An evidence-based serious game app for public education on antibiotic use and resistance: A randomized controlled trial

Zhilian Huang, Jing Teng Ow, Wern Ee Tang, Angela Chow

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Abstract

Background: The misuse and overuse of antibiotics accelerate the development of antimicrobial resistance (AMR). Serious-games, any form of games that serve a greater purpose other than entertainment, could augment public education above ongoing health promotion efforts. Hence, we developed an evidence-based educational serious game app—SteWARdS Antibiotic Defence—to educate users on good antibiotic use practices and AMR through a game quest comprising three mini games and interaction with the non-player characters.

Objective: We aimed to evaluate the effectiveness of the SteWARdS Antibiotic Defence app in improving the knowledge of, attitude toward, and perceptions (KAP) of appropriate antibiotic use and AMR among the public in Singapore.

Methods: We conducted a two-arm parallel randomized controlled trial, recruiting visitors 18–65 years old from two polyclinics in Singapore. Intervention group participants had to download the SteWARdS Antibiotic Defence app (only available in English and on the Android platform) on their smartphones and complete the quest in the app. Participants took half a day to two weeks to complete the quest. The control group received no intervention. Knowledge on antibiotic use and AMR (11 binary questions) was self-administered at baseline, immediately after the intervention, and 6–10 weeks post-intervention, while attitudes and perception (14 three-point Likert scale questions) were self-administered at baseline and 6–10 weeks post-intervention. We also collected participants' feedback on app usage.

Results: Participants (n=348; 142 Intervention, 206 Controls) had a mean age of 36.9 years. Intervention group participants showed significantly greater improvement in knowledge scores compared with controls [0.58 (95% CI: 0.28, 0.87)] after accounting for age, educational level, and exposure to advertisements on antibiotics and AMR. Intervention participants also showed significantly greater improvement in attitude-perception score [0.98 (0.44, 1.52)] after adjusting for marital status and race. More than 95% of participants agreed that the "SteWARdS Antibiotic Defence" app improved their awareness on antibiotic use and AMR. More than 70% agreed that the app is easy to use and enjoyable, and 85.2% would recommend the app to others.

Conclusions: Our educational serious-game app improves participants' KAP on appropriate antibiotic use and AMR. Public education apps should be engaging, educational, easy to use, and have an attractive user interface. Future research should assess the effectiveness of interventions in facilitating long-term knowledge retention and long-lasting behavioural change. Clinical Trial: ClinicalTrials.gov Identifier: NCT05445414; https://clinicaltrials.gov/ct2/show/NCT05445414

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An evidence-based serious game app for public education on antibiotic use and resistance: A randomized controlled trial

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Abstract

Background: The misuse and overuse of antibiotics accelerate the development of antimicrobial resistance (AMR). Serious-games, any form of games that serve a greater purpose

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Conclusions: Our educational serious-game app improves participants' KAP on appropriate antibiotic use and AMR. Public education apps should be engaging, educational, easy to use, and have an attractive user interface. Future research should assess the effectiveness of interventions in facilitating long-term knowledge retention and long-lasting behavioural change.

Trial registration: ClinicalTrials.gov Identifier: NCT05445414

Keywords: Serious game application; randomized controlled trial; antimicrobial resistance; antibiotic use, public education

Introduction

The World Health Organization (WHO) declared antimicrobial resistance (AMR) as one of the top ten global public health threats in 2019[1]. Antibiotic-resistant bacteria can cause humans infections that are harder to treat, leading to higher medical costs, decreased work productivity, and increased mortality[2-4]. By 2050, AMR is projected to cause 10 million annual deaths and up to $100.2 trillion in economic losses worldwide if nothing is done to slow its progression[5]. The widespread misuse and overuse of antibiotics, often driven by the public's lack of knowledge regarding appropriate antibiotic use and AMR, contribute to AMR progression[6, 7]. The need to educate the public on appropriate antibiotic use and AMR is apparent, as better knowledge of antibiotic use was found to be associated with favourable antibiotic attitudes, which lowered the odds of expecting and receiving an antibiotic prescription[8]. Despite yearly public outreach[9] and multiple national educational campaigns on antibiotics and AMR [10], misconceptions about antibiotics – such as believing that antibiotics treat viral infections –

continue to persist among the Singaporean population[7, 8]. Traditional efforts to educate the public on antibiotic use and AMR have shown ambiguous effectiveness[11, 12]. Hence, the lacklustre effectiveness of existing efforts to prevent antibiotic misuse and overuse provide an impetus to explore novel public education methods beyond traditional modalities (e.g., posters and pamphlets)[13].

Serious games have emerged as a promising tool for health education and health promotion across various fields recently[14]. This learning modality encompasses online and offline tools that employ gamification—the use of game-playing elements—to provide an enhanced learning experience. Studies have shown promise of serious games in improving the short-term health knowledge, attitudes and beliefs of young people, but the studies were too heterogeneous to prove the efficacy of this learning modality[15, 16]. There were less serious games studies with older adults, but a web-based serious game co-designed with members of the public to raise pancreatic cancer awareness found a statistically significant improvement of pancreatic cancer awareness[17].

Serious games have also been used to promote good antibiotic use behaviours [16, 18]. Preliminary evidence of serious games interventions on antibiotic use and AMR have shown promise in improving the knowledge of appropriate antibiotic use[16, 19]. However, these studies were primarily focused on children and students. Adults have greater access to antibiotics and are more likely to pass down antibiotic use behaviours to the younger generation[13]. Hence, it is essential to educate young adults on appropriate antibiotic use. Existing studies also limited participants to a controlled environment with restricted playing time and may not fully capture real-world behaviour. Furthermore, many studies overlooked the importance of long-term knowledge retention. The paucity of high-quality randomized controlled trials (RCTs) in the real-world setting highlights a pertinent gap in the evidence base of serious games for public education.

Singapore offers an excellent environment for evaluating serious game applications (apps) given its high smartphone penetration rate (92%)[20] and emphasis on digital transformation[21]. Hence, we developed an evidence-based serious game app—"SteWARdS Antibiotic Defence"—to deliver adult education on appropriate antibiotic use and AMR and aimed to evaluate its effectiveness in improving knowledge of, attitude toward, and perceptions (KAP) of antibiotic use and AMR in Singapore. We also sought user feedback on the "SteWARdS Antibiotic Defence" app.

Methods

Study design

We conducted a parallel two-arm RCT with a 6–10-week follow-up period. Participants in the intervention group had to download and complete the quest in the "SteWARdS Antibiotic Defence" app on their smartphones, while controls received no intervention.

Study setting

We recruited patients and their caregivers from two government-funded primary care clinics (i.e., polyclinics) in Singapore. Recruitment occurred from January – March 2023, and follow-up was completed in early June 2023. The 23 polyclinics in Singapore manage 20% of Singapore's primary healthcare needs by providing subsidized services such as medical treatment for acute and chronic conditions, vaccinations, and health education[22]. Participants seen at the polyclinics mainly have acute conditions that are managed outside the healthcare setting. Hence, while our study recruitment and baseline data collection occurred in the policlinics, the study intervention and follow-ups were administered outside the healthcare setting.

Eligibility criteria

Participants were 18 – 65 years old, had access to an Android smartphone, and were English literate. We excluded those with visual/cognitive impairment, not proficient with smartphone apps, and those unable to install Android mobile applications from the study.

Intervention

App development

The "SteWARdS Antibiotic Defence" app is an evidence-based serious-game mobile app developed by the study team, in collaboration with with Temasek Polytechnic (a public tertiary institution in Singapore), to educate the public on appropriate antibiotic use and AMR. Players learn about appropriate antibiotic use and effective methods to recover from uncomplicated upper respiratory tract infections by interacting with the non-player characters (NPCs) releasing bite-sized information and playing the mini-games in the app. We derived the educational content in the app from a rigorous review of knowledge gaps[7, 8, 23], antibiotic guidance[24], and inputs from healthcare professionals. The in-app messages were also adapted to the local context to ensure their relevance to players[25]. A few knowledge questions in the post-game and post-intervention surveys were reverse scored to reduce to learning effect on knowledge gains. The bite-sized messages and knowledge questions can be found in the Multimedia Appendix Tables S1 and S2.

The pre- and post-game knowledge questions were embedded at the beginning and the end of the quest to reinforce knowledge retention (Figure 1). Completing the 11 baseline knowledge questions is a pre-requisite to proceed to the mini-games while completing the post-game knowledge questions is a pre-requisite to fulfil the requirements of the intervention. Players are allowed to play the mini-games repeatedly once they pass the level, but they can only

complete the pre-post survey once. There is an in-app WhatsApp helpline for participants to contact the study team should they encounter technical difficulties. The feedback form link is also embedded in the app and appears after the completion of the post-knowledge survey. Study team members (data collectors) provided intervention group participants with a one-time unique code to access the app during recruitment. The unique code allowed us to track the pre-post knowledge survey responses, time spent on the app, and interactions with the non-player characters anonymously. We did not analyse the time spent on the app due to glitches that affected data quality.
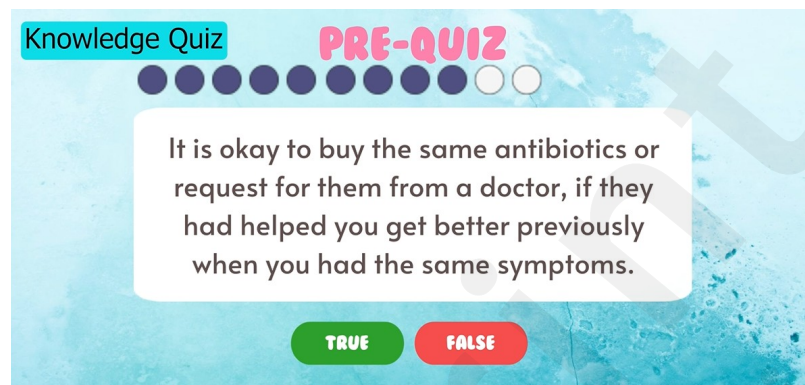

Figure 1: An example of a knowledge question embedded in the app. Participants are expected to complete 11 pre-intervention knowledge questions, followed by the game quest and 11 post-knowledge questions to complete the intervention.

Game components

There are three "worlds" – the 'Supermarket', 'Park' and 'Train station' – that lead to the mini-games in the app. Each "world" comprises 2 NPCs and a mini-game. The supermarket is linked to the Tower Defence game; park is linked to the Match3 game; and train station is linked to the Endless Runner game (Figures 2-5).
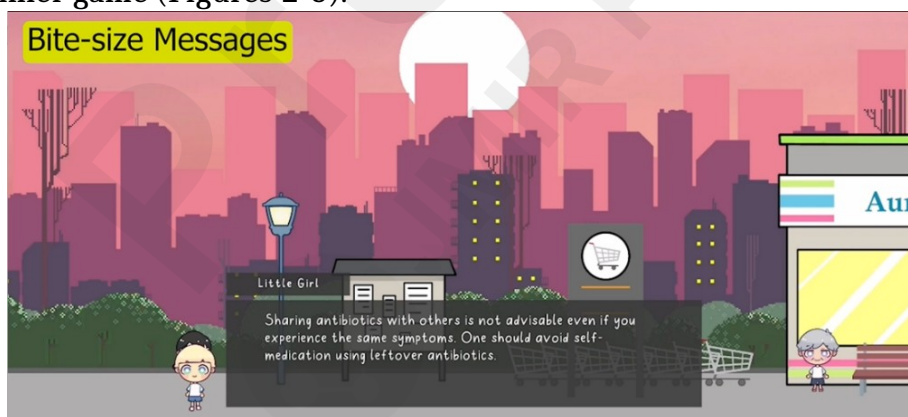

Figure 2: Interaction with a non-player character (NPC) at the park. Bite-sized messages on good antibiotic use practices are released through interactions with the NPCs. The right most NPC leads to the tower defence game.

There are nine levels in the Tower Defence game to teach players about antibiotics and AMR. The first two levels teach players that antibiotics are effective against bacteria and next two introduce the concept that antibiotics are bacteria specific.s Levels 5 and 6 educate players that antibiotics are not effective against viruses, levels 7 and 8 are reinforcements of previously taught concepts and the last level educates players on antibiotic resistance by introducing a superbug that requires an expensive antibiotic (turret) to cure (kill the superbug). Players have to earn coins by passing Tower Defence levels, and playing the Match3 and Endless Runner games.

Figure 3: The Tower Defence game consist of 9 levels. The top figure shows the game interface with C-Stin turrets and the super bug (level 9). The subsequent figures show the messages released at the beginning of level 9 to teach players about the concept of antimicrobial resistance. Players have to choose the appropriate turrets and strategically place them at appropriate locations to effectively target their enemies (bacteria/viruses).

The Endless Runner game is accessible via the train station. The game reinforces the message that antibiotics are only effective against bacteria and not viruses. Players collect coins to purchase turrets at the Tower Defence game while running and uses the antibiotic to shoot away bacteria obstacles and the immunity gun to shoot the virus obstacles.
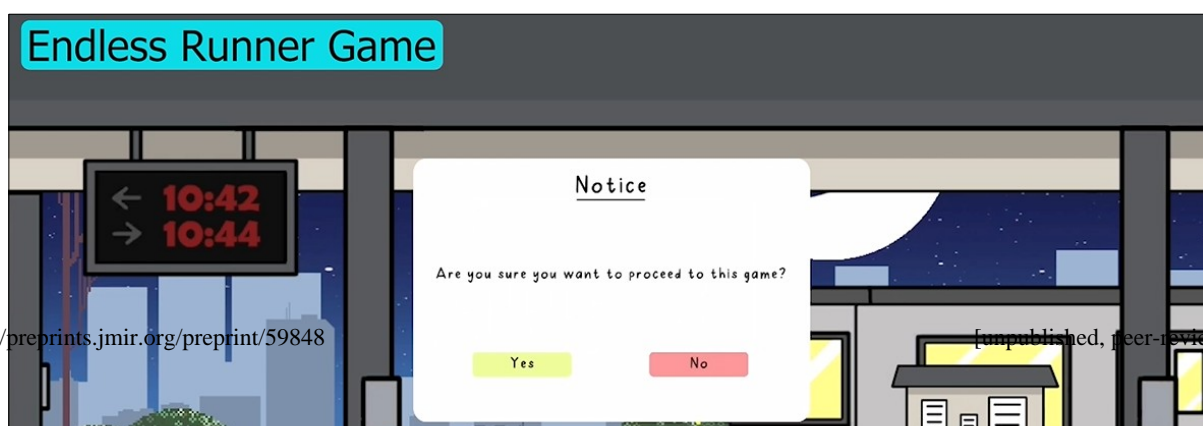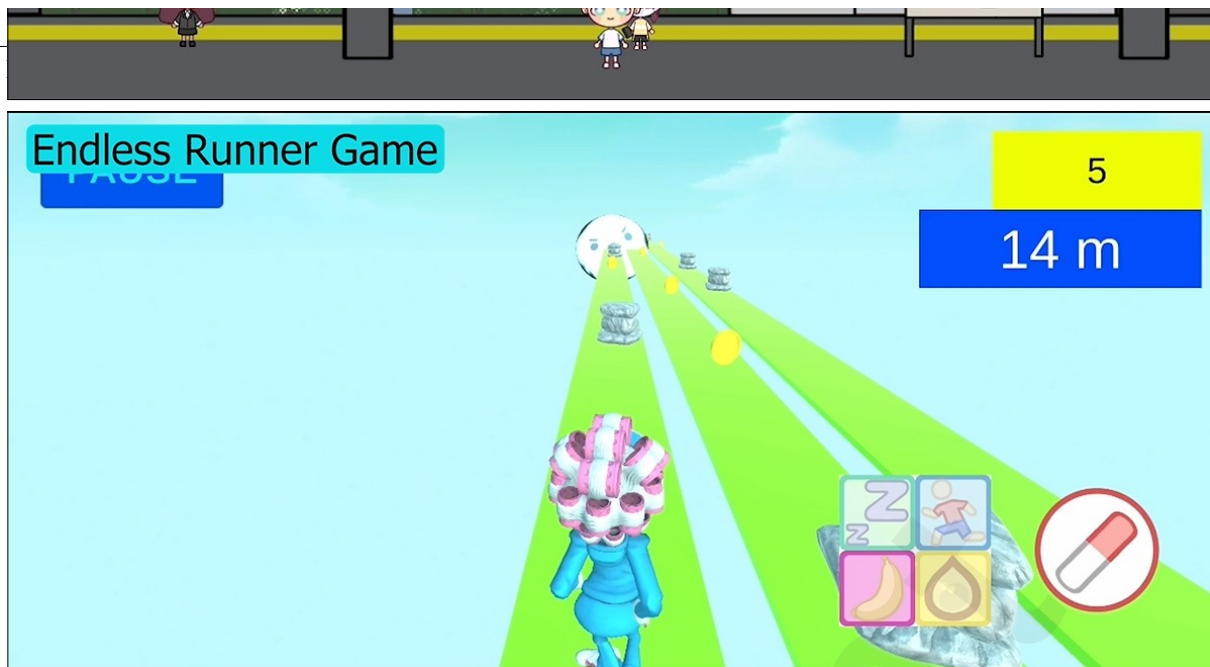
Figure 4: The Endless Runner game can be accessed via the train station (picture on top). The game reinforces the message that antibiotics are only effective against bacteria and not viruses. Players collect coins while running and use the antibiotic gun and immunity gun to shoot at bacteria and virus obstacles, respectively. Coins collected from the Endless Runner game can be used to purchase turrets in the Tower Defence game.

The Match3 game is accessible via the park. The game educates players on good health habits by encouraging focusing on sleep hygiene, nutrition, immunization, and exercise. Players are required to match three or more similar tiles within a specific time limit to successfully clear each of the 10 levels.

Quality sleep, a balanced diet, updated immunization, and exercise keep us healthy.

Next
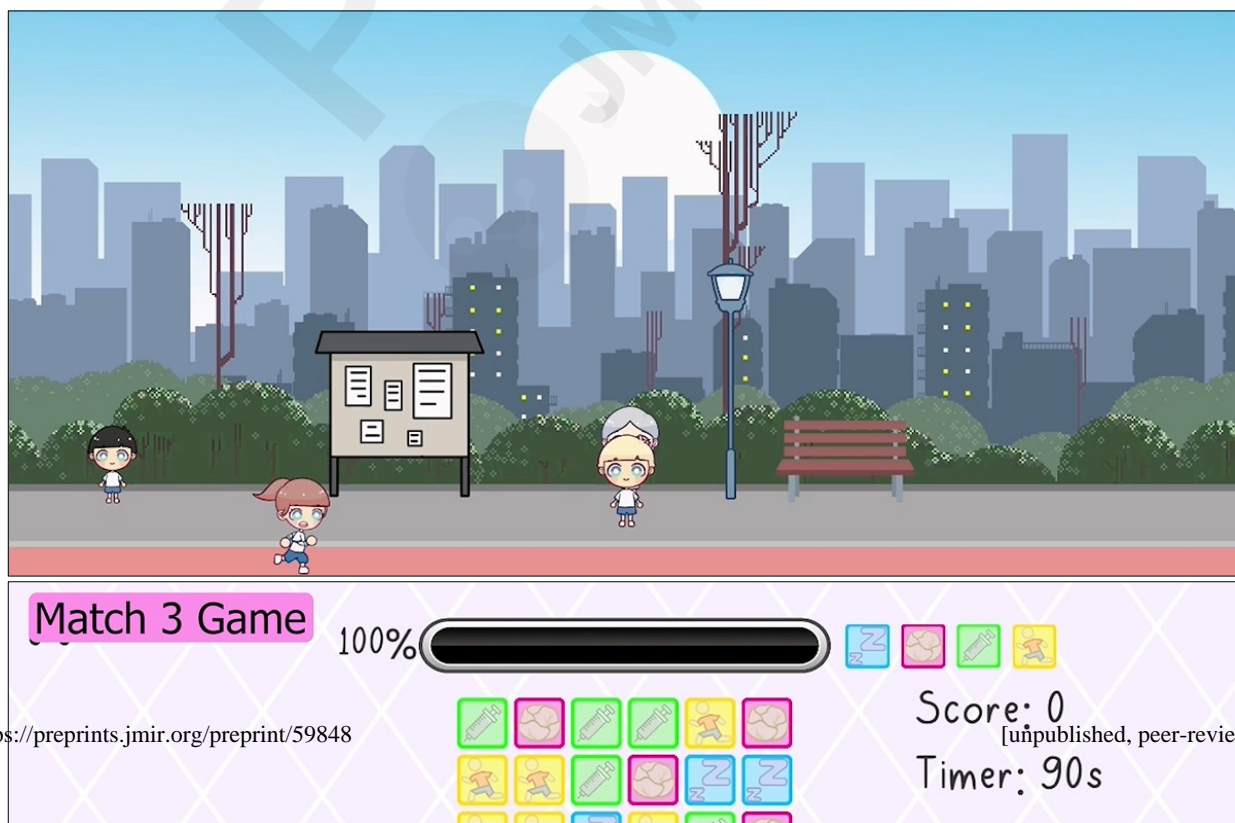
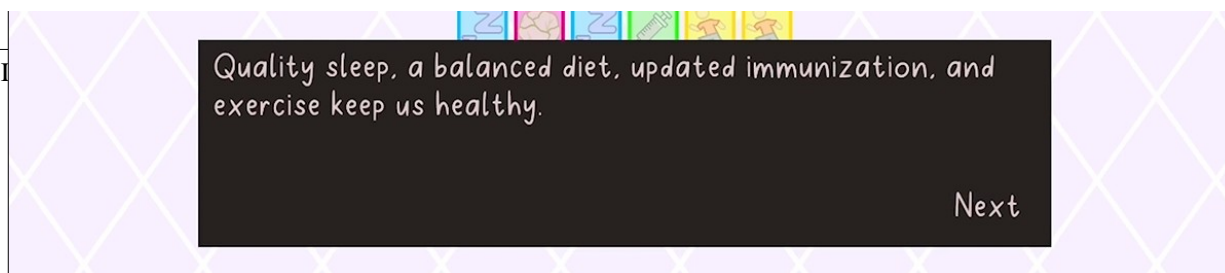**Figure 5:** The Match3 game can be accessed via the park (picture on top). The game educates players on good health habits by encouraging focusing on sleep hygiene, nutrition, immunization, and physical exercise. Players are required to match three or more similar tiles within a specific time limit to successfully clear each of the 10 levels. Bite-sized messages are released before the start of each game to remind players of maintaining a healthy lifestyle.

Further details of the design and principles of the "SteWARdS Antibiotic Defence" app can be found in our published protocol[25]. Individual participants were followed-up according to recruitment schedule from the point of recruitment. Participants took between half a day to two weeks to complete the intervention.

Outcomes

The primary outcome of interest was the change in KAP score of antibiotic use and AMR. The secondary outcome was the level of user satisfaction for the "SteWARdS Antibiotic Defence" app. Primary outcomes were assessed for the intervention and control groups at baseline, immediately post-intervention (intervention group only), and 6–10 weeks post-intervention (from baseline for controls) via self-administered questionnaires. Knowledge was measured via 11 True/False questions, while attitudes and perceptions were measured via 14 questions on a three-point Likert scale. Details of the KAP questionnaire are available in our published protocol[25]. For the intervention group, satisfaction with the "SteWARdS Antibiotic Defence" app was measured with four questions on a five-point Likert scale and the reason(s) for recommending/not recommending the app to others and suggestions for improvement were obtained via open-ended questions, upon quest completion.

Sample size

Assuming an effect size of 0.334 (95% CI: 0.260, 0.407) based on other serious games studies[18], we estimated a minimum sample size of 142 per group to detect a significant change in the knowledge score at a power of 80% and an alpha level of 0.05. We initially planned to recruit 200 participants per arm to account for a 30% attrition rate. We later increased the recruitment numbers to 240 per arm to account for a 40% attrition rate as we observed higher-than-expected dropout rates.

Study procedures

Recruitment occurred on weekdays during the polyclinic's opening hours. Staff members of the polyclinics were trained to recruit participants in their respective polyclinics. The data collectors would systematically walk through every level of the polyclinic systematically to recruit participants daily. We also displayed digital recruitment posters around the polyclinics, so interested visitors could contact the study team. However, only two participants contacted the study team via digital posters.

Data collectors approached the patient or visitor nearest to them who seemed to fall in the eligible age category (18-65 years old) to explain the study while systematically walking around the polyclinic. Next, the data collector explained the study to the person they approached and informed them of the possibility of being randomized into either the "survey group" (Control) or "app and survey" (Intervention) group. Informed consent was obtained from interested participants before asking participants to pick a card to determine the group assignment. Participants knew the group they were assigned to when they were asked to download the app at the end of the iPad data collection. Baseline data collection occurred after randomization because the pre-post knowledge questions were built into the app. We collected participants' KAP responses and demographic data at baseline and reimbursed them a small fee for completing the baseline surveys. All participants received the same amount of reimbursement at the baseline. Reimbursement was tiered to a higher value for the follow-up surveys to motivate participants towards task completion.

Baseline data collection

The baseline data collection process differed slightly for the intervention and control group participants. Intervention group participants had to complete the Attitudes-Perception demographic questionnaire on an iPad and install the "SteWARdS Antibiotic Defence" app on their smartphones. The data collector then provided the participant with a unique code to gain access to the app. Upon logging into the app, participants had to complete 11 baseline knowledge questions, followed by a walkthrough of the basic features of the app. Controls completed the KAP and demographic questionnaire on an iPad.

Control group follow-up

A study team member (i.e., data collector) sends participants a detailed WhatsApp message six weeks after their recruitment date to inform them to complete the post-intervention KAP questionnaire. The study team member sent a reminder if participants did not complete the questionnaire two weeks after the first WhatsApp message.

Intervention group follow-up

Participants had to complete the "SteWARdS Antibiotic Defence" game quest and satisfaction survey and inform the study team via WhatsApp upon intervention completion. Six weeks after participants complete the intervention, a study team member sends a detailed WhatsApp message to inform them to complete the post-intervention KAP questionnaire. A study team member reminded participants who did not complete the quest two weeks after recruitment and two weeks after sending the first KAP WhatsApp message.

Withdrawals and loss to follow-up

Participants who became uncontactable during the study period were classified as loss- to follow-up cases while those who indicated that they wished to be withdrawn from the study were considered as withdrawn cases. Withdrawn cases were asked to uninstall the app and were not further contacted.

Randomization

Eligible participants were 1:1 block randomized into the intervention or control group. Each block comprised two intervention and two control allocations. Participants determined their allocation by picking cards in the block, which was reset after all cards were drawn.

Blinding

Participants were not blinded to the intervention as the data collectors had to explain to participants assigned to the intervention group about the "SteWARdS Antibiotic Defence" app. Apart from the data collectors, all other study team members (including the data analyst) were blinded to the group assignment.

Data analyses

We initially planned to take the intention-to-treat approach in analyzing the study data, but eventually took the per-protocol approach, as our app usage data showed that participants who did not complete the game quest had too few interactions with the app to derive any benefit from the intervention. We standardized the total Knowledge and Attitude-Perception scores to 100% to illustrate the pre-post changes in scores. Correct answers are coded as 1 while wrong answers are coded as 0. Similarly, the "correct" attitudes are coded as 1 while neutral and "incorrect" attitudes are coded as 0.

Chi-square tests and Mann-Whitney-U tests were used for univariate baseline comparisons. Weighted least square regressions (weighted on pre-intervention scores) were used to assess the effect of the intervention on knowledge and KAP scores. The best regression model was chosen based on the lowest Akaike's Information Criterion. All statistical assumptions were checked to ensure the accuracy of analyses. STATA version 15 was used for all statistical analyses.

Participant feedback was analysed qualitatively using thematic analysis. OJT telephoned participants to elaborate on any ambiguous feedback and categorised the feedback into themes. ZH reviewed and discussed the categorization with OJT until a consensus was reached.

Ethical considerations

This study was approved by the NHG Domain Specific Review Board (DSRB Ref: 2022/00479) in Singapore. Informed consent was obtained from participants after the data collector had fully explained the study to them. Each participant was given a unique research ID linked to their personal details (e.g., name and contact details). Only DSRB approved study team members have access to participant data. All identifiable information is stored in password

protected files in the institutions' server. Data collected from the surveys and app only contained participants' research IDs. Participants were reimbursed S$5 for completing the baseline and demographic survey, S$10 for completing the post-intervention survey, and S$25 for completing the app intervention and satisfaction survey (intervention group participants only).

Results

Participant flow

We approached 1985 patients and visitors of polyclinics over three months, and 1144 (57.6%) consented to take part in our study. Of these consenting participants, 470 (41.1%) did not own an Android phone, 100 (8.7%) did not meet our age requirements, 80 (7.0%) were not proficient in the English language, 7 (0.6%) had difficulty downloading the app, and 7 (0.6%) had visual/cognitive impairment. We block randomized 480 (32.0%) eligible participants into two arms. Of these randomly assigned participants, 206/240 (85.8%) in the control group and 142/240 (59.1%) in the intervention group completed the study and had their outcomes assessed. Ninety-eight intervention group participants did not complete the game quest (16 withdrew; 82 dropped out) in the app (Figure 6).
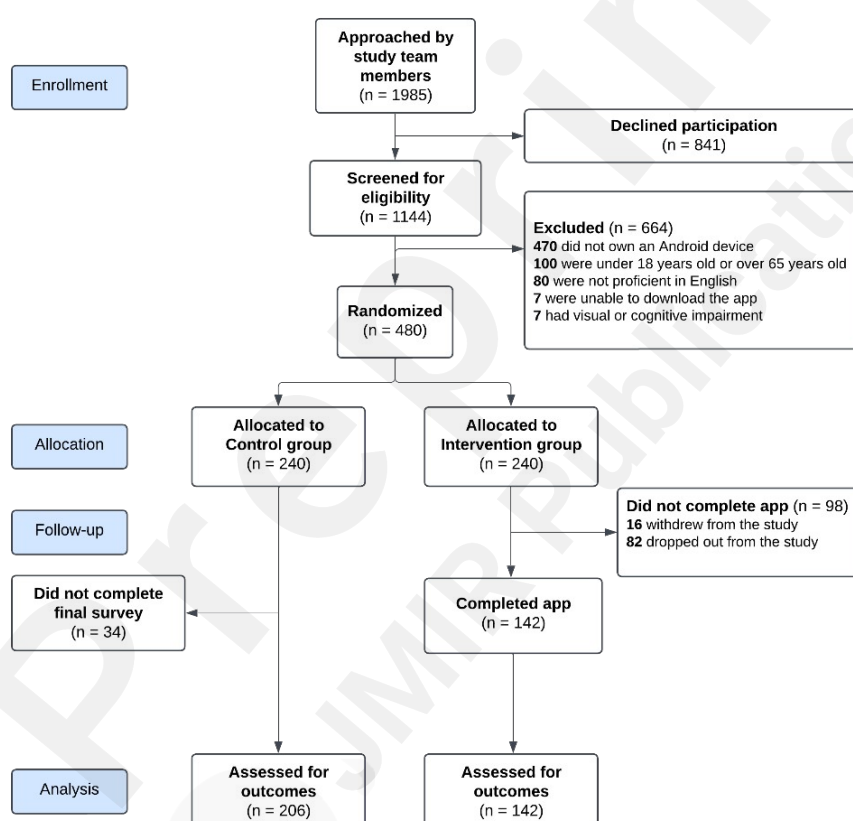
Figure 6: CONSORT flow diagram of a two-arm Randomized Controlled Trial conducted on participants recruited from government-funded primary care clinics between January 2023 - March 2023 in Singapore. 1985 people were approached, 1144 were screened for eligibility and 480 were recruited into the study and randomized equally into the control or intervention group. The outcomes of 142 intervention participants and 206 controls were eventually assessed.

Recruitment

Recruitment occurred between January 2023 – March 2023, and follow-up was completed by early June 2023. We ceased recruitment when we achieved 240 participants per arm.

Baseline data

Table 1 shows participants' baseline characteristics. The randomization produced comparable groups as there were no significant between-group differences in participants' sociodemographic characteristics at baseline. Participants had a mean (SD) age of 36.9 (12.2) years. Our participant profile fits Singapore's population profile in terms of ethnicity (72.4% Chinese; 17.5% Malays; 6.9% Indians), education level (36.8% had tertiary education), and housing type (78.6% residing in conventional public housing flats). There were also no significant between-group differences in the mean (SD) baseline knowledge score 8.4/11 (1.6), but the attitude-perception score was significantly higher in controls (9.6 (2.6)) compared with intervention participants (8.8 (3.0)). In addition, 60.1% of participants had no exposure to advertisements on antibiotic use at baseline.

Table 1: Baseline characteristics of the RCT participants recruited from government-funded primary care clinics between January 2023 - March 2023

Baseline characteristics of respondents, n (%)	All participants (N=348)	Intervention group (N=142)	Control group (N=206)	P-value
Sociodemographic factors	n (%)	n (%)	n (%)	
Age, mean (SD)	36.9 (12.2)	35.9 (12.0)	37.6 (12.3)	.210
Sex				
Male	181 (52.0%)	76 (53.5%)	105 (51.0%)	.640
Female	167 (48.0%)	66 (46.5%)	101 (49.0%)	
Race				
Chinese	252 (72.4%)	106 (74.7%)	146 (70.9%)	
Malay	61 (17.5%)	23 (16.2%)	38 (18.5%)	.786
Indian	24 (6.9%)	8 (5.6%)	16 (7.8%)	
Other races	11 (3.2%)	5 (3.5%)	6 (2.9%)	
Educational level				
Tertiary education	128 (36.8%)	47 (33.1%)	81 (39.3%)	.237
Non-tertiary education	220 (63.2%)	95 (66.9%)	125 (60.7%)	
Marital status				
Married	169 (48.7%)	65 (45.2%)	101 (49.3%)	.364
Unmarried	178 (51.3%)	77 (54.2%)	104 (50.7%)	
Housing				
HDB 3-room flat and below	81 (23.3%)	33 (23.2%)	48 (23.3%)	
HDB 4 or 5-room flat	194 (55.8%)	80 (56.3%)	114 (55.3%)	.975
Above HDB 5-room/private property	73 (21.0%)	29 (20.4%)	44 (21.4%)	
Knowledge, Attitude, and Perceptions on antibiotics and AMR				
Advertisement on antibiotic use				
Had seen advertisements	139 (39.9%)	61 (43.0%)	78 (37.9%)	.340
Had NOT seen advertisements	209 (60.1%)	81 (57.0%)	128 (62.1%)	
Knowledge score, mean (SD) [Maximum score: 11]	8.4 (1.6)	8.5 (1.6)	8.3 (1.7)	.163
Attitude-perception score, mean (SD) [Maximum score: 14]	9.3 (2.8)	8.8 (3.0)	9.6 (2.6)	.004

Tertiary education: University and above

HDB flat: Flats developed by Singapore's public housing authority

The randomization produced comparable groups as there were no significant between-group differences in participants' sociodemographic characteristics at baseline. Our participant profile fits Singapore's population profile in terms of ethnicity and housing type.

Change in knowledge score

The mean standardized knowledge score improved from 77.6% at baseline to 82.4% post-game and 83.5% 6-10 weeks post-intervention among intervention group participants, while controls had a modest improvement of 75.4% from baseline to 78.1% at 6-10 weeks post-baseline (Multimedia Appendix Figure 1).

The multivariable regression analyses (Table 2) showed that intervention group participants had greater improvement in knowledge compared with controls [between-group differences (95% CI): 0.58 (0.28, 0.87)] after accounting for age, educational level, and exposure to advertisements on antibiotics and AMR.

Table 2: Multivariable weighted least square regression analysis of the association between the intervention and knowledge score at 6–10-week post-intervention

Model variables	Outcome: 6–10-week post-intervention Knowledge score		
	Effect sizes (95% CI)	P-value	VIF
Randomization group			
Control	Ref		
Intervention	0.58 (0.28, 0.87)*	<.001	1.04
Knowledge			
Baseline knowledge score	0.24 (0.17, 0.32)*	<.001	1.08
Age group			
Aged 18 - 25	Ref		
Aged 26 - 35	-0.75 (-1.19, -0.31)*	.001	1.91
Aged 36 - 50	-0.43 (-0.90, 0.03)	.065	2.49
Aged 51 - 65	-0.45 (-0.99, 0.08)	.094	2.05
Marital status			
Not Married	Ref		
Married	-0.32 (-0.67, 0.03)	.069	1.51
Education status			
Non-Tertiary education	Ref		
Tertiary Education	0.77 (0.45, 1.09)*	<.001	1.13
Advertisement on antibiotics and AMR			
Have not seen advertisements	Ref		
Have seen advertisements	0.39 (0.09, 0.69)*	.010	1.05

*p<0.05

Intervention group participants had greater improvement in knowledge compared to baseline after accounting for age, educational level, and exposure to advertisements on antibiotics and AMR

Change in attitude-perception score

The mean standardized attitudes-perception score improved from 62.6% at baseline to 77.7% post-intervention among intervention group participants, while controls had a modest improvement of 68.9% from baseline to 71.9% post-intervention (Multimedia Appendix Figure S3). The proportion of intervention group participants with the "correct" attitudes and perceptions increased for all 14 statements post-intervention (Multimedia Appendix Figure S4). However, intervention group participants continues to have misconceptions about antibiotic use after completing the game quest. The proportion of participants with correct responses for the statement "I need antibiotics to recover from serious symptoms from the

common cold and flu" increased from 29.6% pre- to 46.5% post-intervention, and for "I need antibiotics if I continue to have flu symptoms after two weeks" increased from 22.5% pre- to 38.7% post-intervention.

The multivariable regression analyses (Table 3) showed that intervention group participants had better attitudes-perception improvement compared with controls [0.98 (0.44, 1.52)] after accounting for marital status and ethnicity.

Table 3: Multivariable weighted least square regression analysis of the association between the intervention and Attitude-Perception score at 6–10-week post-intervention

Model variables	Outcome = 6–10-week post-intervention Attitude-Perception score		
	Effect sizes (95% CI)	P-value	VIF
Randomization group			
Control	Ref		
Intervention	0.98 (0.44, 1.52)*	<.001	1.30
Attitude-Perception			
Baseline Attitude-Perception score	0.46 (0.39, 0.53)*	<.001	1.26
Education status			
Non-Tertiary education	Ref		
Tertiary Education	0.56 (-0.13, 1.26)	.109	1.67
Ethnicity			
Chinese	Ref		
Malay	-2.86 (-3.56, -2.15)*	<.001	1.84
Indian	-1.28 (-2.19, -0.36)*	.006	1.71
Others	-0.19 (-2.10, 1.72)	.847	1.03
Marital status			
Not Married	Ref		
Married	-1.39 (-1.99, -0.78)*	<.001	1.67

*p<0.05
intervention group participants had better attitudes-perception improvement compared with controls after accounting for marital status and ethnicity.

App satisfaction

The majority of participants (>95%) agreed that the "SteWARdS Antibiotic Defence" app improved their awareness on antibiotic use and AMR. More than 70% agreed that the app is easy to use and enjoyable, and 85.2% would recommend the app to others (Table 4).

Participants who would recommend "SteWARdS Antibiotic Defence" found the app user-friendly, fun, enjoyable, and interesting. Some participants also lauded the app's unique learning modality and felt that the intervention addressed an important public health topic, raised their awareness of AMR, and improved their knowledge on appropriate antibiotic use (Multimedia Appendix Table S5).

"It provides information about antibiotic resistance in an easy to understand, engaging way."
"It is much more engaging compared to reading or [looking] through long videos."

Participants who would not recommend the app mainly had a poor user experience and were frustrated with technical difficulties in navigating the app. Some technologically astute players found the game boring, repetitive, and unfulfilling.

"There were technical issues that made completing the game annoying."

One participant found no value in recommending the app to friends/family member working in healthcare. Those who found the games difficult to play (mostly older adults) or experienced usability issues (e.g., small fonts) also expressed dissatisfaction with the intervention.

"Seniors may not be able to understand how to play the games."

Table 4: Satisfaction in using the "SteWARdS Antibiotic Defence" app (n=142)

App satisfaction	Responses
[User experience] *How far would you agree that the app:	n (%)
Improved awareness on antibiotic use	135 (95.1%)
Improved awareness on antimicrobial resistance	136 (95.8%)
Is easy to use	105 (73.9%)
Is enjoyable to use	100 (70.4%)
[User satisfaction]	n (%)
Would recommend the app to others	121 (85.2%)

*User experience was measured on a five-point Likert scale. We report the proportion of respondents who agreed with the statements on user experience. The majority of participants agreed that the "SteWARdS Antibiotic Defence" app improved their awareness on antibiotic use and AMR. More than 70% agreed that the app is easy to use and enjoyable, and would recommend the app to others.

Suggestions for app improvement
Suggestions to improve the quality of "SteWARdS Antibiotic Defence" include (Multimedia Appendix Table S6):

Refining game mechanics

Participants pointed out that the mini-games should focus on reinforcing concepts the study team intended to teach. For example, one mini-game leans towards self-care instead of teaching about antibiotics use and AMR. Some participants also suggested improving the game's instructional clarity, calibrating the in-game economy to optimize the game's difficulty level, and increasing the number of interactive elements.

"The upgrades in the Tower Defence Game is overpowered and makes it too easy."

"Let users know how much the coins earned from "endless runner" are worth. This ties into the other game "tower defence" because you need coins to build the towers."

Enhancing user interface

Participants suggested having a consistent art style, larger word fonts to cater to older adults, and graphics with a closer resemblance to bacteria and viruses.

"Maybe the educational message displayed before each game can be read out."

"The 3D games can have better art style to match with the other 2D games and environment."

Having more app features

Suggested app features include adding music and sound effects within the mini-games, allowing players to create personal profiles, and in-app game demonstrations.

"More sound effects would be nice."

Bug fixes

Participants suggested to improve the app's responsiveness, sensitivity, speed, and fixing the glitches.

"*Developer to look into the app responsiveness and the graphics."*

Discussion

We evaluated the effectiveness of an evidence-based serious game mobile app in improving the KAP of appropriate antibiotic use and AMR among Singapore residents. To our knowledge, this is the first RCT assessing the effectiveness of a serious game mobile app intervention for public education on appropriate antibiotic use and AMR. We also assessed the effectiveness of the app in short-term knowledge retention at 6-10 weeks post-intervention, which has often been overlooked. Furthermore, we assessed the app in a real-world context in the community and not in the controlled environment of an experimental setting.

We observed a significant effect size of 0.58 (95% CI: 0.28, 0.87) in knowledge improvement, which concurs with other serious game studies on chronic disease management among young people[26] and healthy lifestyle promotion[27]. However, a similar Singapore study on dengue prevention observed significant improvements of participants' knowledge, attitudes and practices from baseline but no between-group mean differences[28]. The difference in observations is likely attributed to the exposure of relevant information sources among controls in the dengue study, which attenuated the effects of the app intervention. Tertiary-educated adults were positively associated with higher post-intervention scores. They may fare better at learning the more difficult AMR concepts as studies have shown that AMR concepts are hard to teach. Participants with no or limited understanding of the aetiology of antibiotic resistance would face difficulty connecting AMR with antibiotic misuse[29]. Furthermore, misconceptions about antibiotic use are generally hard to rectify.

We also observed a significant effect size of 0.98 (95% CI: 0.44, 1.52) in attitude-perception improvement with the "SteWARdS Antibiotic Defence" app. Other studies have found mixed results in the effectiveness of serious games in improving the adoption of healthy behaviours, such as fruit and vegetables intake among adolescents[15]. The effectiveness of serious games in changing attitudes and perceptions are hard to measure as studies are often multifaceted. Therefore, it is essential to have well-designed interventions targeted at the correct population, well-accepted by participants, and with attainable goals for interventions to be successful. While we recruited participants between ages 18 – 65, the app was originally developed for young adults as this group of people was found to have the lowest knowledge in antibiotic use and AMR[7].

Our "SteWARdS Antibiotic Defence" app received an overall positive rating, but the ratings should be interpreted with caution as the satisfaction survey was only filled by participants who completed the game quest in the app. It is unclear if participants dropped out of the intervention due to dissatisfaction with the app or a lack of time to complete the quest. Other studies assessing the effectiveness of serious games in health education have observed high satisfaction among participants[30, 31]. However, there is limited evidence on the satisfaction with health education delivered via serious games in the general population and even fewer studies reporting participant satisfaction. Hence, the feedback and suggestions we gathered from participants are valuable in identifying population-specific shortcomings of the intervention and informing app enhancements that could increase the success of intervention scale-ups.

Despite a modest improvement in KAP scores in the intervention group, improved health literacy may not translate to desired behavioural change[13, 32]. Health literacy interventions

have led to improved health outcomes in some studies, but the links between health literacy improvement and behavioural change have not been established with higher quality studies[33]. Effective interventions are also integral to attaining successful behavioural change. One way to improve the learning outcomes, suggested by our participants, is to weave the intended learning concepts into the game mechanics rather than displaying informational text boxes for players to read. Such enhancements would possibly improve user engagement and lead to better learning outcomes[34].

A few limitations exist in our study. First, measurement errors in KAP scores might occur if intervention group participants had requested their friends or family members to help with study completion. Nonetheless, controls could also have had help in completing the post-intervention survey. Therefore, any bias is likely towards the null, which attenuates the intervention's true effect. Second, there is a ceiling effect for participants with near-perfect baseline scores, which could attenuate the positive effects of the intervention. Third, we randomised participants prior to baseline data collection because the knowledge questions were embedded in the app. Fourth, there may be a learning effect in the intervention group as these participants completed the knowledge questionnaire three times. Hence, the positive effects observed in the intervention group could be a combination of the serious game and learning effect from the immediate post-game survey. Including a study group with a traditional form of learning (e.g., brochures) may enable us to assess the effect of the serious game app more accurately. Lastly, we included only attendees at two government-funded primary care clinics (polyclinics). Despite the limitations in recruitment, the sociodemographic distribution of our participants is representative of the Singaporean population. Hence, our findings are generalizable to the rest of the country.

In addition, we noticed several older adults rejecting study participation due to a lack of interest in completing the mobile app quest. Their lack of interest implies an additional effort to change their mindsets, and serious-game interventions may not be the best modality for educating older adults on public health issues. Reminders were also integral in driving the app completion rate. Hence, the actual uptake rate may be lower in the population. Future research should assess the effectiveness of interventions that facilitate long-term knowledge retention and long-lasting behavioural change in antibiotic use and AMR[35].

Conclusion

In conclusion, our educational serious game app improves participants' KAP on appropriate antibiotic use and AMR. Public education apps should be engaging, educational, easy-to-use, and have an attractive user-interface. Interventions should also aim to achieve long-term knowledge retention and long-lasting behavioural change.

Acknowledgements

Data availability

Deidentified data that support the findings of this study are available on request from AC or ZH.

Author contributions

ZH co-developed the app, conceived the manuscript, obtained the catalyst grant, analysed the data, and drafted the manuscript. OJT administered the study, analysed the data, and drafted the manuscript. WET provided inputs to the study design and support for running the trial. AC co-developed the app and provided inputs to the study design of the trial. All authors critically reviewed the manuscript.

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Conflict of Interest

All authors report no potential conflicts of interest.

Abbreviations

AMR: Antimicrobial resistance
KAP: Knowledge, Attitudes, and Perceptions
Mobile applications: apps
NPC: Non-player characters
RCT: Randomized controlled trial

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Supplementary Files

Figures

An example of a knowledge question embedded in the app. Participants are expected to complete 11 pre-intervention knowledge questions, followed by the game quest and 11 post-knowledge questions to complete the intervention.
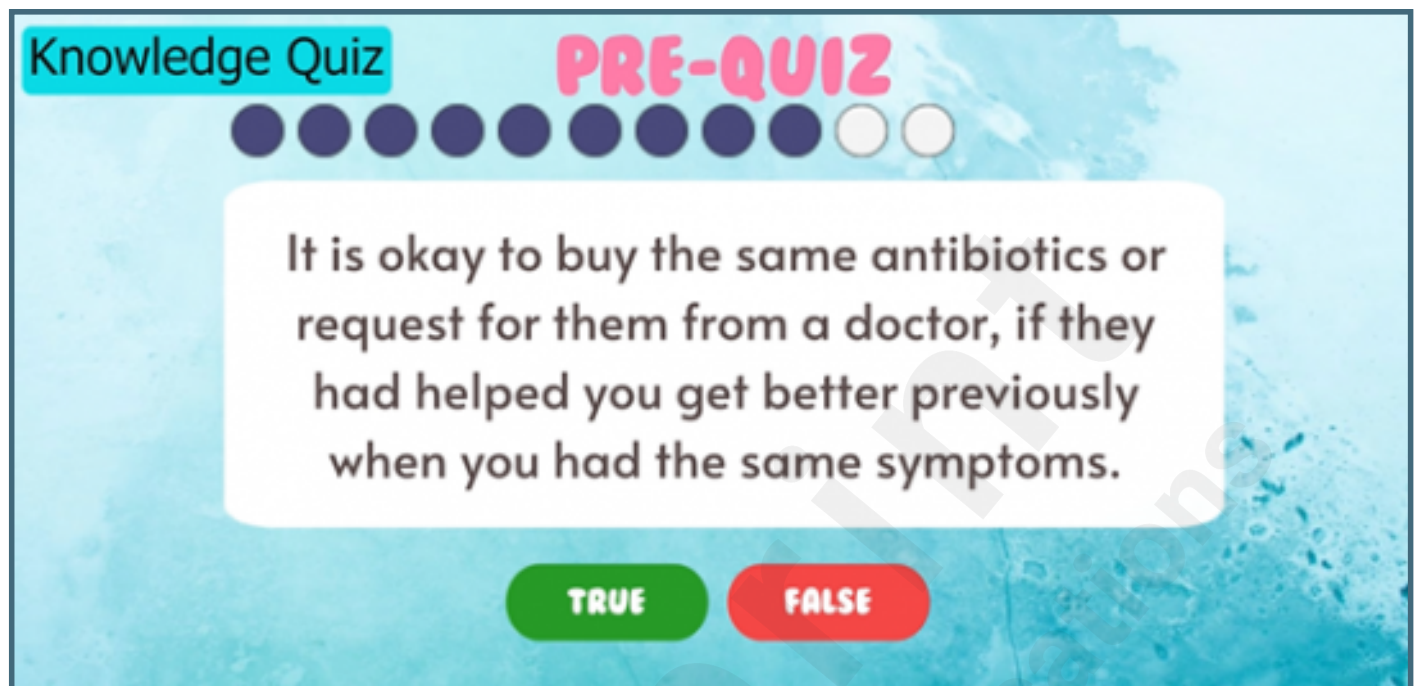
Interaction with a non-player character (NPC) at the park. Bite-sized messages on good antibiotic use practices are released through interactions with the NPCs. The right most NPC leads to the tower defence game.
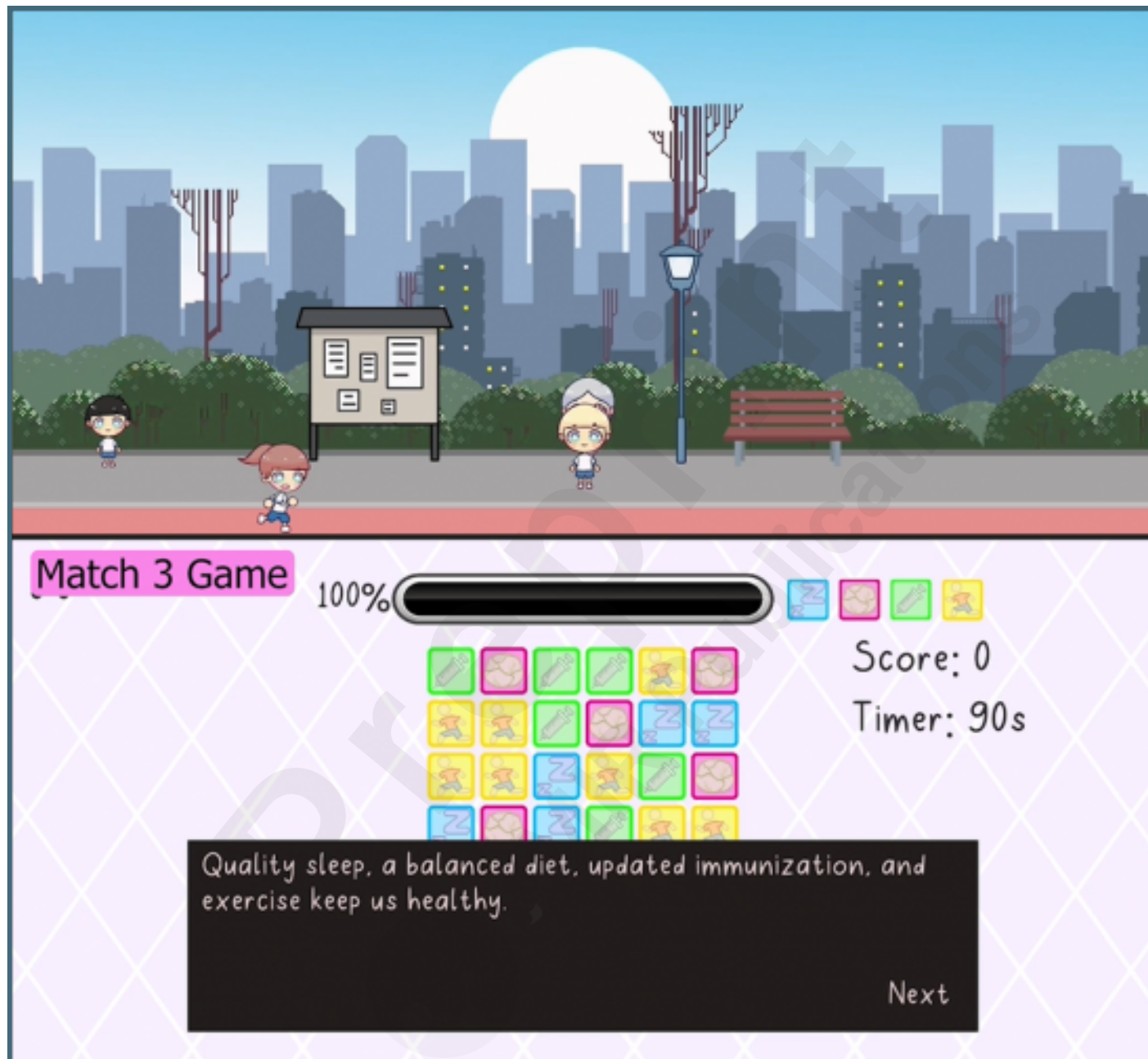
The Tower Defence game consist of 9 levels. The top figure shows the game interface with C-Stin turrets and the super bug (level 9). The subsequent figures show the messages released at the beginning of level 9 to teach players about the concept of antimicrobial resistance. Players have to choose the appropriate turrets and strategically place them at appropriate locations to effectively target their enemies (bacteria/viruses).
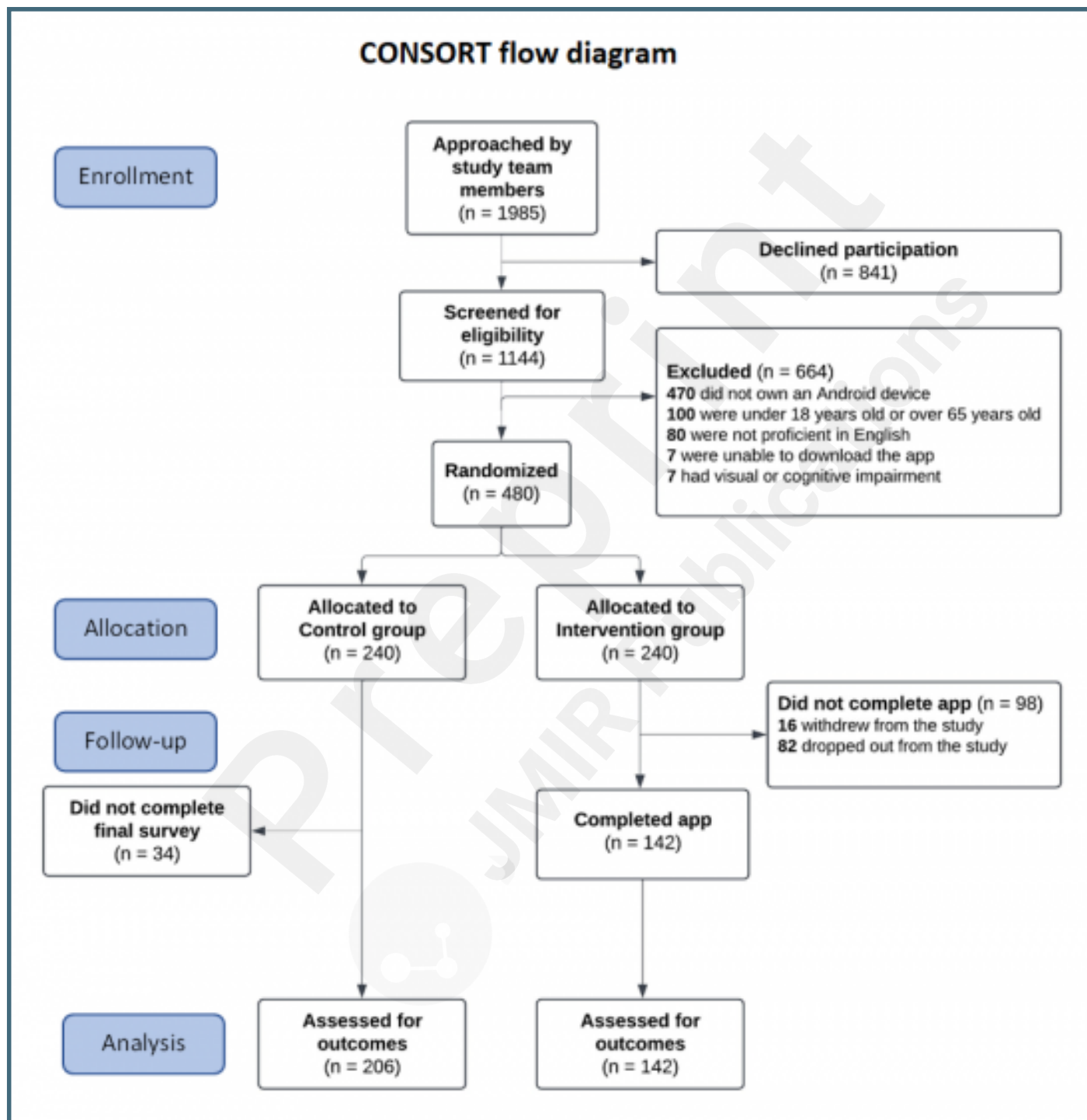
The Endless Runner game can be accessed via the train station (picture on top). The game reinforces the message that antibiotics are only effective against bacteria and not viruses. Players collect coins while running and use the antibiotic gun and immunity gun to shoot at bacteria and virus obstacles, respectively. Coins collected from the Endless Runner game can be used to purchase turrets in the Tower Defence game.

The Match3 game can be accessed via the park (picture on top). The game educates players on good health habits by encouraging focusing on sleep hygiene, nutrition, immunization, and physical exercise. Players are required to match three or more similar tiles within a specific time limit to successfully clear each of the 10 levels. Bite-sized messages are released before the start of each game to remind players of maintaining a healthy lifestyle.

CONSORT flow diagram of a two-arm Randomized Controlled Trial conducted on participants recruited from government-funded primary care clinics between January 2023 - March 2023 in Singapore. 1985 people were approached, 1144 were screened for eligibility and 480 were recruited into the study and randomized equally into the control or intervention group. The outcomes of 142 intervention participants and 206 controls were eventually assessed.

Multimedia Appendixes

Supplementary files.
URL: http://asset.jmir.pub/assets/79b01c81fdbdf6ec91841378464586de.docx