Analysis and Design of an mHealth Intervention for Community-Based Health Education: An Empirical Evidence of Coronary Heart Disease Prevention Program Among Working Adults

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Abstract. The massive expansion of mobile technologies is leading to a digital revolution that is reshaping health education for improved population-level health outcomes. This study investigated the analysis and design of a mobile health (mHealth) intervention for community-wide education. Hence, we employed a design science approach capable of translating health and community activities into practical design guidelines for suitable interventions to improve knowledge and skills among working adults. An mHealth artifact was developed for a Coronary Heart Disease (CHD) prevention program on awareness, knowledge, stress and lifestyle management. The effectiveness of the artifact was demonstrated through a pilot randomized, controlled trial (RCT) with 80 participants as an imperative empirical evidence. The study, therefore, contributed to the cumulative theoretical development of HCI, mobile health, and public health education. Moreover, our findings provided a number of insights for academic bodies, health practitioners, and developers of mobile health in planning educational interventions for smartphone users.

Keywords: Mobile health (mHealth) · Community-based intervention · Health education · Coronary Heart Diseases (CHD) · Randomized controlled trial (RCT)

1 Introduction

The increasing ubiquity of mobile health (mHealth) technologies is transforming healthcare services for wider reach, improved health outcomes, and reduced financial burdens of health systems worldwide. By 2018, mHealth promises to extend its coverage to 1.7 billion people for mobile-based interventions [1]. Such interventions have been extensively studied as viable for chronic disease management [2–4], and health promotion [5–7].

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The current trends emphasize community-based interventions as the primary approach for achieving community-wide changes in health and risk behaviors. In spite of great efforts in community-based programs (e.g. Minnesota Heart Health Program, Stanford Five-City Projects…), modest population-level impacts were previously discussed [8, 9]. There was the lack of tools with customizations to penetrate every corner of the community for better outcomes [10]. Therefore, this research employed a design science approach to developing an mHealth intervention for community-based education to address such issue. By removing both geographical and temporal constraints, the use of mobile applications (apps) is the next suitable wave of health education support artifacts to extend social and technical boundaries towards personalized interventions. Furthermore, the study established theoretical foundations capable of translating health practices into practical design guidelines for community-based interventions.

As an empirical evidence, a pilot randomized, controlled trial (RCT) was conducted for a Coronary Heart Disease (CHD) Prevention Program. This community-based program successfully demonstrated the effectiveness of an mHealth intervention for improved CHD knowledge and stress levels among working adults.

Based on theoretical and practical groundwork, our study contributed to the cumulative theoretical development of mobile health and community-based health education. It provided a principled guideline to analysis and design of mHealth artifacts for academic bodies, health practitioners, and developers of mHealth.

The structure of the paper is as follows. Firstly, we described the literature background of our study in the next section. Secondly, the analysis of an mHealth intervention for community-based health education was discussed. And then, the paper illustrated the design concepts of our mHealth intervention. Fourthly, an RCT, in which 80 working adults were randomized to either the control group (n = 40) or the intervention group (n = 40), was presented with great details. Lastly, we concluded our paper with findings and contributions of the research in the final section.

2 Literature Background

2.1 Mobile Health (mHealth)

The rapid advancement of mobile technologies has paved the path for new health interventions, "mobile health" or "mHealth" [11]. It is broadly defined as "the use of mobile computing and communication technologies in healthcare and public health" [12] which is capable of delivering health services to a huge number of people as well as large communities. With the prevalence of over 6 billion smartphone users [13], mHealth has been introduced into a variety of activities such as disease management and prevention [14–16], care surveillance [17–19] and instructional interventions [16, 20] anytime and anywhere. In 2015, 44% of patients worldwide had witnessed the use of mobile devices by clinicians in healthcare processes [21].

With the significant advantages of usability and mobility [2, 22], mHealth apps are promising to penetrate broad communities to achieve public health impacts.

2.2 Community-Based Health Education

Community-based programs have been originally shaped in the 1980s when synergistic interaction effects were observed with the cost-effective mass media and communication channels [23]. Since then, the development of community-based health education has been gradually progressed beyond individual levels to provide population-wide strategies for targeting entire communities including large cohorts at different levels of risks [24]. Such programs were integrated and wide-ranging, not limited to geographic areas (e.g., worksites, medical care settings, schools, or organizations), and are targeted at diverse communities characterized by patterns of behavior (e.g., Internet chat rooms or smartphone users), experience (e.g., heart attack survivors), or norms and values (e.g., a culture of working population) [25]. Notably, the National Heart, Lung, and Blood Institute (NHLBI) has demonstrated three community-wide health education interventions: (i) the Minnesota Heart Health Program, (ii) the Stanford Five-City Project and, (iii) the Pawtucket Heart Health Program. These projects were rigorously designed to deliver community education sessions to promote healthy lifestyles and to reduce risks of cardiovascular diseases at a population level [26]. Nevertheless, Merzel and D'Afflitti [10] argued that the projects have several limiting factors such as insufficient tailoring capability to reach sub-segments of communities and inadequate community penetration to attain population-wide impacts. To bridge the gap between health educators and the population, this study proposed the analysis and design of an mHealth intervention for community-based health education.

Besides, using science-based materials, resources, and program structures of the NHLBI projects, a logic model for community education strategy was suggested by Hurtado et al. [27]. It described four main activities: (i) recruiting community members, (ii) identifying participants for health education, (iii) assessing participant knowledge and behaviors based on established instruments and measures, and (iv) conducting education sessions using educational materials and teaching tools. In this research, these activities are investigated to implement a community-wide intervention with customizable education programs.

3 Analysis of an mHealth Intervention for Community-Based Health Education

This study is a design science research (DSR) situated in the field of Human-Computer Interaction (HCI) in which the ways that people interact with mobile technologies are analyzed in order to design new artifacts [28]. It employed a theoretical framework as described by Nguyen and Poo [29] in Fig. 1 to comprehend mHealth interventions for community-based health education [27].

Grounded in Activity Theory [30] and Mobile Learning [31], such intervention is scrutinized as a collective activity system in which mobile devices are interactive agents capable of communicating with participants to deliver tailored health as well as behavioral knowledge and resources. The following components are constructed from the theoretical framework.

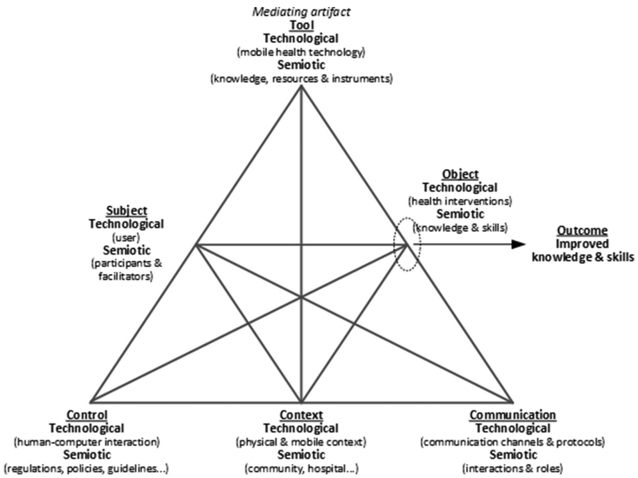

Fig. 1. Analysis and design framework for mHealth interventions [29]

(1) *Subject.* Two key roles are identified in community-based health education: participants who undertake interventions, and facilitators who enable interventions.
(2) *Object*. The primary objective is to provide educational interventions to improve knowledge and to develop behavior-change skills.
(3) *Tool*. It is a vital companion of community-based delivery via mobile devices. Mobile apps have excellent capabilities to facilitate health education activities [32, 33].
(4) *Control*. Full control over community-based program structures and information sharing are integrated into mHealth interventions.
(5) *Context*. Both locational and temporal constraints have been removed in the environment of mobile health. Communities can be virtually defined based on patterns of behavior or other factors.
(6) *Communication*. The use of mobile technologies empowers the participants with different forms of communication such as e-mail, short message service (SMS), and push notifications.
(7) *Outcome*. The outcome is a transformation of participants' knowledge and skills to modify behaviors and to reduce the individual risks at different levels.

Engagement between people and mobile technology develops meanings and objectives of these activity sub-systems; therefore, analyzing the complexity of community-based education entails operationalization of the dialectical relationship between people and technology as semiotic and technological aspects. Both perspectives are considered in details to improve participants' knowledge and skills as shown in Table 1.

Table 1. Analysis of mHealth interventions for community-based health education

Component	Semiotic perspective	Technological perspective
Subject	*Participants*: individuals, families, and social networks who undertake the mHealth interventions *Facilitators*: healthcare practitioners, community volunteers, and training agents who facilitate mHealth interventions	• Mobile devices (e.g., iPhone, iPad, Samsung Galaxy phones and tablets…) • Mobile applications for mHealth interventions
Object	*Participants*: • Knowledge and skills to be learned by health experts/facilitator • Achievements of program objectives • Applications and reinforcement of knowledge and skills *Facilitators*: • Ability to impart knowledge and skills to participants • Setup of program objectives • Assessment of participants' progress and achievements	• Mobile-enabled health education programs • Mobile-based subject-matter contents • High portability, availability and accessibility to knowledge and resources
Tool	• Knowledge and skill development resources • Multimedia for health education (e.g., videos, audios, and interactive formats) • Geographically agnostic program and content delivery environment • Alert and reminding mechanisms	• Device-independent capabilities on mobile devices • Mobile-based health artifacts • Knowledge and skills assessment tools • Offline synchronization of programs and contents
Control	• Structured educational programs with objectives and guided steps • Enrolment and involvement in health education programs. • Control of intervention tools	• User-friendly and responsive design for multiple display resolutions • Individual and community-based access and privacy control • Longitudinal and activity tracking
Context	• Locational and temporal independent • Disease-specific communities • Multi-community participation	• Role-based management • Individual and community-based coordination • Geolocation services
Communication	• Locational and temporal independent • One-to-one communication between facilitators and participants • Community-based communications for health education • Information sharing and remote tracking	• Mobile communications (e.g., 4G, 3G, GPRS…) • Messaging via Short Message Service (SMS), email, and push notifications • Robust content and message delivery structure

4 Designing an mHealth Artifact for Community-Based Health Education

Based on the analysis of the mHealth intervention for health education, we proposed an mHealth platform as an IT artifact. It aims to bring community-based health education to the next level where programs and contents can be prepared for delivery via smartphones.

4.1 System Architecture

We designed our mHealth artifact with two major sub-systems: (i) a cloud-based service platform, (ii) mobile apps for health education. Figure 2 demonstrates the overall architecture of the mHealth platform.

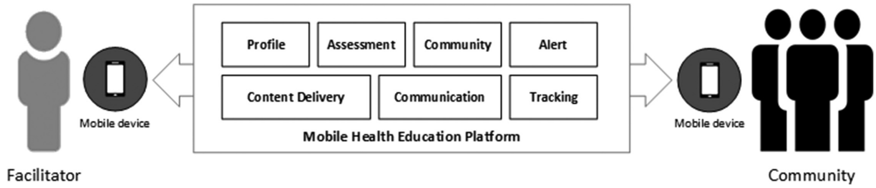

Fig. 2. Overall architecture of mHealth education platform

The cloud-based service platform leverages on an enterprise system architecture for developing and deploying modular and extensible modules and applications. It comprises of multiple services: profile and personalization, program and content delivery, assessment and tools, community management, communication and notifications, alerts and reminders, and tracking. These services expose RESTful interfaces to provide interoperability between cloud-based backbone framework and mobile apps.

4.2 Design Concepts of an mHealth Artifact for Community-Based Education

Leveraged on the proposed system architecture, the key design concepts of our mHealth artifact are highlighted as the following.

Profile Personalization. The mHealth intervention begins with facilitators inviting participants to join their health education program. Once invited, the participants are provided with the links in Apple AppStore and Google Play to download and to install the mHealth app. Upon completion of a self-enrolment process, the participant is automatically associated with a specific community and the health education program based on essential profile data. Furthermore, user preferences are captured for customization and tracking of program objectives and progress.

Program and Content Delivery. The mobile apps have capabilities of receiving dynamic community-specific programs and content packages during its loading process. A community-based education program is designed as a hierarchical collection of program objectives and sub-objectives; hence, participants' achievements are reflected in a detailed and structured manner during the intervention. Mobile-based subject-matter contents and media are presented with intuitive navigations in various display form factors and orientations. Offline synchronization features allow participants to view these always-at-hand knowledge and skill building resources. Figure 3 shows the screens of our mobile apps for the CHD prevention program with the multi-level program structure and learning resources.

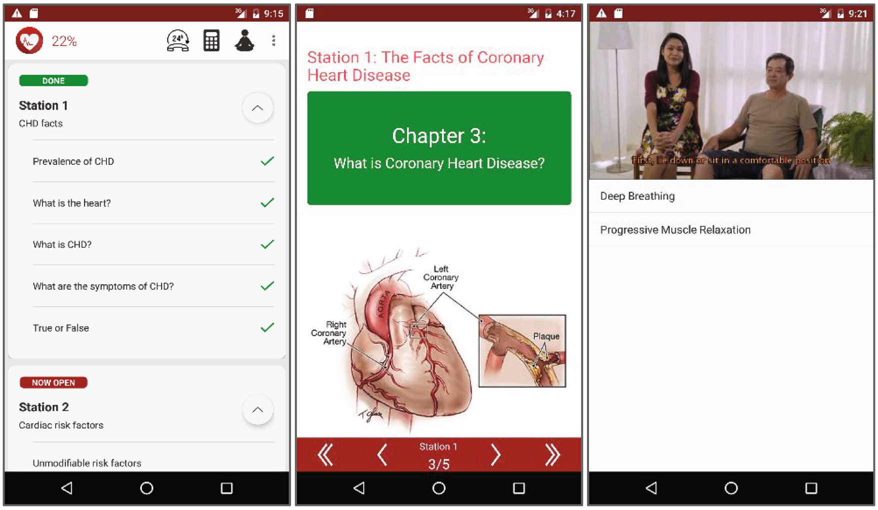

Fig. 3. Program and content delivery screens for CHD prevention program

Health and Assessment Tools. Tools play a critical role to facilitate the subjects to achieve objectives in mHealth interventions. The implementation of health and assessment tools in mobile apps, therefore, is necessary for educational activities. Community facilitators can employ such tool for knowledge assessment and disease-specific instruments. For instance, BMI, risk prediction of heart attack or coronary death, and calories consumption calculators are introduced in the CHD prevention program to raise awareness and modify lifestyle behaviors of the participants as illustrated in Fig. 4.

Activity Tracking. The mobile app is capable of tracking participants' activities, even in the absence of network connectivity. It employs view tracking technologies to capture movements and reading patterns in mobile screens, as well as uploads the de-identified data to the cloud-based service whenever the network is available. Such data are useful for facilitators to keep track of participants' progress and levels of involvement within the programs.

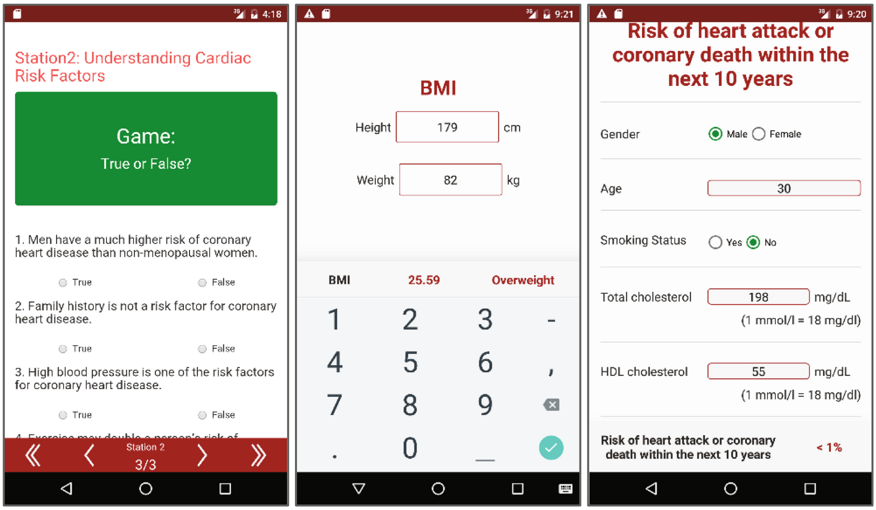

Fig. 4. Health and assessment tools for CHD prevention program

Communication and Notifications. This feature enables various types of interactions between facilitators and participants over in-app messaging, push notifications, and SMS. One-to-one messaging allows facilitators to keep in touch with an individual for direct and personalized intervention; while one-to-many messaging provides a necessary mechanism to reach out to a community, or specific sub-community groups. It is imperative to guarantee the delivery, and to monitor the reading status such message for useful communications.

Alerts and Reminders. The mHealth intervention offers alerts and reminders as tools for knowledge reinforcement and lifestyle modifications in community-wide health education. These tools aid facilitators to schedule multiple reminders tailoring to individuals and community members based on their profile data.

5 Coronary Heart Disease Prevention Program Among Working Adults

Coronary Heart Disease (CHD) is the most common type of Cardiovascular Disease (CVD), which has been long recognized as a major problem for public health [34]. It is predicted to be responsible for a total of 11.1 million deaths worldwide in 2020, and to remain as the top cause of death for next 20 years [35]. CHD is a result of lipid accumulation in coronary arteries which narrows blood flow and increase the risks of heart attacks and stroke [36]. Such risk causes detrimental impacts on the adult workforces leading to lower work performance, reduced income, and job insecure due to restricted work capacity [37]. With high rates of deaths and hospitalization found in many countries [27, 38, 39], CHD has become a bulky burden on the economies of working adults and existing healthcare systems.

Our empirical study was designed to evaluate the effectiveness of the proposed mHealth artifact for CHD prevention program in a community of working adults in Singapore. A comprehensive 4-week program was developed comprising a multi-level program structure, learning objectives, heart health assessment tools, and supporting materials [40]. There are four learning stations: (i) the facts about CHD, its prevalence in the community, and common signs and symptoms of CHD; (ii) the cardiac risks factors: non-modifiable and modifiable; (iii) the healthy lifestyle including balancing diet, physical exercise, regular health monitoring, and smoking cessation (for smokers); and (iv) the techniques for stress management. In addition, two educational videos for deep breathing exercise and progressive muscle relaxation were included in the mHealth intervention. Moreover, self-assessment calculators such as body mass index (BMI), daily calories, and CHD risk prediction for next 10 years were incorporated into the mobile apps. Figure 5 demonstrates the structure of the CHD prevention program and contents.

Facilitators of the CHD prevention program were cardio-trained practitioner nurses and research assistants who remotely coordinated the participants throughout the program. A 20-min briefing session was provided at the beginning of the mHealth intervention.

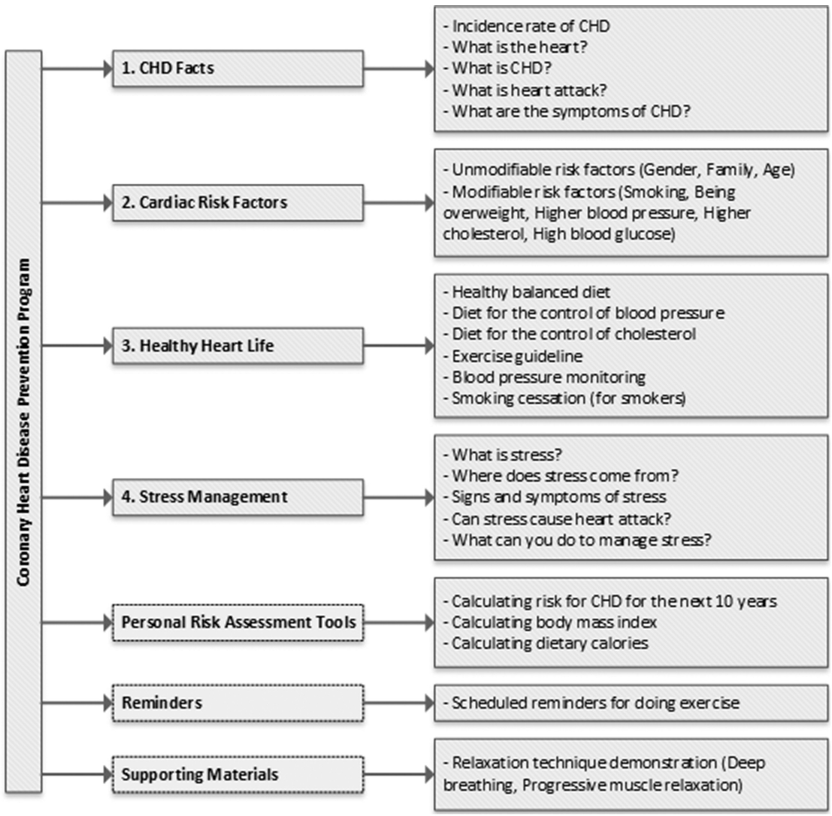

Fig. 5. CHD prevention program and contents

5.1 Empirical Settings

This study adopted a pilot randomized, controlled trial (RCT) in which participants were recruited from the working population via poster advertisements. They were full-time workers aged between 21 to 65 years old. As the mHealth artifact was developed in English, using smartphones in daily activities and understanding the language are compulsory criteria. The study excluded individuals who: (i) had a clinical history of heart-related diseases, (ii) worked in health-relevant institutions, (iii) had reading difficulties. The sample size of 80 was used in the RCT with 40 participants in a control group and 40 participants in an intervention group as suggested in previous work [41]. The mHealth intervention was offered to the participants of the intervention group; while, the control group was provided with web links to heart education materials for self-exploratory learning.

There were 60 participants (77.5%) aged between 21 and 40 years old, and 61 participants are Chinese (76.3%). Majority of the participants were female (n = 52, 65.0%), had less than 10 years of professional experience (n = 46, 57.6%), and married (n = 42, 52.5%). Table 2 reports the demographic characteristics of both the intervention group and the control group.

Table 2. Demographic characteristics of the pilot randomized controlled trial

Demographic variable	Intervention group (n = 40)		Control group (n = 40)	
	n	(%)	n	(%)
Age (years)				
21–30	20	(50%)	14	(35%)
31–40	15	(37.5%)	13	(32.5%)
41–50	2	(5%)	4	(10%)
51–65	3	(7.5%)	9	(22.5%)
Gender				
Male	12	(30%)	16	(40%)
Female	28	(70%)	24	(60%)
Ethnicity				
Chinese	33	(82.5%)	28	(70%)
Malay	5	(12.5%)	9	(22.5%)
Indian	1	(2.5%)	2	(5%)
Others	1	(2.5%)	1	(2.5%)
Marital status				
Married	17	(42.5%)	25	(62.5%)
Single	23	(57.5%)	15	(37.5%)
Education				
No formal education	1	(2.5%)	0	

(*continued*)

Table 2. (*continued*)

Demographic variable	Intervention group (n = 40)		Control group (n = 40)	
	n	(%)	n	(%)
Secondary School	7	(17.5%)	10	(25%)
ITE/Polytechnic/Junior College	16	(40%)	12	(30%)
University	16	(40%)	18	(45%)
Occupation				
Admin/Clerical	6	15%	6	(15%)
IT/Engineering	19	47.5%	16	(40%)
Teaching	1	2.5%	2	(5%)
Others	14	35%	16	(40%)
Years of working				
<5	17	(42.5%)	10	(25%)
5–10	9	(22.5%)	10	(25%)
11–20	11	(27.5%)	10	(25%)
21–30	1	(2.5%)	6	(15%)
31–50	2	(5.0%)	4	(10%)
Family history of CHD				
Yes	1	(2.5%)	4	(10%)
No	39	(97.5%)	36	(90%)

5.2 Instruments and Measures

Three questionnaires and outcome measures were employed in the study: (i) Social-demographic information questionnaire, (ii) Heart Disease Fact Questionnaire-2 (HDFQ-2), and (iii) Perceived Stress Scale-10 item (PSS-10).

Social-Demographic Information Questionnaire. The demographic characteristics of participants including gender, age group, marital status, ethnicity, occupation, and education were collected.

Heart Disease Fact Questionnaire-2 (HDFQ-2). A 25-item questionnaire of yes/no questions was utilized to assess the participants' knowledge of CHD risk factors (e.g., gender, age, family history, and heart-related lifestyles). A maximum of 25 points for each participant was calculated with 1-point for each correctly-answered question. The HDFQ-2 has adequate readability [42] and good internal reliability with Cronbach's alpha of 0.84 [43].

Perceived Stress Scale-10 Item (PSS-10). A 10-item instrument for measuring participants' stress level. It uses a 5-point Likert scale with higher score hinting greater stress level during the 4-week program. The PSS-10 score ranges between 10 to 50 self-reported by the participants. An acceptable internal consistency (Cronbach's alpha > 0.8) has been discussed in previous works [44, 45].

5.3 Evaluation and Discussion

The collected data of 80 working adults were analyzed using IBM Statistical Package for the Social Sciences (SPSS) 21.0.

The pilot RCT encompassed two factors: the within-subjects factor is time with two levels (baseline and 4-week intervention), and the between-subjects factor is an intervention (yes for the intervention group, and no for the control group). Mixed ANOVA models were employed to compare the mean differences of CHD knowledge between the two groups based on these factors. Figure 6 illustrates the effects of these factors on CHD knowledge and stress level.

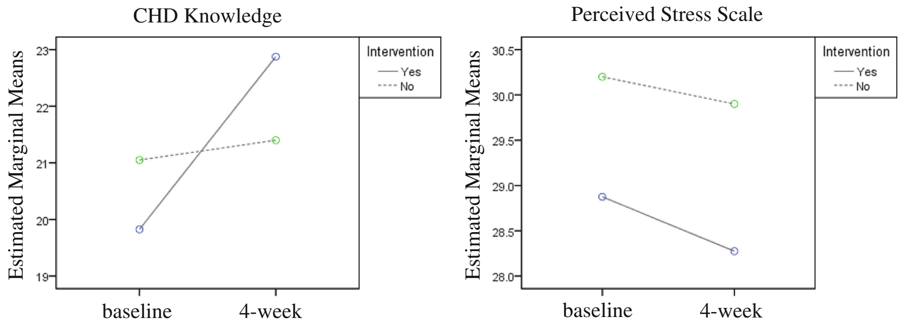

Fig. 6. Profile plots for HDFQ-2 score and PSS-10 scale

In terms of CHD knowledge, a significant difference across the two time points was identified where $F(1,78) = 27.37$, $p < 0.05$; but there was no significant differences between the groups with $F(1,78) = 0.94$, $p > 0.05$. Importantly, there was a significant interaction between time and intervention, $F(1,78) = 17.26$, $p < 0.05$ which was observable in Fig. 6. The follow-up examination of the interaction effect corrected with Bonferroni showed the following simple main effects: (i) for the intervention group, the 4-week mHealth intervention led to higher CHD knowledge than at the baseline ($F(1,78) = 44.04$, $p < 0{,}05$); while (ii) for the control group, the 4-week exploratory learning had no effect with $F(1,78) = 0.58$, $p > 0.05$.

For the PSS-10 score, the study utilized Chi-square tests to examine the effects of nonparametric distributions. There was no significant difference between the two groups at the baseline ($p = 0.218 > 0.05$); however, a significant difference between the two groups was identified after the 4-week intervention ($p = 0.038 < 0.05$). Figure 6 demonstrated the lower stress level in the intervention group after the intervention.

The study results provided empirical evidence on the effectiveness of the mHealth artifact for CHD prevention program. This education program is associated with significant improvements in CHD knowledge in the community of working adults for those who used the proposed mHealth mobile apps. Moreover, a lower level of stress was reported after the program which hints to the constructive effects of contents, tools and supporting materials on stress management.

6 Conclusion

The success of community-based health education greatly depends on educational program planning and design, as well as, the coordination between facilitators and participants which are being empowered by mHealth technologies. This study proposed a DSR approach to developing an effective artifact for such education program via mobile devices. A comprehensive set of design concepts for mHealth interventions was introduced to facilitate the community-wide process of knowledge and skills building. Moreover, the effectiveness of such mobile-based artifact was empirically demonstrated through a pilot randomized, controlled trial of a 4-week CHD prevention program. Improvements in CHD knowledge and stress management among working adults in Singapore have been found as the evidence for feasible community-based mobile health education.

This study contributed to the cumulative theoretical development of mobile health, and community-based health education in three folds. First, the relationship between mHealth innovations and health education was evidently highlighted to make clear the requirements for a theoretical discourse. Second, the proposed approach was capable of analyzing and designing health education programs for any types of communities in the direction of social learning. Last but not least, the study took one step further in advancing mHealth with an empirical evidence of effective mobile-enabled community-based health education.

There are multiple implications for developers of mobile-based health interventions. The study developed a holistic approach to system analysis and design of mHealth apps of community-based health education. Furthermore, its findings on semiotic and technological requirements are well-informed and practical for developing mobile-based education programs and contents.

This paper is not without limitations. It adopted the sampling method for pilot research which limits the external validity of the study. Besides, short-period effects were detected; however, long-term effects of such mobile-based interventions should be evaluated in future research. In this pilot RCT, monetary reimbursements were provided to prevent dropouts; nevertheless, changes in initiatives, incentive structures, regulations, and policies are required to establish effective community-based health education in the long-run.

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