interventions

revealed significant diversity in content and structure and utilization of gaming as the primary HIV prevention technique. These findings align with previous research highlighting the lack of uniformity in language, conceptualization, and utilization of serious games to improve knowledge, behavior, or health outcomes [50••, 51••]. However, despite the interventions' uniqueness, they showed significant improvements in knowledge and/or behavioral outcomes among diverse adolescents and adults. These findings are aligned with previous studies highlighting those serious games increased the impact of health interventions by (1) extending the reach of online programs to individuals with limited access, (2) improving engagement by making activities enjoyable, thus reducing attrition, and (3) creating a safe and reactive environment for participants to practice new skills to encourage behavior change without fear of adverse consequences [21, 57, 58].

Additionally, 14 interventions were developed for sexual and gender minority youth and young adults. Including LGBT + specific content in HIV prevention is important since documented minority stress, discrimination, and victimization severely impact their health and relationships. The minority stress theory describes chronic, distal (discrimination events), and proximal (negative cognitive processes) that affect individuals from racial, gender, and sexual minority groups [59]. Moreover, sexual minority individuals—especially adolescents and young adults—use diverse media platforms to connect with friends, express themselves, and access telehealth and other resources. Given these unique risk factors, the development of HIV prevention interventions targeted to this population's unique needs and risk factors remains a public health priority.

The US Surgeon General's Advisory highlighted digital technology's and video gaming's positive impact on sexual minority individuals [60]. MyPEEPs [40••], Keep It Up! [43••, 44••], SOLVE [46•], HealthMpowerment [47••, 48••], Viral Combat [50••], and several other interventions each included content targeted to MSM and/or transgender women (refer to Table 1). These interventions reported positive behavioral improvements, including increased HIV testing, reduced sexual encounters, reduced STIs, and increased PrEP dosing. These findings are significant given that previous studies have found that knowledge improvements do not always equate to behavioral changes, especially among sexual and gender minority groups. Moreover, findings underscore the utility of implementing gaming to reach populations with limited access to educational resources and social support and those reluctant to engage in traditional healthcare services.

## Implications for Future Research

In our review of serious gaming interventions for HIV prevention, outcomes focused on knowledge and attitudes related to

HIV testing, delaying sexual initiation, and improvements in HIV and AIDs literacy. In a small number of studies, behavioral improvements were noted for improved sexual risk communication, condom use, and HIV testing. Only two studies focused on PrEP uptake and adherence as outcomes, which is timely given that PrEP has documented efficacy if used correctly [61]; on the other hand, PrEP coverage is lowest among adolescents and young adults with young MSM ages 16–24 at 15.6% compared to 23.4% overall [62]. Future work should focus on developing gaming interventions for youth to encourage PrEP uptake and adherence.

Notably, there is an opportunity to adapt and implement serious gaming interventions in global settings given that they are attractive to youth. Moreover, adolescents and young adults (10–24 years old) represent over a quarter of the world's population, and 90% live in low-income and middle-income countries [63]. Furthermore, approximately 1600 adolescents and young adults acquire HIV yearly [63]. The increasing number of youth acquiring HIV in low-income and middle-income countries underlies the urgency of HIV prevention efforts in this demographic group. The evidence within this review supports the use of game-based interventions for meeting those needs.

## Conclusion

This review provides an overview of serious gaming interventions which can be further implemented and evaluated by others aiming to improve HIV-related knowledge and behavioral outcome among adolescents and young adults. Gaming interventions that go beyond entertainment to educational and training purposes have been proven novel in empowering young people with sexual health information that may positively impact their health choices. Even though the results of this study showed variability of methods used in serious games among the included interventions, most of the studies still showed significant improvements in HIV-related knowledge and/or behavioral outcomes. Although the implementation of serious games in HIV prevention research is still in its infancy, gaming appears to be a viable and engaging method to improve knowledge and behavioral outcomes among diverse groups of adolescents and young adults globally.

**Data Availability** No datasets were generated or analyzed during the current study. This study consist of a review of literature.

## Declarations

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

**Competing Interests** The authors declare no competing interests.

## References

Papers of particular interest, published recently, have been highlighted as:

- Of importance
- Of major importance

1. HIV.gov. Overview: data & trends: U.S. Statistics. In: HIV Basics. HIV.gov. 2021. <https://www.hiv.gov/hiv-basics/overview/data-and-trends/statistics>. Accessed 14 Jun 2022.
2. D'Souza G, Golub ET, Gange SJ. The changing science of HIV epidemiology in the United States. *Acad J of Epidemiol*. 2019. <https://doi.org/10.1007/s001090000086>.
3. Smith LR, Patel VV, Tsai AC, Mittal ML, Quinn K, Earnshaw VA, Poteat T. Integrating intersectional and syndemic frameworks for ending the US HIV epidemic. *Am J Public Health*. 2022;112(S4):S340–3.
4. Aidala AA, Wilson MG, Shubert V, Gogolishvili D, Globerman J, Rueda S, Rourke SB. Housing status, medical care, and health outcomes among people living with HIV/AIDS a systematic review. *Am J Public Health*. 2016;106(1):e1–23.
5. ● Ferrari M, McIlwaine SV, Reynolds JA, Archie S, Boydell K, Lal S, Shah JL, Henderson J, Alvarez-Jimenez M, Andersson, Boruff J, Lundedal Nielsen RK, Lyer SN. Digital game interventions for youth mental health services (gaming my way to recovery): protocol for a scoping review. *JMIR Res Protoc*. 2020; <https://doi.org/10.2196/13834>. **This study shows the value of digital gaming interventions for mental health.**
6. Walther BK. Playing and gaming. *Game studies*. 2003;3(1):1–20.
7. Qian M, Clark KR. Game-based learning and 21st century skills: a review of recent research. *Comput Hum Behav*. 2016;63:50–8. <https://doi.org/10.1016/j.chb.2016.05.023>.
8. Karagiorgas DN, Niemann S. Gamification and game-based learning. *J Educ Technol Syst*. 2017;45(4):499–519.
9. Caserman P, Hoffmann K, Müller P, Schaub M, Straßburg K, Wiemeyer J, Bruder R, Göbel S. Quality criteria for serious games: serious part, game part, and balance. *JMIR serious games*. 2020;8(3):e19037.
10. Deterding, Sebastian, et al. From game design elements to gamefulness: defining gamification. *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments*. 2011.
11. Krath, Jeanine, Linda Schürmann, and Harald FO Von Korfflesch. Revealing the theoretical basis of gamification: a systematic review and analysis of theory in research on gamification, serious games and game-based learning. *Comp Human Behav* 125 (2021): 106963
12. Naslund John A, et al. Emerging mHealth and eHealth interventions for serious mental illness a review of the literature. *J Mental Health*. 2015;24(5):321–32.
13. Moss RJ, Süle A, Kohl S eHealth and mHealth. *Eur J Hosp Pharm*. 2019;26:57–8.
14. Holzmann SL, Dischl F, Schäfer H, Groh G, Hauner H, Holzzapfel C. Digital gaming for nutritional education: a survey on preferences, motives, and needs of children and adolescents. *JMIR Form Res*. 2019. <https://doi.org/10.2196/10284>.
15. Drummond D, Hadchouel A, Tesnière A. Serious games for health: three steps forward. *Adv in Simul*. 2017. <https://doi.org/10.1186/s41077-017-0036-3>.
16. Banerjee VD, Varshey P. Digital gaming interventions: a novel paradigm in mental health? 2021; <https://doi.org/10.1080/09540261.2020.1839392>
17. ● Ferrari M, McIlwaine SV, Reynolds JA, Archie S, Boydell K, Lal S, Shah JL, Henderson J, Alvarez-Jimenez M, Andersson, Boruff J, Lundedal Nielsen RK, Lyer SN. Digital game interventions for youth mental health services (gaming my way to recovery): protocol for a scoping review. *JMIR Res Protoc*. 2020; <https://doi.org/10.2196/13834>. **This study shows the value of digital gaming interventions for mental health.**
18. Whiteley LB, Olsen EM, Haubrick KK, Odoom E, Tarantino N, Brown LK. A review of interventions to enhance HIV medication adherence. *Curr HIV/AIDS Rep*. 2021. <https://doi.org/10.1007/s11904-021-00568-9>.
19. ●● Hightow-Weidman L, Muessig K, Knudtson K, Srivatsa M, Lawrence E, LeGrand S, Hotten A, Hosek S. A gamified smartphone app to support engagement in care and medication adherence for HIV-positive young men who have sex with men (AllyQuest): development and pilot study. *JMIR Public Health Surveill*. 2018; <https://doi.org/10.2196/publichealth.8923> **(This study compiles and compares various in-person and digital HIV interventions.)**
20. Primack BA, Carroll MV, McNamara M, Klem ML, King B, Rich M, Chan CW, Nayak S. Role of video games in improving health-related outcomes: a systematic review. *Am J Prev Med*. 2012. <https://doi.org/10.1016/j.amepre.2012.02.023>.
21. Fleming TM, Bavin L, Stasiak K, Hermansson-Webb E, Merry SN, Cheek C, Lucassen M, Lau HM, Pollmuller B, Hetrick S. Serious games and gamification for mental health: current status and promising directions. *Front Psychiatry*. 2017. <https://doi.org/10.3389/fpsy.2016.00215>.
22. O'Dea S. Share of U.S. teenagers with smartphone access 2018, by household income. In: *Technology & Telecommunications*. Statista. 2020. <https://www.statista.com/statistics/256544/teen-cell-phone-and-smartphone-ownership-in-the-us-by-household-income/> Accessed 20 Jun 2022.
23. Collins PY, Vellozo J, Concepcion T, Oseso L, Chwastiak L, Kemp CG, Wagenaar BH. Intervening for HIV prevention and mental health: a review of global literature. *J Int AIDS Soc*. 2021;24:e25710.
24. Kimmel AD, Martin EG, Galadima H, Bono RS, Tehrani AB, Cyrus JW, Krist AH. Clinical outcomes of HIV care delivery models in the US: a systematic review. *AIDS care*. 2016;28(10):1215–22.
25. Garrard J. *The Matrix Method*. 5<sup>th</sup> ed. Minneapolis: Jones & Bartlett Learning; 2017.
26. ●● Fiellin LE, Kyriakides TC, Hieftje KD, Pendergrass TM, Duncan LR, Dziura JD, Sawyer BG, Fiellin DA. The design and implementation of a randomized controlled trial of a risk reduction and human immunodeficiency virus prevention video game intervention in minority adolescents: PlayForward: Elm City Stories. *Clin Trials*. 2016. <https://doi.org/10.1177/1740774516637871>. **Playforward trial showed value of HIV video game intervention in minority youth.**
27. ●● Pendergrass T, Hieftje K, Duncan L, Fiellin L. Videogame intervention to encourage HIV testing and counseling among adolescents. *Mhealth*. 2020; <https://doi.org/10.21037/mhealth.2020.01.05>. **PlayTest! trial promoted HIV testing and counseling for youth-centered videogame intervention.**
28. ●● Winskell K, Sabben G, Akelo V, Ondeng'e K, Obong'o C, Stephenson R, Warhol D, Mudhune V. A smartphone game-based intervention (Tumaini) to prevent HIV among young Africans: pilot randomized controlled trial. *JMIR Mhealth Uhealth*. 2018; <https://doi.org/10.2196/10482>. **Tumaini trial evaluated an effective phone game-based HIV intervention in African adolescents.**
29. ●● Mudhune V, Sabben G, Ondenge K, Mbeda C, Morales M, Lyles RH, Arego J, Ndivo R, Bednarczyk RA, Komro K, Winskell K. The efficacy of a smartphone game to prevent HIV among young Africans: protocol for a randomized controlled trial in the context of COVID-19. *JMIR research protocols*.

- 2022;11(3):e35117. <https://doi.org/10.2196/35117>. **This described an HIV gaming intervention.**
30. ● Sabben G, Akelo V, Mudhune V, Ondenge K, Ndivo R, Stephenson R, Winskell K. A smartphone game to prevent HIV among young Africans: protocol for a randomized pilot study of a mobile intervention. *JMIR Research Protocols*. 2019;8(3):e11209. <https://doi.org/10.2196/11209>. **This described an HIV gaming intervention.**
  31. ● Shegog R, Markham C, Peskin M, Dancel M, Coton C, Tortolero S. “It’s your game”: an innovative multimedia virtual world to prevent HIV/STI and pregnancy in middle school youth. *Stud Health Technol Info*. 2007;129(Pt 2):983–7. **This assessed an HIV gaming intervention.**
  32. ● Shegog R, Peskin MF, Markham C, Thiel M, Karny E, Addy RC, Johnson KA, Tortolero S. It’s Your Game-Tech: toward sexual health in the digital age. *Creat Educ*. 2014. <https://doi.org/10.4236/ce.2014.515161>. **This study developed a web-based game for HIV/STI intervention among middle school youth.**
  33. ● Peskin MF, Shegog R, Markham CM, Thiel M, Baumler ER, Addy RC, Gabay EK, Emery ST. Efficacy of It’s Your Game-Tech: a computer-based sexual health education program for middle school youth. *J Adolesc Health*. 2015;56(5):515–21. <https://doi.org/10.1016/j.jadohealth.2015.01.001>. **This assessed an HIV gaming intervention.**
  34. ● Javidi WL, Lipsey N, Brasileiro J, Javidi F, Jhala A. Redeveloping a digital sexual health intervention for adolescents to allow for broader dissemination: implications for HIV and STD prevention. *AIDS Educ Prev*. 2021;33(2):89–102. <https://doi.org/10.1521/aeap.2021.33.2.89>. **This study assessed an HIV gaming intervention.**
  35. ● Haruna H, Hu X, Chu SKW, Mellecker RR, Gabriel G, Ndekao PS. Improving sexual health education programs for adolescent students through game-based learning and gamification. *Int J Environ Res Public Health*. 2018. <https://doi.org/10.3390/ijerph15092027>. **This study highlights the merit of gamification for sexual education prevention in youth.**
  36. ● Roberto AJ, Zimmerman RS, Carlyle KE, Abner EL. A computer-based approach to preventing pregnancy, STD, and HIV in rural adolescents. *J Health Commun*. 2007. <https://doi.org/10.1080/10810730601096622>. **This assessed an HIV gaming intervention.**
  37. ● Datta S, Burns J, Maughan-Brown B, Darling M, Eyal K. Risking it all for love? Resetting beliefs about HIV risk among low-income South African teens. *J Econ Behav Organ*. 2015. <https://doi.org/10.1016/j.jebo.2015.02.020>. **This study focused on knowledge outcomes for South African youth.**
  38. ● Card JJ, Kuhn T, Solomon J, Benner TA, Wingood GM, DiClemente RJ. Translating an effective group-based HIV prevention program to a program delivered primarily by a computer: methods and outcomes. *AIDS Educ Prev*. 2011. <https://doi.org/10.1521/aeap.2011.23.2.159>. **This study included a cultural, behavioral component to a digital HIV prevention program.**
  39. ● Astuty R, Amiruddin R, Mallongi A, Utami RA. Social media and simulation game on alliteration HIV and AIDS TKBM in Makassar port. *Enferm Clin*. 2020. <https://doi.org/10.1016/j.enfcli.2019.10.100>. **This study showed increased HIV/AIDS literacy through social media methods and simulation games.**
  40. ● Schnell R, Kuhns LM, Pearson C, Batey DS, Bruce J, Hidalgo MA, Hirshfield S, Janulis P, Jia H, Radix A, Belkind U, Rodriguez RG, Garofalo R. Efficacy of MyPEEPS mobile, an HIV prevention intervention using mobile technology, on reducing sexual risk among same-sex attracted adolescent males: a randomized clinical trial. *JAMA Network Open*. 2022;5(9):e2231853. <https://doi.org/10.1001/jamanetworkopen.2022.31853>. **This assessed an HIV gaming intervention.**
  41. ● Kuhns LM, Garofalo R, Hidalgo M, et al. A randomized controlled efficacy trial of an mHealth HIV prevention intervention for sexual minority young men: MyPEEPS mobile study protocol. *BMC Public Health*. 2020;20:65. <https://doi.org/10.1186/s12889-020-8180-4>. **This described an HIV gaming intervention.**
  42. ● Wilbourn B, Howell TH, Castel AD, D’Angelo L, Trexler C, Carr R, Greenberg D. Development, refinement, and acceptability of digital gaming to improve HIV testing among adolescents and young adults at risk for HIV. *Games for health journal*. 2020;9(1):53–63. <https://doi.org/10.1089/g4h.2018.0162>. **This assessed an HIV gaming intervention.**
  43. ● Mustanski B, Garofalo R, Monahan C, Gratzler B, Andrews R. Feasibility, acceptability, and preliminary efficacy of an online HIV prevention program for diverse young men who have sex with men: the keep it up! intervention. *AIDS Behav*. 2013;17(9):2999–3012. <https://doi.org/10.1007/s10461-013-0507-z>. **This study assessed an HIV gaming intervention.**
  44. ● Mustanski B, Parsons JT, Sullivan PS, Madkins K, Rosenberg E, Swann G. Biomedical and behavioral outcomes of Keep It Up!: an eHealth HIV prevention program RCT. *Am J Prev Med*. 2018. <https://doi.org/10.1016/j.amepre.2018.04.026>. **This trial examined the efficacy of an online HIV prevention program for men.**
  45. ● Mustanski B, Madkins K, Greene GJ, Parsons JT, Johnson BA, Sullivan P, Bass M, Abel R. Internet-based HIV prevention with at-home sexually transmitted infection testing for young men having sex with men: study protocol of a randomized controlled trial of Keep It Up! 20. *JMIR Research Protocols*. 2017;6(1):1. <https://doi.org/10.2196/resprot.5740>. **This study assessed an HIV gaming intervention.**
  46. ● Christensen JL, Miller CL, Appleby PR, Corsbie-Massay C, Gustavo GC, Marsella SC, Read SJ. Reducing shame in a game that predicts HIV risk reduction for young adult men who have sex with men: a randomized trial delivered nationally over the web. *J Int AIDS Soc*. 2013. <https://doi.org/10.7448/IAS.16.3.18716>. **This HIV prevention study allowed men to work on reducing sexual stigma in digital scenarios.**
  47. ● Muessig KE, Baltierra NB, Pike EC, LeGrand S, Hightow-Weidman LB. Achieving HIV risk reduction through HealthMpowerment.org, a user-driven eHealth intervention for young Black men who have sex with men and transgender women who have sex with men. *Digit Cult Educ*. 2014;6(3):164–82. **HealthMpowerment.org trial evaluated an HIV web-based intervention for young Black men.**
  48. ● Hightow-Weidman LB, Muessig KE, Pike EC, et al. HealthMpowerment.org: building community through a mobile-optimized, online health promotion intervention. *Health Educ Behav*. 2015;42(4):493–9. <https://doi.org/10.1177/1090198114562043>. **HealthMpowerment.org trial evaluated an HIV web-based intervention for young Black men.**
  49. ● Muessig KE, Golinkoff JM, Hightow-Weidman LB, Rochelle AE, Mulawa MI, Hirshfield S, Rosengren AL, Aryal S, Buckner N, Wilson MS, Watson DL, Houang S, Bauermeister JA. Increasing HIV testing and viral suppression via stigma reduction in a social networking mobile health intervention among Black and Latinx young men and transgender women who have sex with men (HealthMpowerment): protocol for a randomized controlled trial. *JMIR research protocols*. 2020;9(12):e24043. <https://doi.org/10.2196/24043>. **This study assessed an HIV gaming intervention.**
  50. ● Whiteley LB, Olsen EM, Haubrick KK, Odoom E, Tarantino N, Brown LK. A review of interventions to enhance HIV medication adherence. *Curr HIV/AIDS Rep*. 2021. <https://doi.org/10.1007/s11904-021-00568-9>. **This study compares and compares various in-person and digital HIV interventions.**
  51. ● Whiteley OE, Mena L, Haubrick K, Craker L, Hershkowitz D, Brown LK. A mobile gaming intervention for persons on



- pre-exposure prophylaxis: protocol for intervention development and randomized controlled trial. *JMIR Research Protocols*. 2020;9(9):e18640–e18640. <https://doi.org/10.2196/18640>. **This described an HIV gaming intervention.**
- 52.●● Castel WB, Trexler C, D'Angelo LD, Greenberg D. A digital gaming intervention to improve HIV testing for adolescents and young adults: protocol for development and a pilot randomized controlled trial. *JMIR Research Protocols*. 2021;10(6):e29792–e29792. <https://doi.org/10.2196/29792>. **This described an HIV gaming intervention.**
  - 53.●● Tang J, Chen Y, Yu X, et al. AIDS fighter health defense: protocol for a randomized controlled trial to test a game-based intervention to improve adolescents' AIDS prevention ability. *BMC Infect Dis*. 2021;21:469. <https://doi.org/10.1186/s12879-021-06161-0>. **This described an HIV gaming intervention.**
  - 54.●● Rawat S, Wilkerson JM, Lawler SM, Patankar P, Rosser BS, Shukla K, Ekstrand ML. Recommendations for the development of a mobile HIV prevention intervention for men who have sex with men and Hijras in Mumbai: qualitative study. *JMIR Public Health Surveillance*. 2018;4(2):e9088. **This described the development of an HIV gaming intervention.**
  - 55.●● Lukhele MP, El-Saaidi C, Techasrivichien T, Suguimoto SP, Ono Kihara M, Kihara M. Efficacy of mobile serious games in increasing HIV risk perception in Swaziland: a randomized control trial (SGprev Trial) research protocol. *JMIR Research Protocols*. 2016;5(4):e224–e224. **This described an HIV gaming intervention.**
  - 56.●● LeGrand S, Knudtson K, Benkeser D, Muessig K, Mcgee A, Sullivan PS, Hightow-Weidman L. Testing the efficacy of a social networking gamification app to improve pre-exposure prophylaxis adherence (P3: Prepared, Protected, emPowered): protocol for a randomized controlled trial. *JMIR Research Protocols*. 2018;7(12):e10448. <https://doi.org/10.2196/10448>. **This described an HIV gaming intervention.**
  57. van der Meulen H, McCashin D, O'Reilly G, Coyle D. Using computer games to support mental health interventions: naturalistic deployment study. *JMIR Ment Health*. 2019. <https://doi.org/10.2196/12430>.
  58. Hartmann A, Gommer L. To play or not to play: on the motivational effects of games in engineering education. *Eur J Eng Educ*. 2021; <https://doi.org/10.1080/03043797.2019.1690430>
  59. Meyer IH. Prejudice, social stress, and mental health in lesbian, gay, and bisexual populations: conceptual issues and research evidence. *Psychol Bull*. 2003;129(5):674–97. <https://doi.org/10.1037/0033-2909.129.5.674>.
  60. The Surgeon General. Protecting youth mental health. In: *The US Surgeon General Advisory*. 2021. <https://www.hhs.gov/sites/default/files/surgeon-general-youth-mental-health-advisory.pdf>. Accessed 23 Jun 2022.
  61. Center of Disease Control. PrEP effectiveness. <https://www.cdc.gov/hiv/basics/prep/prep-effectiveness.html#:~:text=PrEP%20reduces%20the%20risk%20of,74%25%20when%20taken%20as%20prescribed>.
  62. Center of Disease Control. PrEP for HIV Prevention in the U.S. <https://www.cdc.gov/nchhstp/newsroom/fact-sheets/hiv/PrEP-for-hiv-prevention-in-the-US-factsheet.html>
  63. Understand young people in low-income countries. 2018. <https://media.nature.com/original/magazine-assets/d41586-018-02107-w/d41586-018-02107-w.pdf>
- Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.
- Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.