TreeCare: Development and Evaluation of a Persuasive Mobile Game for Promoting Physical Activity

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***Abstract*—Increased physical activity has been shown to reduce morbidity and mortality among adults. Over the years, mobile apps have been developed to encourage people to engage in physical activity, such as walking or running, by employing various persuasive strategies. However, the choice of these strategies is often based on designers' intuition without knowing if the strategies will be effective for target audience and the target behaviour. To address this gap, we conduct a study with 103 adults to assess the perceived effectiveness of 12 widely used strategies in health games design. The strategies are based on the Persuasive Systems Design (PSD) framework. Our results reveal that the strategies are effective for promoting physical activity at varying degrees. These results inform the development of the game, called TreeCare. Next, we conduct a 3-week field study involving 23 target users to evaluate the game in terms of effectiveness and usability. Our results show that TreeCare significantly improved users' physical activity levels. In addition, the game is found to be easy to use, engaging, aesthetically pleasing, and enjoyable. We reflect on our findings and offer practical guidelines to inform the design of effective and usable persuasive applications.**

Keywords—physical activity, persuasive game, persuasive technology, mobile game, behaviour change system, health and wellness, user-centered design

I. INTRODUCTION

Sedentariness, which involves prolonged sitting or reclining, is a common phenomenon in workplaces, schools, homes, and communities [1]. For example, office workers spend most of their working hours sitting [2], students exhibit sedentary behaviour (SB) due to academic-related activities (e.g., studying, working on computers, sitting in class, etc.) [3], commuters spend hours sitting in cars or buses especially in traffic-prone areas. In addition, many adults watch television for hours [4]. According to Owen et al., physical movement is essential for human survival [5]. This assertion is corroborated by existing evidence which has linked SB to cardio-metabolic health risk [6]. Specifically, SB is associated with cardio-vascular disease [7], coronary heart disease [8], overweight and obesity [9], etc. Also, reduced activity or physical inactivity poses similar health risk as SB [10]. Therefore, interventions that help individuals to reduce SB and increase physical activity will produce positive health outcomes.

Mobile health (mHealth) apps including games are increasingly used to deliver physical activity interventions due to the presence of movement tracking sensors (e.g., accelerometer, gyroscope, magnetometer, global positioning system, etc.) in most smartphones and the ubiquitous nature of mobile phones. For instance, accelerometer embedded in phones have been used to estimate sedentary minutes [11] and step counts [12]. To influence users to adopt healthy behaviours, these apps employ various persuasive strategies. For example, strategies (such as self-monitoring, praise, reminder, suggestion, personalization, etc.) have been operationalized in mHealth games to promote physical activity [13], as well as in other apps to discourage smoking [14], encourage healthy eating [15], and so on. Research has shown that the effectiveness of these persuasive strategies may vary from one behaviour domain to another and from one user and user group to another, considering many context-dependent factors that may influence their effectiveness [16]. However, the choice of these strategies is often based on designers' own intuition without knowing if the strategies will be effective for target audience and the target behaviour.

To address this gap, first, we conduct an online survey with 103 participants to assess the perceived persuasiveness or effectiveness of 12 widely used strategies in health games design (i.e., *self-monitoring*, *simulation*, *reminder*, *reward*, *reduction*, *praise*, *suggestion*, *recognition*, *competition*, *cooperation*, *personalization*, and *social comparison*). The strategies are based on the Persuasive Systems Design (PSD) framework [17]. To collect data from participants, we follow an established method that has been used by several Human-Computer Interaction researchers including [35] to operationalize the strategies and study their perceived persuasiveness or effectiveness. Specifically, we designed and presented low-fidelity prototypes operationalizing each strategy in the domain of physical activity, followed by validated scales measuring perceived persuasiveness [18], [35]. We analyze the quantitative data collected from the survey and recorded our empirical findings which revealed that all the strategies are effective in promoting physical activity at varying degrees. These results inform the development of the TreeCare game.

To evaluate the actual effectiveness and usability of the game, we conduct a 3-week field study involving 23 target users. Our results show that TreeCare significantly improved users' physical activity levels (step counts). In addition, the game is found to be easy to use, engaging, aesthetically pleasing, and enjoyable.

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Our work offers five major contributions in the area of persuasive and behaviour change design in Human-Computer Interaction (HCI). First, in most existing persuasive technology research, the choice of the persuasive strategies is often based on designers' own intuition without knowing if the strategies will be effective for target audience and the target behaviour. We address this gap by employing a robust methodology that first investigates the effectiveness of persuasive strategies that are commonly used in health games design based on the literature for promoting physical activity prior to development. Second, we validate and compare the persuasiveness of individual strategies and reveal that the strategies differ significantly in their overall persuasiveness for motivating health behaviour change. Third, we design, develop, and conduct a mixed method evaluation of TreeCare to show that persuasive applications implementing our validated strategies are effective at promoting physical activity. Fourth, we deconstruct how various strategies were operationalized in persuasive games for health. Finally, we reflect on our findings and offer practical guidelines to inform the design of effective and usable persuasive and behaviour change applications.

II. Related Work

A. Persuasive Strategies

At the core of persuasive systems (such as persuasive games) is the concept of persuasion which focuses on motivating people to change their attitude and/or behaviour without using force or deception [19]. These systems achieve persuasion through diverse persuasive strategies or behaviour change techniques. Over the years, persuasive and behaviour change researchers have focused on developing persuasive strategies for developing effective persuasive technologies. In line with this, Fogg [19] developed seven persuasive strategies called persuasive tools. Building on Fogg's work, Oinas-Kukkonen et al. [17] proposed 28 persuasive strategies in their popular Persuasive Systems Design (PSD) framework. However, in the context of persuasive games, the PSD strategies described in Table I are the commonly used strategies [20]–[22].

B. Operationalization of Persuasive Strategies in Mobile Games for Health

Researchers have designed mobile games that operationalize various strategies to deliver health interventions such as physical activity, healthy eating, smoking cessation, oral health, disease management, and weight/obesity management.

For example, Fujiki et al. [23] developed the NEAT-o-Race – a game to motivate players to be physically active. Two competing players move along a racing track as they walk or run in the real world and can see each other's performance – *competition* and *social comparison* strategies. Their movements are tracked through a wearable accelerometer paired with each player's cellphone via Bluetooth – *self-monitoring* strategy. Players accumulate activity points as they move and are praised with motivating words when they lead their opponent – *reward* and *praise* strategies. These activity points can be used to access hints (*suggestion* strategy) on the NEAT-o-Sudoku puzzle game. Similarly, Lin et al. [24] designed the Fish'n'Steps game to discourage sedentary lifestyle in players. They mapped physical activity (daily step counts) to the growth of a fish in a tank using the *simulation* strategy. On the other hand, Consolvo et al. [25], through the UbiFit game, visualized physical activities (walking, running, etc.) performed during the week as flowers blooming in a garden (based on the cause-and-effect of the *simulation* strategy). Players can view progress towards their weekly goals (*self-monitoring* strategy). Another game in the physical activity category include HealthyTogether designed by Chen et al. [26] which allows users to exercise together in pairs (*cooperation* strategy).

LunchTime is a slow-casual game for motivating healthy eating [27]. Players play the role of a restaurant visitor, and the goal is to choose the healthiest option from a list of food choices. Players are awarded points (*reward* strategy) and each player is allowed to view and compare their points with that of other players – *social comparison* strategy.

In the area of health management, a number of games has been developed. For example, to manage asthma disease, Elias et al. [28] developed the InSpire game which encourages patients to assess their lungs often using a spirometer interfaced with the game. Every correct maneuver of the spirometer causes the dragon character to breathe fire, and the player can visually track real-time spirometry readings – *simulation* and *self-monitoring* strategies. On the other hand, Ismail et al. [29] focused on discouraging smoking behaviour among school children through their "Smoke Shooter" game. Players improve the health of their lungs (visually represented using an image) when they shoot down cigarettes and cigarette boxes (*simulation* strategy) and earn points in the process (*reward* strategy). Health facts about the dangers of smoking are randomly displayed to players using the *suggestion* strategy.

C. Our Research Goal

The health games reviewed above employed varying number of strategies ranging from 1 to 5. However, the choice of strategies was based on designers' own intuition without knowing if the strategies would be effective for target audience and the target behaviour. To address this gap, we selected 12 popular strategies from the PSD framework [17] (see Table I) including those employed in the reviewed games, and then applied a robust methodology to determine the perceived effectiveness of these strategies in motivating physical activity behaviour change among adults. Using only the effective strategies, we developed and conducted a mixed method evaluation of a persuasive and fun game (TreeCare) to show that persuasive applications implementing our validated persuasive strategies are effective in promoting physical activity.

TABLE I. Persuasive Strategies and the Corresponding Descriptions

Strategy	Description
Self-Monitoring	Provides means for users to track progress (or performance) towards their goals.
Simulation	Allows users to observe the link between cause and effect with respect to the target behaviour.
Reminder	Reminds users of their target behaviour during system use.
Reward	Provides virtual rewards for users in order to give credit for performing the target behaviour.
Reduction	Reduces the effort that users expend with respect to performing their target behaviour.

Praise	Offers praise through words, images, symbols, or sounds to motivate users based on the target behaviour.
Suggestion	Provides helpful suggestions or tips for users on how to achieve the target behaviour during system use.
Recognition	Provides public recognition for users who perform their target behaviour.
Competition	Provides means for competing with other users to perform the target behaviour.
Cooperation	Provides means for cooperating (or working together) with other users in performing the target behaviour.
Personalization	Provides personalized content or services for users.
Social Comparison	Provides means for comparing performance with the performance of other users. Social comparison does not involve an overt competition.

III. Study Design and Methods

We employed well-established techniques and procedures highlighted below:

- We conducted a study to investigate the perceived effectiveness/persuasiveness of 12 strategies from the PSD model (see Table I) that are widely used in heath games design for motivating behaviour change.
- We developed the game based on our findings from the first study.
- We conducted a field study to evaluate the game's effectiveness in motivating users to be physically active, as well as its usability.

A. Measurement Instrument

To collect data for our first study, we followed an established methodology that has been used in many related research including [30], [31]. Specifically, we developed low-fidelity prototypes operationalizing the strategies in the context of a persuasive game for promoting physical activity. We chose the tree metaphor (which links physical activity level to the health of a tree) as our design idea since people are closely connected to their natural environment [32]. We iteratively designed and refined the prototypes to ensure that they clearly portray the individual strategies and are easily understood by target audience from diverse backgrounds. In addition, prototypes have been widely employed by HCI researchers and shown to be effective at depicting design ideas for evaluation purposes [33]. We created the prototypes using the Balsamiq wireframing tool [34]. Fig. 1 shows the prototype illustrating the *simulation* strategy.

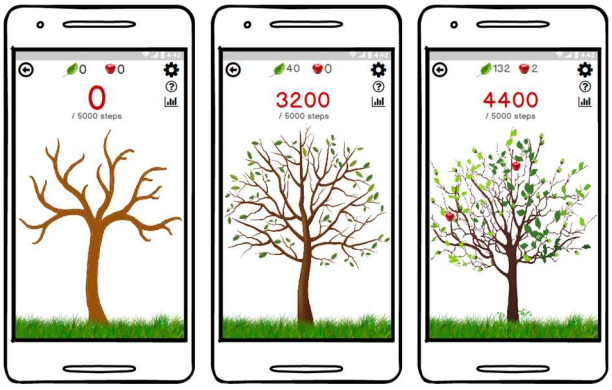

Fig.1. Prototype illustrating the *Simulation* strategy which reveals the cause-and-effect link between step count and the health of a tree.

To elicit feedback on the persuasiveness of the strategies, each prototype was followed by a validated scale for assessing perceived persuasiveness. The scale was adapted from Drozd et al. [18] and has been used in many other persuasive technology research including [31], [35]. Each question was measured using a 7-point Likert scale ranging from "1 – Strongly Disagree" and "7 – Strongly Agree". Participants were asked to examine each prototype (embedded as a set of images, arranged in a way that imitates user interaction with the game) for a while, and then answer the four perceived persuasiveness questions that follow. We also included questions for assessing participants' demographics (such as age, gender, and employment status) and physical activity behaviour, as adapted from the Global Physical Activity Questionnaire (GPAQ) [36].

B. Data Collection

We recruited participants within and outside Canada for our study. Recruitment notices were shared on a university's mailing lists and website, as well as publicly on social media platforms. Participants were required to indicate their consent prior to commencing the online survey. To eliminate possible bias due to the ordering of the prototypes, we used the rotation or randomization functionality of the Opinio survey tool to vary the ordering of the prototypes for each participant.

1) Participants: We included a total of 103 responses in our analysis, having removed incomplete responses. Our inclusion criteria require that participants are: (i) 18 years or older, (ii) sit for long periods (at least 1 hour) or rarely engage in consistent physical activity (such as walking and running), and (iii) exercise frequently but sit for long periods. Participants who are unable to exercise (e.g., walking or running) due to health-related constraints were excluded from the study. In general, our participants make up a diverse population in terms of age, gender, employment status, and physical activity behaviour (see Table II). In addition, participants were sedentary for approximately 9.09 hours on average daily. Participants were automatically entered into a draw to win a gift card as compensation in compliance with the study ethics approval and the winner contacted via email.

TABLE II. Demographic Information of Participants

Total Participants = 103	
Age Group	18-25 (40%), 26-35 (46%), 36-45 (7%), Above 45 (8%)
Gender	Male (54%), Female (45%), Other (1%)
Employment Status	Full-time Employed (45%), Part-time Employed (17%), Unemployed (21%), Other (17%)
Moderate-intensity activities at work (e.g., walking) in a week	Every day (32%), 6 days (9%), 5 days (14%), 4 days (9%), 3 days (7%), 2 days (8%), 1 day (4%), Never (18%)
Walk or cycle for at least 10 minutes to places in a week	Every day (30%), 6 days (9%), 5 days (18%), 4 days (5%), 3 days (8%), 2 days (5%), 1 day (8%), Never (17%)
Moderate-intensity sports, fitness, or recreational activities in a week	Every day (17%), 6 days (5%), 5 days (13%), 4 days (7%), 3 days (13%), 2 days (13%), 1 day (14%), Never (20%)
Vigorous-intensity sports, fitness, or recreational activities (e.g., running) in a week	Every day (0%), 6 days (4%), 5 days (5%), 4 days (2%), 3 days (7%), 2 days (11%), 1 day (18%), Never (53%)

C. Data Analysis

We used well-known analytical tools and procedures to analyze the data collected. The steps taken to analyze our data are summarized below:

- We determined the suitability of our data for further analysis using the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett Test of Sphericity [37]. Specifically, the tests examine the overall sampling adequacy of our data and also check to see if there is redundancy between the variables that we can summarize with fewer factors. Conducting these tests is an essential step prior to further analysis, such as the comparative analysis of the persuasiveness of multiple strategies conducted in this paper.
- To examine and compare the persuasiveness of the strategies, we first calculated an average score per participant across the four items measuring the perceived persuasiveness or effectiveness for each strategy. This average score is also called the *persuasiveness score*. Next, we conducted a one-sample t-test to determine the overall persuasiveness of individual strategies using the neutral rating of 4 as the test value. Finally, we conducted a Repeated-Measure Analysis of Variance (RM-ANOVA) with strategy type as the within subject factor (after validating for ANOVA assumptions), followed by pairwise comparisons using the Bonferroni method. When sphericity assumption was violated, we used the Greenhouse-Geisser method to correct the degrees of freedom.

D. Measurement Validation

We determined the KMO value and Bartlett Test of Sphericity using SPSS version 25. Our results revealed that the KMO value was 0.905, well above the recommended value of 0.6 [37]. Also, the Bartlett Test of Sphericity was statistically significant ($\chi^2(1176) = 7234.908$, $p<.0001$). These results showed that our data are suitable for further analysis [38].

IV. Results

In this section, we present the results showing and comparing the overall persuasiveness of the various strategies.

A. Comparing the Persuasiveness of the Strategies Overall

In general, the result of the one-sample t-test revealed that the overall persuasiveness of the 12 strategies are significantly higher than the neutral rating of 4 ($p<.0001$). This means that our participants perceived the strategies as effective with respect to their ability to motivate behaviour change but at varying degrees, as shown in Fig. 2. *Suggestion* is the most persuasive (M=5.529, SD=1.347), followed by *simulation* (M=5.464, SD=1.371), *self-monitoring* (M=5.461, SD=1.284), *reminder* (M=5.381, SD=1.419), and *praise* (M=5.313, SD=1.513). *Recognition* is the least persuasive (M=4.968, SD=1.776). The rest of the strategies (*competition*, *reward*, *cooperation*, *reduction*, *personalization*, and *social comparison*) are in the middle, with *competition* leading the group. The results of the RM-ANOVA showed significant main effects of strategy type on persuasiveness ($F_{8.414, 858.253} = 3.391$, $p<.001$). This means that there are significant differences between the strategies with respect to their persuasiveness overall. For example, the Bonferroni-corrected pairwise comparisons showed that *suggestion*, *simulation*, and *self-monitoring* strategies are the most persuasive, significantly different from the *recognition* strategy: ($p<.038$), ($p<.024$), ($p<.029$) respectively.

In summary, the 12 strategies were perceived to be effective for motivating behaviour change. Therefore, we employed these strategies in the development of our game.

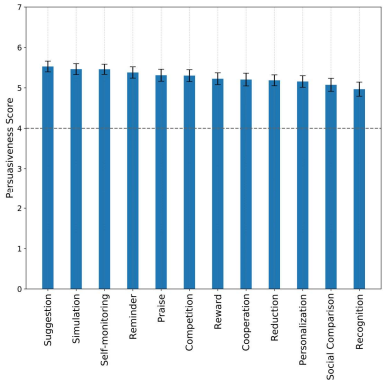

Fig. 2. A bar chart showing the overall persuasiveness of the twelve strategies on a scale ranging from 1 to 7. The horizontal line indicates the neutral rating of 4.

V. Game Development

TreeCare is a persuasive mobile game that uses the metaphor of a flourishing tree to represent a player's physical activity level (step count) in the real-world and doing so regularly (see Fig. 3), while an empty tree with no leaf and fruit represents low or no activity. In other words, the health of the tree is dependent on the players' physical activity level in the real-world. Every new player starts the game with an empty tree which, in turn, will grow leaves and then fruits as the player becomes physically active. The penalty for low physical activity is deteriorating health of the tree which is reflected by the loss of leaves/fruits. This aims to show the negative effects of sedentary behaviour or low activity on an individual's health and the benefit of physical activity.

Based on the results of our first study, we implemented 12 effective strategies in the game. Also, the cause-and-effect link between players' physical activity level and the health of a tree (*simulation* strategy), tracking of players' progress/performance (*self-monitoring* strategy), and contextual tips on how to meet target goals (*suggestion* strategy) represent the core features of the game since these strategies were perceived as the most effective.

We implemented TreeCare for Android devices using the Unity framework (for game development) and Android Studio (for developing mobile apps for Android platforms). We retrieved step counts in real-time from phone sensors using three Google Fit APIs (i.e., Sensors API, Recording API, and History API). An alternative is to collect step counts using activity trackers (e.g., Fitbit); however, majority of our target users may not have one. We used the Activity Recognition API to sense or detect users' contextual state (e.g., "in a vehicle", "stationary", etc.). Hence, the game engine can detect when a user is travelling (in a vehicle) or sedentary (stationary) for more than 30 minutes, and then sends a push notification (or tip) to suggest an activity (such as taking a walk).

Furthermore, the game has three modes: *Starter* mode, *Challenger* mode, and the *Tournament* mode. The Starter mode is a single-player mode with no competition, while the Challenger mode allows individual players to compete with each other in a challenge. On the other hand, the Tournament mode is a team-based mode where a team of *n* players competes with other teams in a tournament. The Starter and Challenger modes have been discussed extensively in our previous work, including the game architecture [39].

A. Game Elements and Persuasive Strategies

Table III presents the game elements and the corresponding persuasive strategies.

TABLE III. GAME ELEMENTS AND THE CORRESPONDING STRATEGIES

Game Element	Strategies
Tree's Growth	Simulation
Leaf and Fruit Counter	Self-monitoring
Steps Counter	Self-monitoring, Personalization
Tip	Suggestion, Reduction
Activity Chart	Self-monitoring
Virtual Trophy	Reward
Streak Coin	Reward
Steps Challenge	Competition
Leaderboard	Competition, Recognition, Social Comparison
Congratulatory Message	Praise
Position Tracker	Self-monitoring
Personal Settings	Personalization
Team	Cooperation
Reminder	Reminder

VI. GAME EVALUATION

We conducted a 3-week (24 days) field study during which 23 participants installed and used TreeCare. The inclusion criteria require that participants be 18 years of age or older, sit for at least 1 hour or rarely engage in consistent physical activity (such as walking and running), or exercise frequently but sit for long periods. In addition, participants should own an Android smartphone. However, people with health conditions that prevent them from actively walking or running were excluded from the study. Participants were required to interact with the game, such as observing their step counts as they walk or run, observing leaves and fruits appear on their trees, tracking their progress or performance, joining challenges and tracking their positions on the leaderboard, etc. Participants received a monetary compensation of $10 for participating in the study in compliance with the study ethics approval. As regards demographics, 30% of participants were within the age range of 18 to 25 years, while 70% were above 25 years of age. In addition, 48% were males, while 52% were females.

After the evaluation period, participants were asked to fill an online questionnaire/survey containing both quantitative and qualitative questions to assess the effectiveness and usability of TreeCare. Also, we randomly selected and interviewed 10 participants with the aim of eliciting more detailed feedback about the game's effectiveness in improving their physical activity levels.

A. Step Count Analysis and Results

For the purpose of comparative analysis, we used the first 8 days as the *baseline* because it reveals the usual step counts of users before intervention comes into effect, while the next 16 days represent the *intervention* period. As shown in Fig. 4, the overall average daily step count of users increased from 4560.48 (SD=1367.83) baseline to 6487.62 (SD=2422.33) during the intervention period. We conducted a one-sample t-test to investigate whether there are significant differences in the step counts during the intervention period with respect to the daily step goal of 5000. Our results showed that the step counts during the intervention period are significantly higher than the daily step goal of 5000 (p<.027).

Fig 3. A player's tree within the game.

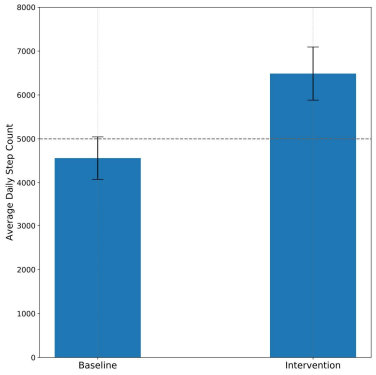

Fig 4. Comparing the average daily step count of baseline and intervention. The horizontal dashed line is the initial daily goal of 5000 steps set for users within the game.

B. Effectiveness of the Game in Improving Users' Physical Activity Levels

Majority of participants – 20 out of 23 participants (87%) – found the game to be effective in improving their physical activity levels, after analyzing their qualitative comments (including interview transcripts) using the thematic analysis method. The following themes summarize how TreeCare influenced participants to increase their activity levels:

1) Drive to improve tree's health: Participants found the link between their physical activity levels and the health of a tree as naturally motivating. Many participants also feel emotionally connected to the tree. Hence, they made conscious effort to increase their activity levels to make their trees look healthy with green leaves and fruits (see sample comment below):

> *"Seeing my tree lose its leaves the two days I was not so physically active **clearly motivated me to walk**. I imagine it is my real-life withering."* [P17]

2) Daily goal effect: Participants found the daily step goal in the game motivating and they tend to increase their physical activity to ensure they meet their goal, as shown in the following comment:

> *"...By knowing my daily goal, TreeCare makes me to **consciously walk more to complete my daily goal**. If I noticed that I have some steps left to meet my goal, I **walk around to ensure I meet it**. That actually **helps me**." [P14]*

3) Drive to win a challenge: Participants who joined a challenge were motivated to walk more than before to be above other players on the leaderboard (see sample comment below):

> *"**The challenge aspect motivates me**. When I see that I am at the second position, I try to catch up with the person in the first position."* [P16]

4) Change in habit: Participants affirmed that TreeCare positively changed their habit or behaviour by motivating them to be physically active, as shown in the comment below:

> *"It really keeps me a bit fit as a mini **means of exercise**"* [P7]

C. Usability

In this section, we present our findings after analyzing (using the thematic analysis method) the participants' qualitative responses to usability-related questions covering ease of use, user interface and aesthetics, overall experience, and likelihood to recommend the game to other target users.

1) Ease of use: All the 23 participants affirmed that TreeCare is easy to use. They also provided comments in response to the follow-up questions to justify their opinions. Sample themes extracted from their comments with respect to the game's ease of use include *Simplicity and intuitiveness, Ease of navigation, Stress-free (no manual input), and User guide*. Below is a comment from one of the participants:

> *"TreeCare is **simple and straightforward**. It does not have many things on the main screen, and you can access the step count, my progress from clicking the small icons on the corner…"* [P13]

2) User interface: All the 23 participants liked TreeCare's user interface including the layout, colour, graphics, and animation (see sample comment below):

> *"I **like the overall interface**. It is **neat**, **appealing** and **consistent**. I like the random gardener walking by as he is like an Easter egg that you can only find if you check the app long enough."* [P17]

3) Overall experience: Participants were asked to describe their overall experience with TreeCare. Our findings revealed that 19 out of the 23 participants (83%) had positive experiences (see sample comment below):

> *"It is an **enjoyable** app and **easy to use**. I like the idea of the tree; it is **new** for me! and it makes the walking something you **enjoy**."* [P20]

4) Recommending the game to other target users: We asked participants if they would recommend TreeCare to other adults, such as their friends, family members, colleagues, etc. 22 out of 23 participants (96%) affirmed that they would recommend TreeCare to other people. The following themes revealed the reasons for their decisions: *Promotion of physical activity*, *Motivating concept*, *Fun intervention*, *Health improvement*, as well as *Activity monitoring and Goal setting*.

VII. Discussion

In this section, we discuss the implications of our design approach and empirical findings.

A. TreeCare as a User-centred Persuasive Game

Previous research has recommended various strategies for persuasive games to promote health and wellness such as personalization, reward, competition, social comparison, etc. [31]. By creating prototypes operationalizing the various strategies, we allowed users to freely determine which of the strategies will persuade or motivate them in relation to the prototype, the design concept, and within the physical activity domain. Although this added an additional work and layer to the persuasive game design process, it increases the probability of success and helped us in making informed decisions based on our findings as opposed to the conventional approach where designers make all design decisions based solely on their own intuition. Specifically, the approach affords us the opportunity to either proceed with the game design using effective strategies and the tree metaphor/concept or refine the concept and revalidate with users. Interestingly, our results showed that users significantly found all the strategies effective with respect to their ability to motivate physical activity. This also means that they found the design idea (tree metaphor) interesting and also effective to influence physical activity change in their daily lives. Furthermore, our results revealed the degree of effectiveness of the various strategies and this helped us to ensure that the most effective strategies are part of the TreeCare design. The results will also guide developers of persuasive applications targeting physical activity on which strategies to employ or focus on to achieve desired behaviour change.

B. Effectiveness in Promoting Physical Activity Behaviour Change

Our results revealed that users generally found the link between a tree's health and physical activity motivating and fun. Also, users found the ability to set daily step goal and track progress visually as motivating. Furthermore, the competition-based and cooperation-based features of the game further improved users' physical activity levels, as most users walked more than anticipated in order to rank higher than other users or teams on the leaderboard. This aligns with research which shows that gamified and persuasive systems (such as TreeCare) can motivate people to take charge of their health and achieve their ultimate wellness goal [40].

C. Usability and Aesthetics

Our findings showed that users found the game to be visually appealing and easy to use. Moreover, most users had great experience overall using TreeCare to track their physical activity on a daily basis. Our effort to produce an aesthetically pleasing and usable game is based on the usability-aesthetic effect which highlights users' tendency to perceive attractive products as more usable [41]. Therefore, TreeCare is not only motivating and fun, but also attractive and usable.

D. Design Guidelines

In this section, we recommend 8 practical guidelines to inform the design of effective and usable persuasive applications, based on our findings.

1) Use meaningful design objects that users can easily associate with and feel emotionally connected to in your design

Simulation which tend to use some visualization to show the cause-and-effect of an individual's behaviour is one of the popular strategies used in persuasive and behaviour change design. Our game evaluation findings revealed that design objects contribute to the motivational appeal of persuasive applications. Participants easily associate with and feel emotionally connected to the tree metaphor in TreeCare. Therefore, designers should carefully choose design objects that would make meaning to the target audience and that they found personally relevant.

2) Allow users to set a daily goal

Research has stressed the importance of goal setting, in line with the goal setting theory [42], to success in the area of behaviour change. Our findings revealed the importance of goal setting in motivating behaviour change. Therefore, designers of persuasive applications should allow users to set individual goals and also provide some level of agency in adapting their goals as they deem necessary.

3) Implement competition to motivate physical activity

Several persuasive and behaviour change research has established the effectiveness of competition at motivating behaviour change by tapping into human tendencies to compete. Based on the results of our first study, *competition* emerged as one of the effective strategies. Unsurprisingly, competition is one of the most frequently employed for persuasive games design. According to Orji et al. [31], competition motivates through three main mechanisms: (1) It reinforces and encourages behaviours, (2) It makes behaviour fun and appear easier to do than usual, (3) It makes people committed to (and focused on) the behaviour. Our findings confirmed that competition motivates behaviour change through these three fundamental mechanisms in addition to making users stay alert during a challenge or tournament.

4) Make the persuasive application easy to use

Research has shown that users often assess ease of use based on perceived simplicity versus complexity [43]. Users like to interact with applications that are simple and straightforward. Our findings revealed users' acceptance of the game due to its simplicity, intuitiveness, ease of navigation, etc. This aligns with research evidence that ease of use is central to users' acceptance of a technology [44].

5) Make the application's user interface attractive

Research has affirmed the strong association between aesthetics and usability [41]. In other words, users tend to perceive an aesthetically pleasing user interface as more usable. Based on our findings, users found TreeCare's user interface to be attractive or aesthetically pleasing, which further improved user interaction with the game.

6) Allow users to customize themes

Customization is concerned with allowing users to modify some aspects of the user interface (e.g., colour, graphics, layout of controls or widgets, etc.). Research has shown that customization offers two psychological gratifications to users – sense of identity and sense of control [45]. Our findings revealed the importance of customization in that while majority of users liked the greenish theme, one participant suggested the ability to choose a different colour theme. Therefore, designers of persuasive applications should include features that allow users to customize the appearance of the user interface, especially the theme.

7) Provide accurate and reliable feedback

Based on our evaluation findings, TreeCare worked very well overall. However, a participant felt that the reported step count is not an accurate reflection of his/her actual steps. Although the algorithm used for step count in the game (via Google Fit APIs) is reliable, research should consider integrating multiple activity trackers to improve accuracy and avoid errors. As an alternative, the tracking algorithm employed by the APIs can further be refined to increase its robustness. Hence, designers/developers should ensure that their applications are designed to provide accurate and reliable behavioural feedback as an inaccurate feedback may demotivate user.

8) Design persuasive application to integrate into user's daily life without interfering with their primary task unnecessarily

Due to its ubiquitous nature, smartphones are increasingly becoming an integral part of people's everyday lives. Majority rely on their phones for personal, social, and economic purposes, and will not accommodate any form of disruption to normal usage. As a result, researchers have found ways to blend technology with the specifics or patterns of people's daily lifestyle [46]. Similarly, TreeCare was designed such that it does not interfere with users' daily phone usage by providing functionalities that track steps and contextual states in the background without the need to open the app.

VIII. Conclusion and Future Work

In this paper, we developed and evaluated a persuasive mobile exergame (TreeCare) for promoting physical activity and reducing sedentary behaviour. Our user-centered methodology is in three stages. First, target users assessed the perceived effectiveness of selected persuasive strategies through an online survey prior to game development. The results from this study revealed effective strategies which are then employed within the game. Afterwards, a field study was conducted to evaluate the game with target users. Based on our findings, the game significantly improved users' physical activity levels. In addition, the game was found to be easy to use, engaging, aesthetically pleasing, and enjoyable. Persuasive technology researchers and designers could employ our validated strategies to improve the effectiveness of persuasive and behaviour change applications targeting health domains such as physical activity. Also, the eight design guidelines recommended in this work offer insights into how to design and develop persuasive and behaviour change applications that are motivating, appealing, and engaging.

As part of future work, we will enhance TreeCare by including additional visualizations, tracking calories burned, and integrating with popular fitness trackers (e.g., Fitbit) – which are based on the *self-monitoring* strategy, as well as supporting theme customization – which is based on the *personalization* strategy. We will also implement the iOS version of the game. Finally, we will conduct a long-term field study (6 to 12 months) to evaluate the game with larger and more diverse population of our target audience, and also present insightful analysis of game effectiveness, such as persuasion effect of the game based on age group, gender, and personality traits.

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