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Smartphone-based gamification intervention to increase physical activity participation among patients with coronary heart disease: a randomized controlled trial

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Abstract

Introduction: Despite proven benefits, patients with the coronary disease typically fail to participate in sufficient physical activity. Effective interventions should be implemented to help patients maintain a healthy lifestyle and modify their present behavior. Gamification is the use of game design features (such as points, leaderboards, and progress bars) to improve motivation and engagement. It shows the potential for encouraging patients to engage in physical activity. However, empirical evidence on the efficacy of such interventions among patients with coronary heart disease is still emerging.

Purpose: The aim of the study is to explore whether a smartphone-based gamification intervention could increase physical activity participation and other physical and psychological outcomes in coronary heart disease patients.

Methods: Participants with coronary heart disease were randomly assigned to three groups (control group, individual group, and team group). The individual and team groups received gamified behavior intervention based on behavioral economics. The team group combined gamified intervention with social interaction. The intervention lasted 12 weeks, with another 12 weeks of follow-up. The primary outcomes included the change in daily steps and the proportion of patient days that step goals were achieved. The secondary outcomes included competence, autonomy, relatedness, and autonomous motivation.

Results: For the individual group, smartphone-based gamification intervention significantly increased physical activity among CHD patients over the 12-week period (step count difference 988; 95% CI, 259 - 1717; $P<0.01$) and had a good maintenance effect during the follow-up period (step count difference 819; 95% CI, 24-1613; $P<0.01$). There is also

significant differences in competence, autonomous motivation, BMI, and waist circumference in 12 weeks between control group and individual group. For the team group, gamification intervention with collaboration didn't result in significant increases in physical activity. But patients in this group had a significant increase in competence, relatedness, and autonomous motivation.

Conclusion: A smartphone-based gamification intervention was proven to be an effective way to increase motivation and physical activity engagement, with a substantial maintenance impact.

Keywords: physical activity, behavioral intervention, mobile health, gamification, randomized controlled trial

1. Background

In China, coronary heart disease (CHD) is the main cause of death. In 2021, approximately 11 million people were statistically afflicted by CHD[1]. Exercise-based cardiac rehabilitation and secondary prevention (CR/SP) is a Class I recommendation for CHD treatment by the American Heart Association, the American Society of Cardiology, and the European Society of Cardiology[2–4]. The latest guidelines recommend that adults should perform at least 150–300 min a week of moderate intensity or 75–150 min a week of vigorous intensity aerobic physical activity (PA) to prevent cardiovascular disease[5]. Despite the documented benefits of physical activity, it is often challenging for people to embrace the necessary lifestyle changes to improve PA, particularly for patients with cardiovascular

disease. Previous research reported that patients typically fail to attain their daily physical activity goals[6]. Our pre-project survey of 290 post-PCI patients in Changchun, China found that 72.1% (209/290) of patients did not meet the guideline recommendations.

Digital health tools have become an essential medium to deliver behavioral change interventions[7–9] and have demonstrated promising ability to improve physical activity levels[10]. Digital health technology is also an essential medium for delivering cardiac telerehabilitation, which has been shown to be as effective as center-based CR and more cost-effective [11-13]. WeChat is the most popular social networking app in China, with 1.3 billion active users[14]. A study demonstrated that WeChat-based intervention could improve adherence to secondary prevention[15]. WeChat applets are lightweight applications that are a component of the WeChat ecosystem that may be utilized independently without installation. In China, WeChat applets are more readily accepted and utilized than smartphone applications. The first quarter of 2022 recorded 500 million active WeChat applet users every day, providing it an ideal platform for the dissemination of digital health interventions in China[14].

Gamification is the use of game design elements (such as points, leaderboards, progress bars, and badges) in non-game contexts to increase motivation and engagement[16]. There is growing interest in the application of gamification in digital health to promote healthy behavioral changes[17–21], especially in promoting physical activity levels[22]. Previous studies indicated that 64% of the top 50 most popular smartphone apps incorporated gamification[23]. Moreover, as the concept of gamification is relatively new, empirical evidence on the efficacy of gamification physical activity behavioral change interventions among patients with CHD is

still emerging.

Gamification interventions are rarely based on a sound theoretical framework[19,20]. Behavioral economics principles combine traditional economic principles with psychological concepts to explain how humans act and make decisions[24]. Behavioral economics principles can be embedded with a gamification intervention delivered via mobile devices to help individuals achieve their physical activity goals[25]. Several earlier studies have employed behavioral economics principles to assist patients with losing weight, quitting smoking, and adhering to medications[26-28]. However, limited data is available on applying these concepts to improve physical activity participation in patients with CHD.

This study used behavioral economics principles to develop a gamification WeChat applet called "TahneeWeh" to address the aforementioned research gap. The purpose of this study was to examine the impact of a smartphone-based gamification intervention on physical activity participation and various relevant physical and psychological outcomes.

2. Methods

2.1 Study design

This was a single-blind, randomized, controlled trial with three arms to evaluate the effects of a smartphone-based gamification intervention on physical activity participation, biomedical and lifestyle-related risk factors, intrinsic motivation, enjoyment, competence, autonomy, relatedness, social support, and mental health. A total of 108 participants were randomly divided into three groups (control group, individual group, and team group). Patients in the control group only received daily step goal setting. The individual and the team group received gamified behavioral intervention based on the concepts of behavioral

economics. The team group also received social incentives based on the individual group. The intervention lasted 12 weeks, and the follow-up was 12 weeks. All patients just received WeChat applet-based step goal setting in the follow-up period. The study protocol has previously been published[29].

2.2 Recruitment

Experienced clinical nurses and researchers were responsible for recruiting participants. Recruitment occurred at the cardiac rehabilitation center of an A-class hospital in Changchun, China. Patients were eligible for the trial if they were between the ages of 18 and 70, diagnosed with CHD (including acute myocardial infarction and unstable angina), received percutaneous coronary intervention (PCI) treatment during hospitalization, provided written informed consent, possessed a smartphone with an active WeChat account, and spoke Chinese. Exclusion criteria included contraindications for exercise rehabilitation (e.g., untreated ventricular tachycardia, severe heart failure, uncontrollable hypertension or hypotension, significant exercise restriction), inability to use the WeChat applet after instruction, lack of Internet access at home, need for a walking aid, and enrollment in other clinical trials.

2.3 Control

During the 12-week intervention and 12-week follow-up, all patients received step-by-step goal setting and were able to track their progress via a WeChat applet. Personalized daily step goals were set in the WeChat applet backstage based on patients' baseline daily step counts, and the goals increased gradually from the baseline by 15% each week during the first six weeks and then remained constant during the last six weeks, as described elsewhere[30]. Participants could contact the rehabilitation team anytime to adjust if

it is due to physical conditions. Moreover, patients could see their daily progress toward their goals using a circular dial on the WeChat applet. Of note, patients in the control group received no other interventions.

2.4 Intervention

Patients in the individual and team groups received the gamification intervention based on behavioral economics principles via the WeChat applet. In the individual group, patients maintained points and levels and received rewards based on their step counts. Patients in the team group had to cooperate with other team members to maintain points and levels and receive rewards.

2.6.1 Individual group

Patients in the individual group received 140 points every Monday (20 points per day), and if they met their daily step goal, no points were deducted; if they did not, 20 points were deducted. From lowest to highest, a total of five levels were established: bronze, silver, gold, platinum, and diamonds. Patients were assigned the gold level at the beginning of the trial. If a patient's total score for the week was less than 80, the level decreased, and if it was≥ 80, the level increased. If a patient's level was diamond at the end of the intervention, he or she was awarded a modest prize. Patients in the two intervention groups received weekly progress-based feedback automatically.

2.4.2 Team group

In the team group, gamification incorporated social interaction. Patients were assigned to a team of 3 people who did not know each other before the intervention. Every Monday, the patients received 140 points (20 for each day, 10 for themselves, and 10 for their team). If the

patient achieved the step goals and the other two people in his/her team also achieved the step goals, no points were deducted. If the patient achieved the step goals but the other two people in his/her team didn't, 10 points for their team were deducted. If neither the patient nor the other two people in his/her team achieved the step goal, 20 points were deducted.

2.5 Outcome measures and data collection

The primary outcome was physical activity participation, which includes a change in mean daily steps from the baseline to 12 and 24 weeks, as well as the proportion of patient days that step goals were achieved in 12 and 24 weeks. The daily step counts were measured and recorded by smartphone accelerometers.

The secondary outcomes included biomedical risk factors, which included the body weight(kg), waist circumference (cm), body mass index (BMI), systolic blood pressure (mmHg), diastolic blood pressure (mmHg), resting heart rate (bpm/min), lifestyle-related risk factors, including smoking, intrinsic motivation, enjoyment, competence, autonomy, and relatedness, social support, anxiety symptom, and depressive symptoms. All of the measurements for baseline and 12 weeks were taken at a hospital. However, due to COVID-19, patients were unable to come back to the hospital in 24 weeks; we used Wechat to send the link of the questionnaires to the patients, and biomedical risk factors were not measured in 24 weeks. In addition, at 12 weeks, both intervention groups completed the System Usability Scale (SUS). Furthermore, we conducted a semi-structured interview to better comprehend the patients' satisfaction, perceptions, and experiences in the two intervention groups.

2.6 Statistical analysis

All continuous variables were reported as mean and SD, and categorical variables were described as frequencies and percentages. Between-group changes in daily step count, the proportion of patient-days that step goals attained, self-reported physical activity, biomedical and lifestyle-related risk factors, intrinsic motivation, enjoyment, competence, autonomy, and relatedness, social support, and mental health was compared using a paired t-test or Wilcoxon test depending on the data distribution. And the differences in categorical variables were compared using the $\chi 2$ test or Fisher's exact test. Multiple imputations for data were used that are missing and with step values <1000 because evidence indicates that these values are unlikely to represent the capture of actual activity[31,32]. For the qualitative data, recordings were made, transcribed, and topics were extracted from the transcripts. All statistical analyses were two-sided, and $P < 0.05$ were considered statistically significant. We used SPSS V.20.0 for data analysis.

2. Results

In this trial, a total of 108 patients with coronary heart disease were randomized (Figure 1). The mean age of patients was 53.0 years, and 18.5% (n = 20) were female (Table 1). Other patient characteristics were similar between the study groups, except for diastolic blood pressure, which was significantly lower in the control group compared to the intervention groups. The mean ($\pm$SD) numbers of participant baseline daily steps were 5866 ($\pm$2152) in the control group, 5796 ($\pm$2900) in the individual group, and 6133 ($\pm$4200) in the team group, which were not significantly different (P = .940). One hundred three patients (95.4%) completed the 12-week intervention, and 93 (86.1%) patients completed the entire 24-week

study. During the intervention period, step data that were missing or had values less than 1000 steps per day represented 21.3% (643 of 3024 participant-days) of observations in the control group, 16.7% (505 of 3024 participant-days) of observations in the individual group and 19.0% (575 of 3024 participant-days) of observations in the team group. During the follow-up period, these percentages increased to 29.7% (898 of 3024), 24.4% (738 of 3024), and 26.2% (792 of 3024), respectively (Supplementary Figure 1). No adverse events related to the interventions were reported during the entire trial.

3.1 Primary outcomes

The mean daily steps by week and study arm are depicted in Figure 2. The individual group had the highest physical activity levels during the entire trial. Mean steps per day for the overall intervention and follow-up periods are depicted by the arm in Table 2. Compared with the control group, patients in the individual group had a significantly greater increase in mean daily steps from baseline during the intervention (difference 988; 95% CI, 259 - 1717; P<0.01) and follow-up (difference 819; 95% CI, 24-1613; P<0.01). No significant difference of change in step counts was found between team group and control group.

The proportion of days that step goals were achieved was 0.29 in the control group, 0.38 in the individual group, and 0.32 in the team group. These levels were lower in the follow-up period at 0.25 in the control group, 0.30 in the individual group, and 0.26 in the team group (Table 3). Compared with the control group, patients had a significantly greater proportion of days that step goals were achieved in the individual group during the intervention (difference from control, 0.08 ; 95% CI, 0.04-0.13; P < .001) and follow-up (difference from control, 0.07 ; 95% CI, 0.06-0.09; P < .05). There were no significant differences between the team

group and the control group during the intervention and follow-up periods.

3.2 Secondary outcomes

As shown in Table 4 and Table 5, in the intervention period, compared with the control group, patients in the individual group had a significantly greater increase in competence (difference 0.6, 95% CI, 0.3 - 0.8; P<.001) and autonomous motivation (difference 3.3, 2.2-2.4; P<.001), and a significant decrease in BMI (difference -0.4; 95% CI -0.6 to -0.2; P<.001) and waist circumference (difference -1.2; 95% CI -1.7 to -0.6; P<.001). Patients in the team group had a significantly greater increase in competence (difference 0.3; 95% CI 0.1 to 0.6; P<.001), relatedness (difference 0.9; 95% CI 0.7 to 1.2; P<.001) and autonomous motivation (difference 3.0; 95% CI 2.1 to 4.0; P<.001). No significant difference was found in autonomy, PACES score, SSRS, GAD-7, and PHQ-9 between the intervention group and the control group. In the follow-up period, competence was significantly different from control in only the individual group (difference from control, 0.9; 95% CI, 0.2-1.6; P < .05).

Patients in the two intervention groups also completed the system usability scale after 12 weeks. Patients have a high score in satisfaction (3.5 in individual group and 3.3 in team group) and use efficiency (3.2 in individual group and 3.1 in team group). The learnability score in the team group (2.9) and individual group (2.5) is considered low (Supplementary Figure 1).

3.3 Qualitative outcomes

A total of 18 patients in the individual group and 15 in the team group participated in the semi-structured interview.

Motivation to increase physical activity

Most of the patients in the individual group were positive about the Wechat applet and intervention. They thought the game was useful, and interesting and could motivate them to do more physical activity. P14 said:

I feel being supervised increases my motivation; I have a step goal every day, which motivates me.

Another patient said:

The game is useful and exciting, I want to do walk more to keep my points.

There were mixed responses on improving physical activity in the team group. Half of the patients in the team group were positive about the support provided by the intervention and motivated by the team members, P20 remarked:

I am in a team, and I will not let my team members lose their points.

Another patient said:

I like the design of the team; I feel I am not alone.

However, almost half patients in the team group also have negative points for the game; some of them feel controlled and forced when they are in the game.

My team member was so lazy, and he just didn't finish his steps, I could not contact him to motivate him, which was really annoying and made me disappointed and lose interest to continue the game.

Another patient said:

I don't care others' steps, I don't want to be in a team.

The complexity of the system

Most of the patients in the individual group reported that the system is easy to use and

don’t need too much time to spend on the WeChat applet. For example, P 28 said:

I don't need to enter my steps and any information manually, the scores update automatically, and I can check my scores every day, it's very easy, the only thing I need to figure out is my daily step goal but it's right in the middle of the screen so it's not very complicated.

But some people in the team group think the game mechanics are a little difficult, P 98 said:

This gamification mechanic is a bit difficult for me, I can't figure out why I always have no team points, how my teammates are supposed to work together and then I can't contact my teammates, which bothers me.

Continue to use the system in the future

Most of the patients in the individual group were willing to continue using the WeChat applet to support the maintenance of physical activity, and 60% of patients in the team group were willing to continue. For example, when asked about their motivation to continue using the system, P29 said:

Yes, why not, it’s a good way to keep me healthy...

For patients who did not want to continue using the system, it was mainly because they believed that they already had enough physical activity. P63 said:

I personally don't need it now because I'm not a fat person and I think I already have enough physical activity.

Other patients who would not continue using the system think gamification is too childlike, P55 said:

I think only children play this kind of game; it's too gamey for me, so for me, I probably won't participate in the future.

3. Discussion

In this trial, we used a smartphone-based gamification intervention to encourage patients to engage in more physical activity. We explored the effects of gamification intervention alone (individual group) and gamification combined with social collaboration (team group) on physical activity participation. We found that (1) for the individual group, smartphone-based gamification intervention significantly increased physical activity among CHD patients over the 12-week period and had a good maintenance effect during the follow-up period. Patients also had a significantly great increase in competence and autonomous motivation, and a significant decrease in BMI, and waist circumference in 12 weeks. (2) For the team group, gamification intervention with collaboration didn't result in significant increases in physical activity. But patients in this group had a significant increase in competence, relatedness, and autonomous motivation.

In the individual group, gamification enhanced competence and autonomous motivation, which ultimately led to a rise in physical activity. The competence showed a strong relationship with autonomous motivation, and the autonomy had a strong relationship with physical activity. This could be explained by the Self-Determination Theory[33]. In the game design, a step goal setting and feedback system was used; patients needed to achieve their step goals to maintain their points and levels, which made patients feel that they have the capacity needed for success, so they were more likely to take actions that would help them

achieve their goals[34]. However, our game design did not increase patients' autonomy; this may be because that patients cannot choose their step goals and cannot choose to be in a team or not.

The increase in physical activity also benefits weight and waist circumstance. There appears to be a direct dose-effect association between the number of daily steps done and the duration of intervention with clinical benefits. Consequently, while evaluating the net benefit of any intervention, these aspects need to be taken into account. The result is comparable to a prior study conducted by Nishiwaki et al. They did a crossover study and found that gamification has increased physical activity, and the difference in body fat reduction was significantly greater in the game intervention than in the normal intervention[35]. In a meta-analysis of nine studies on pedometer-based walking interventions for weight loss, Richardson et al. reported a body weight decrease was related to daily step counts rising, which is also consistent with the results of our study[36].

In the team group, participants also received social interaction based on the individual group; the results are that patients had an increase in competence, relatedness, and autonomous motivation; however, this did not result in an increase in physical activity. Gamification with collaboration help patients achieve psychological growth; for example, being in a team lets patients experience a sense of belonging and attachment to other people, which are both helpful to increase motivation. However, there is still a gap between motivation and behavior. There are some positive teams and some negative teams in this group. Team members' behavior may impact their behavior. A previous study found that gamification with collaboration led to significant increases in physical activity of 953 steps

per day within families[37]. According to another study, a comparable collaborative intervention among 2-person teams led to better weight loss if team members lived together than if they lived separately[38]. In this study, however, the participants did not know one other beforehand, and the team group showed the smallest gain in physical activity among the gamification arms. This result implies that collaboration may not be effective when participants lack established social connections.

Limitations of the study

Our study is subject to several limitations. First, the intensity of physical activity via the smartphone accelerometer was not measured. Second, the study was limited to patients with smartphones and a WeChat account, which may have led to a selection bias. Third, comprehensive gamification interventions made it impossible to determine which component was effective.

4. Conclusion

A smartphone-based gamification intervention was effective at boosting motivation and physical activity and had a positive maintenance effect. However, the effectiveness of gamification combined with social interaction needs to be further explored. Our findings suggest that gamification may offer a promising approach to changing health behaviors in cardiac rehabilitation and secondary prevention.

Conflict of interest

The Authors declare that there is no conflict of interest.

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