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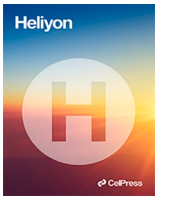

Physical activity virtual intervention for improving mental health among university students during the COVID-19 pandemic: A Co-creation process and evaluation using the Behavior Change Wheel

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A R T I C L E I N F O

Keywords:
Exercise
Mental health
Mobile application
Students
Universities

A B S T R A C T

Background: During the COVID-19 pandemic, there were reductions in university students' physical activity, which further increased their mental distress, calling for technology-based physical activity interventions to address the challenges in delivering in-person interventions. This study aimed to develop a technology-based physical activity intervention and pilot test it.
Methods: We developed a virtually-delivered team-based physical activity challenge using the Behavior Change Wheel and Co-creation Framework based on Self-determination Theory. A pilot study was conducted in the evaluation phase to measure the recruitment rate, dropout rate, change in physical activity, and mental distress while identifying problems and collecting participants' opinions regarding the challenge. Wilcoxon signed-rank tests were conducted to assess the change in physical activity and mental distress. Qualitative data were analyzed using thematic analysis.
Results: A three-week physical activity challenge comprising five identified intervention functions was held with 480 participants. The recruitment rate was 84.8% resulting from 407 virtual challenge participants who were conveniently joined as research participants. The dropout rate for the pilot study was 10.96% resulting from the incompatibility problems with the application. Among sample participants who lacked physical activity, participation in this challenge improved their physical activity by 52.5 min of moderate-intensity physical activity per week and reduced their mental distress by three points of self-reporting questionnaire-20 score. Issues regarding the virtual application and the influence of participation in the challenge on basic psychological

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needs emerged. Participants' opinions identified lack of time as the main barrier to physical activity.
Conclusion: A co-created physical activity intervention developed using the Behavioral Change Wheel Framework inspired high interest from university students and may increase their physical activity and improve their mental health. Several suggestions were discussed to address the identified problems and improve the internal and external validity of the evaluation phase.
Trial registration: TCTR20220720004 (retrospectively registered on July 19, 2022).

List of abbreviations

PA	Physical activity
COVID-19	Coronavirus diseases 2019
BCT	Behavior change techniques
BCW	Behaviour Change Wheel
SDT	Self-Determination Theory
UK	United Kingdom
MRC	Medical Research Council
APEASE	Affordability, Practicability, Effectiveness and cost-effectiveness, Acceptability, Safety, and Equity
COM-B	Capability, Opportunity, Motivation, and Behavior
TIDieR	Template for Intervention Description and Replication
GPAQ	Global Physical Activity Questionnaire
SRQ-20	Self-Reporting Questionnaire 20
MVPA	Moderate-vigorous physical activities
App	*Application*
RCT	Randomized controlled trial

1. Background

Although physical activity (PA) confers benefits for both physical, mental, and cognitive health which are essential for university students, the majority of students do not engage in the recommended amount of PA [1–4]. Moreover, the Coronavirus Disease-2019 (COVID-19) pandemic has disrupted most people's normal life. Implementing containment measures for controlling the infection's transmission, including lockdown, social distancing, and study-from-home policy, significantly reduced university students' PA [5]. Additionally, the disruption of normal life also increased mental distress levels among university students, which were already a growing concern before the pandemic [6].

During the COVID-19 pandemic, the decreased PA and increased mental distress among university students called on universities and policymakers to take measures to reduce these double burdens. Otherwise, a vicious cycle could develop between those two problems [7]. However, there are several challenges in providing in-person PA interventions during the pandemic, such as risk-benefits considerations regarding infection transmission, scattered student residences, and also the closure of certain sports facilities [8,9]. In this case, a remote intervention utilizing technology, such as smartphones and the Internet, could potentially promote PA among university students.

While PA intervention through smartphones offers potential benefits, there are inconsistent results [10,11]. Designing interventions based on theoretical frameworks and embedding certain behavior change techniques (BCT) components were proposed to improve intervention effectiveness [12,13]. The Behaviour Change Wheel (BCW), which was already heavily grounded in behavior change theory, could be used as a toolkit for designing behavior change interventions and embedding behavior change techniques [14]. Technology-delivered interventions should also fit individuals' needs, technologies, and tasks of the intervention to succeed in adoption [15]. Engaging and empowering end-users through a co-creation process were proposed to increase behavior intervention adoption, adherence, and effectiveness [16]. Therefore, we conducted a co-creation process for designing a virtual PA intervention utilizing the BCW and Self-Determination Theory (SDT) to promote PA among university students during the COVID-19 pandemic and to alleviate their mental distress.

2. Methods

We developed a technology-based physical activity intervention, and then pilot-tested it in Universitas Gadjah Mada, Yogyakarta, Indonesia. This study was informed by a combination of the United Kingdom (UK) Medical Research Council (MRC) framework for developing and evaluating complex interventions [17] and the BCW [14] (Fig. 1). The UK MRC helped researchers work with stakeholders in designing, implementing, and evaluating a complex intervention. The BCW facilitated the transition from behavioral

diagnosis into the intervention's design, implementation, and evaluation [14]. We used the SDT to guide the co-creation process of the intervention [14]. The intervention's design, implementation, and evaluation process were conducted by RAW, ZMS, and WW as the researchers over ten steps as recommended for the BCW (Table 1). After briefly describing steps one to three for contextual purposes, we discussed steps four to ten in detail (Table 1). University students as co-creators were involved in steps 4 and 5 to adopt a co-creation framework (Table 1) [16]. In addition, we applied a sub-theory of SDT, the Basic Psychological Needs Theory, to provide support for human basic psychological needs for autonomy, competence, and relatedness because PA interventions supporting these basic needs were found to potentially promote not only the long-term maintenance of PA behavior but also psychological well-being [18–20]. All processes during this study had obtained ethical approval from the Medical and Health Research Ethics Committee of the Faculty of Medicine, Public Health and Nursing, Universitas Gadjah Mada (KE/0783/08/2020), and informed consent from participants was obtained and documented before data collection.

Step 1 Defining the problem in behavioral terms

The first step of the BCW involved defining the problem that requires intervention. Evidence shows that a sufficient amount of PA is required to prevent non-communicable diseases and improve mental and cognitive health [1]. With the majority of university students lacking PA, there are possibilities that university students could get increased non-communicable diseases, increased mental distress, and disrupted cognitive function [2–5].

Step 2 Selecting the target behavior

This step involved considering all possible factors that could be targeted in the intervention. Since BCW recommends starting with small changes, this research focused on PA behavior.

Step 3 Specifying *the target behavior*

Step 3 specified the target behavior by outlining who should perform the behavior, what the persons need to do, when, where, how, and with whom they will do it. For this research, the target behavior was specified as follows: university students should improve their PA gradually to meet the PA guidelines, and they were given autonomy to choose what kind of PA, when, where, how, and with whom they do the PA to support their needs of autonomy [1,21].

Step 4 Identifying what needs to change

Previous works recommended interviews or focus group discussions to understand what needs to change since these methods would help develop participant-centered and co-created interventions [16,22]. This research aimed to inform Step 4 by conducting semi-structured interviews to identify barriers and enablers to PA during the COVID-19 pandemic from university students' perspectives.

A purposive sample of university students was recruited to achieve maximum variabilities using a quota system based on genders, type of housing (house with family, boarding house, dormitory), the island of domicile (Java and outside of Java), study subjects (health science, natural sciences, and socio-humanity sciences), mode of daily transportation (active transport and motor vehicle), and participation in sports clubs [23]. Semi-structured interviews asking participants' enablers and facilitators to PA were conducted through phone calls in August 2020 following an adapted topic guide developed by previous work [24]. After that, anonymized verbatim transcriptions from the recorded phone interviews were made. Data from the interviews were analyzed by two study authors

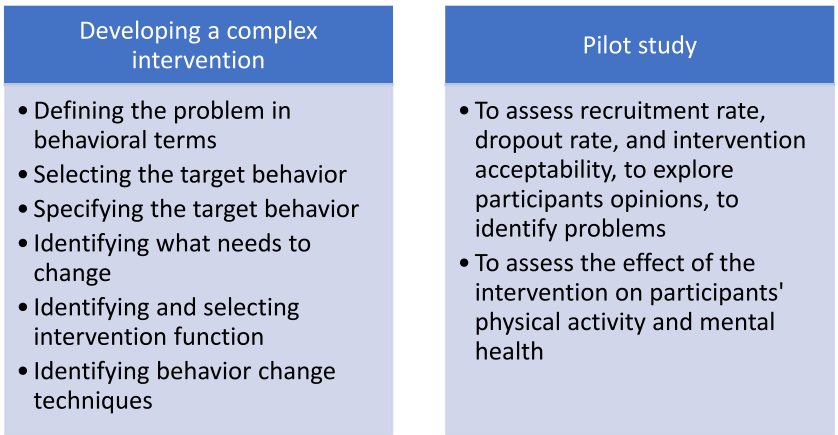

Fig. 1. Design of the study phases.

Table 1
Co-creation process of the intervention.

Steps for the Behavior Change Wheel	Researchers role	Co-creators role
Step 1. Defining the problem in behavioral terms	Identifying problem	
Step 2. Selecting the target behavior	Selecting physical activity as the target behavior	
Step 3. Specifying the target behavior	Specifying the target behavior as follows: university students should improve their PA gradually to meet the PA guidelines	
Step 4. Identifying what needs to change		Co-creation session 1: semi-structured interview Identifying enablers and barriers to physical activities
Step 5. Identifying and selecting intervention function	Identifying potential intervention functions based on enablers and barriers mapped in the previous step	Co-creation session 2: focus group discussion Identifying potential intervention functions based on enablers and barriers mapped in the previous step
	Selecting intervention function identified by researcher and co-creators using the Affordability, Practicability, Effectiveness and cost-effectiveness, Acceptability, Safety, and Equity (APEASE) criteria	
Step 6. Identifying behavior change techniques	Identifying behavior change techniques	
	Linking behavior change techniques to self-determination theory	
Step 7. Pilot study	Implementing the intervention and conducting the pilot study	

independently using thematic analysis following guidelines by Braun and Clarke [25], and identified themes were mapped into the Capability, Opportunity, Motivation, and Behavior (COM-B) model [14]. Data collection was continued until data saturation, which was indicated by no new codes identified in two consecutive transcripts.

Step 5 Identifying and selecting intervention function

To allow co-creation and a collaborative process promoting the importance of equitable research partnerships, university students as end-users were involved in identifying intervention functions [26]. First, a PA researcher identified potential intervention functions to be included in the smartphone-based PA challenge based on the BCW. Then, a convenience sample of university students was recruited to conduct a focus group discussion identifying potential intervention functions to address barriers and facilitate enablers to PA. Before conducting the focus group discussion, co-creators were trained on the BCW to up-skill their capability, and then they were informed that they had equal standing with the academic researchers and had ownership of the intervention [16]. Potential interventions identified by the PA researcher and the students were combined. A policymaker and an app developer analyzed the identified potential intervention using the Affordability, Practicability, Effectiveness and cost-effectiveness, Acceptability, Safety, and Equity (APEASE) criteria to select intervention functions that could be supported at an organizational level [14].

Step 6 Identifying behavior change techniques

Behavior change techniques (BCT) from the BCT Taxonomy were selected based on previous systematic reviews [13,27,28] and selected intervention functions. Then, selected behavior change techniques were implemented in the smartphone app and the challenge. All of the components of BCTs were also analyzed based on their potential to address the basic needs of feeling in control, competent, and connected to others based on SDT [20,21]. After analyzing the rationale of each challenge feature using self-determination theory, we reported the processes used in each feature and the modes of delivery of each feature according to the Template for Intervention Description and Replication Checklist (TIDieR) to allow replication of the intervention [29].

Step 7 Pilot study

Having developed the app and prepared for the challenge in October 2020, we conducted a one-group pretest-posttest quasi-experimental study as a pilot study in Step 7 in November 2020 to test the feasibility of the intervention as well as the effectiveness of the intervention in increasing university students' physical activity and improving their mental health. Some of the pilot study results were presented at the International Society for Physical Activity and Health Virtual Congress 2021 [30]. We conveniently recruited the virtual challenges's participant to be participated in the pilot study.

2.1. Outcome measures

The primary aims of the pilot study were to assess the recruitment rate, dropout rate, and intervention acceptability, as well as to explore participants' opinions and identify problems [31]. The secondary aims of the study were to assess the effect of the challenge on participants' PA and mental distress. The estimated sample size was 73 participants calculated using a formula based on the probability

of a problem of 5.17% [32] with a level of confidence of 0.95 in detecting problems and anticipation of a 20% dropout rate [33].

We compared the number of participants who voluntarily joined as research participants with the total virtual challenge participants to estimate the recruitment rate. Then, we assessed the dropout rate by calculating the percentage of participants who dropped out for any reason of the projected sample size. To assess the smoothness of the assessment procedure, we calculated participants who completed the post-intervention measurement, reporting this rate as a percentage of the total included participants (excluding dropouts).

We collected participants' demographic data, including age, subjects of study, and self-reported weight and height. Participants' physical activity level and mental distress level were examined using the Global Physical Activity Questionnaire (GPAQ) V.2 and the World Health Organization Self-Reporting Questionnaire 20 (SRQ-20) via a Google Form before and at the end of the challenge [34,35]. Through the Google form at the end of the challenge, we also asked participants' opinions using a five-point Likert scale whether (1) participants experienced technical difficulties in recording and monitoring their physical activity using the app, (2) they experienced technical difficulties in measuring their heart rate using the app, (3) they were willing to join in the next challenges, (4) they were willing to recommend the challenge to their friends, (5) they were happy during the challenge, (6) they were able to choose physical activities that suit them, (7) they were able to set their own target, and (8) they felt connected and supported by their friends. We included one open-ended question asking their opinions regarding their experience during the challenge.

2.2. Data analysis

We cleaned GPAQ data and then calculated work-related moderate-vigorous physical activities (MVPA), transportation MVPA, leisure-time MVPA, and total MVPA according to the GPAQ V.2 Analysis Guide [36]. Then, we presented participants' demographic and mental distress at baseline, grouped by their baseline PA category. Mann-Whitney U tests were conducted to determine whether the baseline values between subgroups were similar. After that, we analyzed the pretest and posttest measurements by conducting subgroup analyses based on participants' baseline PA category to anticipate any ceiling effect [37]. To assess the effect of the challenge on participants' PA and mental distress as secondary aims of the study, we conducted Wilcoxon signed-rank tests to determine whether there were changes in PA level and mental distress since the data were not normally distributed. Participants' opinions about their experience during the challenge were presented based on the mean from the Likert scale. Two study authors independently analyzed their responses to the open-ended questions using thematic analysis [23,25].

3. Results

We have described Steps 1–3 in the methods section. New qualitative and quantitative data generated from Steps 4–10 are described below:

Step 4 Identifying what needs to change

A total of 10 interviews were completed during co-creation session 1. Most participants were male, living in dormitories, studying natural science, using motor vehicles for daily transportation, and not joining any sports club (Table 2). The participants had an equal proportion of students who were living on the Java island and islands other than Java. Based on the enablers identified in the thematic analysis, there were awareness of the benefits of PA due to the COVID-19 pandemic mapped into psychological capability, more available time due to less academic burden mapped into physical opportunity, and the goal of maintaining immunity against COVID-19 mapped into reflective motivation (Table 3). On the contrary, the decreased physical ability for PA due to prior COVID-19 infection mapped into physical capability, no friends for PA mapped into social opportunity, and mental effect due to COVID-19 in the form of

Table 2
Maximum variation sample details.

Characteristics	Number
Gender	
Male	6
Female	4
Type of housing	
With parents	3
Dormitory	7
Study subjects	
Health sciences	3
Natural sciences	6
Social sciences	1
Mode of transportation	
Active transport	4
Motor vehicle	6
Participation in a sports club	
Joining a sports club	8
Not joining a sports club	2

fear mapped into reflective motivation were identified as barriers to PA (Table 3). A theme of environmental conditions related to COVID-19 can be mapped into either enabler or barrier to engaging in PA.

> "Parks and gyms were closed. Where can I do exercise?" (Male, Participant #1)

> "The daily COVID-19 cases number in my location is already dropped so that I did not fear anymore to do outdoor physical activities" (Male, Participant #2)

> "There are too many people who did not wear their masks outside. This made me fear to do outdoor physical activities" (Female, Participant #4)

Based on the identified enablers and barriers, potential intervention functions were proposed by a PA researcher and representative of university students (Table 2). Among identified enablers and barriers, only environmental conditions related to COVID-19 could not be addressed using the intervention functions.

Step 5 Identifying and selecting intervention function

Having discussed with the app developer, DA, the leader of the physical activity unit in the Health-Promoting University as the policymaker, concluded that the intervention functions meeting the APEASE criteria were enablement by encouraging PA in any duration, enablement by encouraging frequent short duration low-intensity PA, enablement by providing team-based challenge, education through webinar, and enablement by allowing them to post their PA record to social media (Table 4). Developing an additional application (app) feature for showing educational feeds required extra costs and extra efforts for intervention providers. In addition, previous studies showed that social media, such as Instagram, could be a readily-available engaging channel for disseminating health information and a source of inspiration for health among university students [38,39].

Step 6 Identifying behavior change techniques

Based on previous systematic reviews, it is evident that utilizing self-monitoring on behavior and providing feedback on the performance of the behavior as one of the BCTs from control theory are correlated with PA intervention effectiveness. In addition to these two BCTs, seven additional BCTs were also implemented in the app and challenge features to deliver identified intervention functions for a three-week challenge (November 5th - 25th, 2020). The rationale on how each feature may address the basic needs, detailed process, and the mode of delivery of each feature are reported in Table 5.

Participants could join the challenge in a team with a maximum of three team members. A webinar through the Zoom platform was held to start the challenge officially. In this webinar, participants received educational materials delivered by three lecturers about the

Table 3
List of identified potential intervention functions.

	Theme	Quotes	Potential intervention functions by the PA researcher	Potential intervention functions by co-creators
Facilitators	Awareness of the benefits of physical activity during the covid-19 pandemic (C-Psy)	"During the pandemic, there was abundant educational information showing the benefits of physical activity. This increases my awareness to do regular physical activity. So, I tried to engage in more physical activity than I did before the pandemic." (Male, Participant #6)	Education through the smartphone app	Education through webinar
	More available time due to less academic burden (O-Phys)	"I have got more holidays and leisure time during the covid-19 pandemic. I can manage my time for doing exercise" (Male, Participant #2)	Enablement by encouraging physical activity in any duration	
	The goal of maintaining immunity against COVID-19 (M − Re)	"Regular physical activity can boost my immunity which is very important during this pandemic. This motivates me to engage in regular physical activities" (Female, Participant #4)	Education through the smartphone app	Education through Instagram
Barriers	Less stamina after recovering from COVID-19 (C-Phys)	"After recovering from COVID-19 infection, I still felt easily tired and had less stamina which made me do fewer physical activities" (Female, Participant #9)	Enablement by encouraging frequent, short-duration, low-intensity physical activities	
	Less support from friends (O-Soc)	"There is no friend that invites me to do exercise. I became lazy to engage in any exercise" (Male, Participant #5)	Enablement by providing team-based challenge	Enablement by allowing them to post their physical activity record on social media
	Fear of getting COVID-19 infection (M − Re)	"I fear getting the COVID-19 infection, so I choose to stay at home and avoid doing outdoor physical activities" (Female, Participant #10)	Education through the smartphone app	Education through webinar

Table 4
APEASE criteria of potential intervention functions.

Potential intervention functions	Affordability	Practicability	Effectiveness and cost-effectiveness	Acceptability	Safety	Equity
Education through the smartphone app	N	N	N	Y	Y	Y
Enablement by encouraging physical activity in any duration	Y	Y	Y	Y	Y	Y
Enablement by encouraging frequent, short-duration, low-intensity physical activities	Y	Y	Y	Y	Y	Y
Enablement by providing team-based challenge	Y	Y	Y	Y	Y	Y
Education through webinar	Y	Y	Y	Y	Y	Y
Enablement by allowing them to post their physical activity record on social media	Y	Y	Y	Y	Y	Y

health and emotional benefits of PA and how to perform PA during the pandemic safely. During the three-week challenge, participants were encouraged to log their PA on the app, which required a smartphone with Android OS 4.0 or later, a primary camera, and a flashlight. Each time before starting in a PA, participants were prompted by the app to measure their heart rate by putting their finger on the primary camera, and then the finger was automatically flashed by the flashlight of the phone. Therefore, the app automatically estimated the participants' heart rates before engaging in the activity. If the participants' phone was not compatible with the heart rate measurement feature of the app, participants could manually measure their heart rate by palpating their wrist for 1 min and inputting their measured heart rate on the app. After that, participants were prompted by the app to start the log timer and then started conducting the PA. Afterwards, the participant was prompted to stop the log timer and conducted the heart rate measurement. Then, participants were prompted to choose the type of PA which was done. After that, points and estimated calories burned were displayed to the participants. Participants could also upload their pictures and share the log of their physical activity on their social media.

Participants were informed that they would get points for each logged PA. The points were calculated based on the PA's duration and intensity, as described in Table 5. The points collected from each team member were accumulated into the team points (Fig. 2). Participants were also informed that extra points could be collected if they shared their PA log on their social media and if all the team members engaged in PA in a day. The leaderboards were shown in a real-time manner to display team order and member order in each team by the points collected (Fig. 2). Educational materials about the benefits of PA for maintaining immunity and how to engage in PA safely during the pandemic were provided on Instagram.

Step 7 Pilot study and evaluation

Having promoted the virtual challenge for one week through social media, we got 480 students interested in participating in the challenge. Four hundred and seven of them were also interested in participating in the research resulting in an 84.8% recruitment rate. We justified that the minimum sample size of our pilot study was 73, and this became our cut off of collecting data. Eight of them (10.96%) dropped out because of incompatibility problems with the application. As many as 58 of 65 participants completed the post-intervention measurements. Since three of the 58 participants completing the measurements had implausible GPAQ values, data from 55 participants were included in the analysis.

Participants consisted of 19 males (35%) and 36 females (65%). Most of them had a normal body mass index and studied natural science. Overall, 36 of 55 participants (65%) lacked physical activity. There was no different proportion ($p = .795$) of females in the physically inactive participants (67%) and physically active participants (63%). Physically active participants had significantly lower SRQ-20 points than their referents (Table 6).

Participants who previously did not engage in a recommended amount of PA increased their total moderate-vigorous PA and reduced their mental distress with a median difference of 210 MET.minutes/week ($p = .001$, $z = 4.008$) and three points ($p = .009$, $z = -2.594$) respectively (Table 7). The improvement of total MVPA among physically inactive participants resulted from a significant increase in leisure-time PA (median difference = 150 MET.minutes/week, $p = .001$, $z = 3.907$). On the other hand, there were no significant changes in total MVPA (Median difference = −480 MET.minutes/week, $p = .525$, $z = 0.362$) and mental distress (Median difference = 0 points, $p = .075$, $z = -1.783$) among participants who had already reached the PA guidelines.

We found that participants often experienced technical difficulties in measuring their heart rates using the app (Fig. 3). However, they were willing to join and recommended the next events to their friends. In addition, they felt happy, connected and supported by their friends, and they were also able to choose PA that suits them and to set their own PA target (Fig. 4).

The quantitative findings from the evaluation form were supported by themes identified from the open-ended questions. There were three themes identified from participants' opinions: app issues, support for basic psychological needs, and physical activity opportunities (Table 8). App issues reflected participants' experience of problems while using the app, participants' suggestions for app development, and participants' opinions on the rating system used by the app. Participants revealed that they were experiencing app crashes, user-interface issues, and logging issues arising from the timer problems and real-time logging issues. Participants also felt that the rating system used in the app was unfair because the heart rate measurement was inaccurate and the system was easy to be cheated. Participants suggested connecting the app to the wearable device, developing the app to include multifunction features for other lifestyle behaviors, providing a basic tutorial on how to use the app, and enhancing it with gamification. Basic psychological needs reflected participants' feelings on how joining the three-week challenge could affect their feeling on autonomy, competence, and

Table 5
Characteristics of challenge features.

Potential intervention functions	Challenge Features	Delivery	BCT	Opportunity for satisfying the 3Cs	Opportunity for thwarting the 3Cs
Enablement by encouraging physical activity in any duration and frequent short duration low physical activity intervention	Participants were requested to log their physical activities in a real-time manner using the app	App feature	Self-monitoring of behavior	Competence	N/A
	Participants were informed that they would get points for each logged physical activity in the range of low-intensity to high-intensity physical activity. They were also informed that the points were calculated based on relative intensity calculated using their heart rate before and at the end of physical activity, with 0.5 points per minute for low-intensity physical activity, one point per minute for moderate-intensity physical activity, and two points per minute for vigorous-intensity physical activity [40]. However, participants were not informed about how the app calculated their physical activity intensity.	App feature	Non-specific incentive Positive reinforcement	Competence	Competence (if not achieving at least low intensity or if achieving more than high intensity)
	Providing encouragement and informing how many calories burn after participants record their physical activity	App feature	Feedback on behavior Social reward	Competence	Competence (if not achieving their goal)
Enablement by providing team-based challenge	Encouraging participants to join in a team so that they could support each other in collecting points from individual points and bonus points if there were more than one team members doing physical activities on the same day	App feature	Social support (unspecified)	Relatedness	Autonomy (controlled by others)
	Leader board showing competition between team members and teams	App feature	Social comparison	Competence (if they are satisfied with their rank)	Competence (if they were not satisfied with their rank) Autonomy (external motivation)
Education through Webinar	Providing educational materials to increase awareness of the benefits of physical activity during the COVID-19 pandemic, including benefits for maintaining immunity, and to inform how to do physical activity safely during the COVID-19 pandemic	Webinar	Information about health and emotional consequences Instruction on how to perform the behavior	Competence	Autonomy
Enablement by allowing them to post their physical activity record on social media	Informing that they would get extra points if they posted their physical activity record on social media	App feature	Identity associated with changed behavior Social reward Social comparison (for other participants viewing their Instagram posts)	Competence Relatedness Competence (If they got positive responses from their followers) Competence (if they were satisfied with their physical activity)	Relatedness Competence (If they did not get positive responses from their followers) Competence (if they were not satisfied with their physical activity) Autonomy (external motivation)

social-relatedness for physical activity. Participants felt that the challenge was fun and supported their autonomy in choosing physical activities. Joining the challenge made them more confident to engage in more sports and other PAs. However, the leaderboard made them feel insecure because of the achievement of their friends and other teams. PA opportunities concerned by participants who did not have time to engage in PA.

4. Discussion

We reported the systematic development of a virtually-delivered physical activity (PA) challenge using the BCW approach and co-

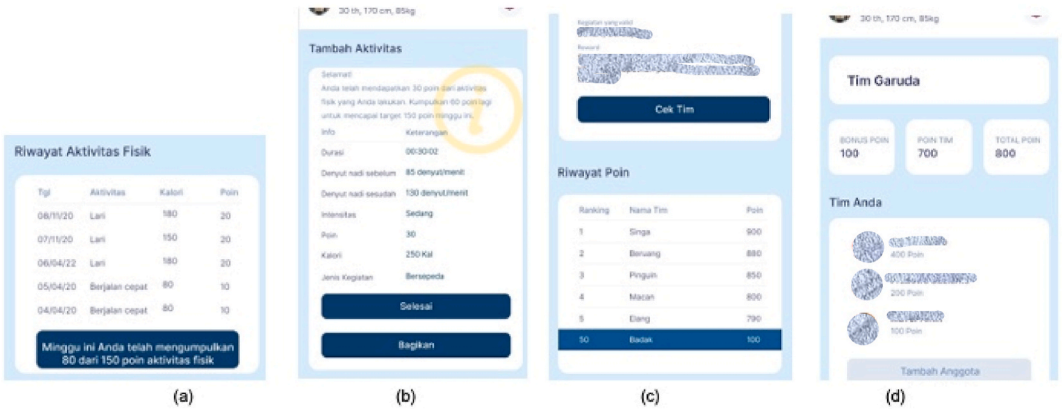

Fig. 2. Screenshot of challenge features: a) self-monitoring of physical activity; b) Point, encouragement, and calories burn; c) leaderboard between teams; d) leaderboard between team members.

Table 6
Baseline demographic and mental distress between physically inactive participants and physically active participants.

	Physically inactive participants (n = 36) (Median (Range))	Physically active participants (n = 19) (Median (Range))	p-value	Z-value
Age (years)	20 (2)	20 (2)	.314	−1.006
Mental distress (points)*	5.50 (18.00)	1.00 (12.00)	0.10	−2.569

* significant at $p < .05$.

Table 7
Changes in physical activity and mental distress between baseline and three weeks.

	Physically inactive participants			Physically active participants		
	Median difference (Range)	*p*-value	z-value	Median difference (Range	*p*-value	z-value
Work-related PA (MET.minutes/week)	0 (10560)	.116	1.572	0 (26040)	.484	.700
Transportation PA (MET.minutes/week)	0 (1720)	.010	2.574	0 (1160)	.074	.1.787
Leisure-time PA (MET.minutes/week)	150 (11100)*	.001	3.907	−480 (9800)	.393	.854
Total PA (MET.minutes/week)	210 (21416)*	.001	4.008	−480 (27100)	.717	.362
Mental distress (points)	−3 (17)*	.009	−2.594	0 (12)	.075	−1.783

* significant at $p < .05$.

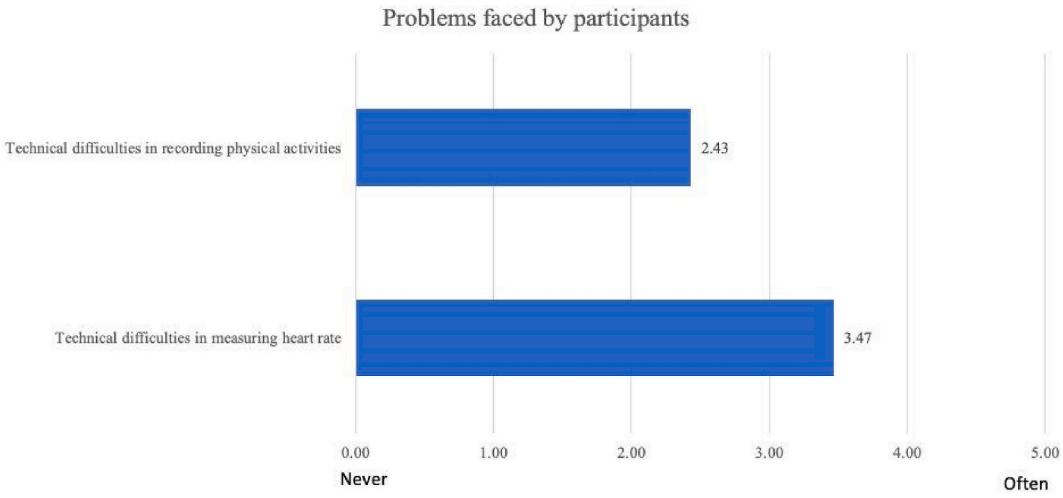

Fig. 3. Problems faced by participants.

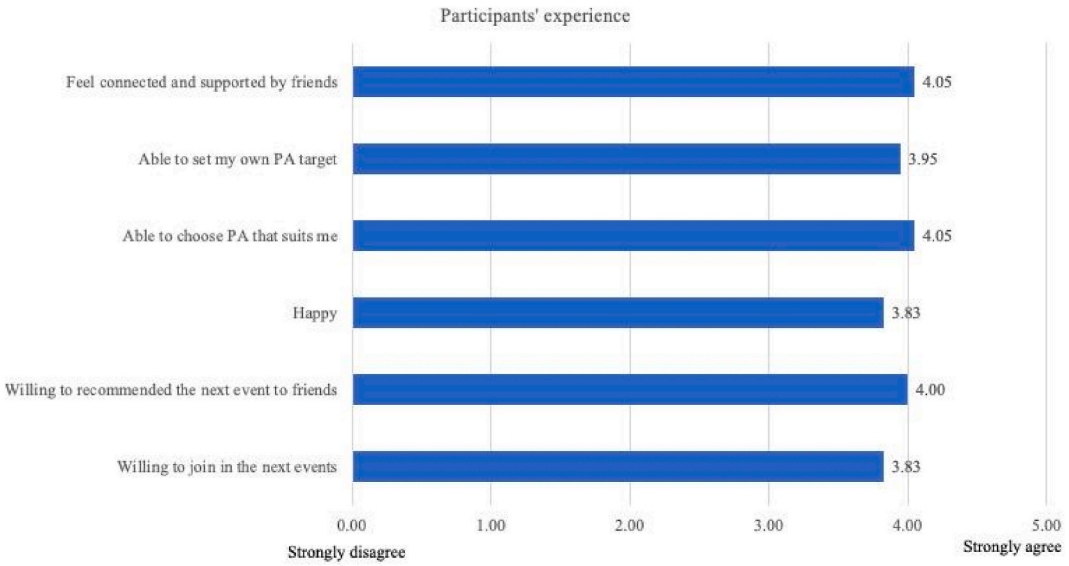

Fig. 4. Participants' experiences during the challenge.

Table 8
Participants' opinions.

Themes	Subthemes	Quotes
App issues	Problems while using the app	I stressed out during the challenge because sometimes the app crashed while I was recording my physical activities (Participants no.1) The challenge ran well, but the app must have been improved because sometimes I got the timer reset while I was logging my activities. (Participant no. 9) At first, I had trouble using the app because the menus and displays were not clear enough. (Participants no.19) I am already used to running every afternoon, so I often do not bring my phone during my running session. This makes me unable to log my exercise session into the app. (Participant no. 22)
	Participants' suggestions for app development	In the next event, the application should be able to connect with wearable devices. (Participant no. 52) We recommend using a multifunctional application that can be used to monitor diet so that participants don't have to install many lifestyle-related applications. (Participant no. 53) If a guide for using the application is provided, it will make it easier for participants. (Participant no. 43) Please provide quests like in the game to make it more exciting. (Participant no. 33)
	Participants' opinions on the rating system used by the app.	The app is not accurate in measuring my heart rate. In fact, this affected the scoring. (Participant no. 24) I think the scoring method can be cheated easily. I saw one participant once conduct high-intensity exercise 9 h per day at one time. This is not possible. (Participant no. 31)
Support for basic psychological needs	Autonomy	I find this challenge very fun and exciting because I can exercise the way I like, and it's as if I have the support of my friends. (Participant no. 8)
	Competence	After exercising regularly and getting up early because I took part in this challenge, I feel much fitter and more confident to engage in more sports activities. (Participant no. 28) I often feel insecure when I see the achievements of my friends and other teams. (Participant no. 47)
	Relatedness	The existence of information about the benefits of exercise and friends who support each other have made me very motivated to exercise. (Participant no. 30)
Physical activity opportunities	Time barriers	Even though this challenge gives me a lot of freedom, I still don't have time to exercise because I don't have much time. I have a lot of coursework and have to prepare for exams. (Participant no. 2)

creation framework based on SDT. The use of the BCW approach and co-creation framework allowed for tailoring the intervention to meet university students' needs and circumstances. After conducting ten steps using the BCW approach, we delivered five challenge features during a three-week PA challenge to provide five intervention functions meeting APEASE criteria addressing university students' enablers and barriers to physical activity during the COVID-19 pandemic and basic psychological needs for exercise based on the SDT. With 480 participants responding after a one-week promotion, this intervention provided promising short-term effects on increasing university students' PA by 210 MET.minutes/week, equivalent to 52.5 moderate intensity PA/week, and alleviating mental

distress by three points of SRQ-20 score among participants who previously lacked PA during the COVID-19 pandemic.

Our finding on PA outcomes, which was higher than the previous systematic review, emphasized that co-created PA intervention based on a theoretical framework and incorporating effective BCT combinations could increase the intervention effectiveness [10,12,13,16]. However, the higher effectiveness could also be attributed to the floor effect of the lower PA baseline of our participants during the COVID-19 pandemic [5,9]. In addition, the developed intervention seems to be accepted by the participants. Participants were happy during this challenge, likely to join this future challenge again and invite their friends to participate (Fig. 3). They also perceived that this challenge could satisfy their basic psychological needs for exercise since they felt that they could choose PA that suited them, set their own target, and feel attached to and supported by their group (Fig. 3). However, the challenge could not address time barriers which were identified as the common barriers to PA among university students [41,42]. Multicomponent interventions and policies could be suggested to address time barriers for PA among university students.

Among the sample participants, the majority of them were females who lacked PA. This finding is consistent with a previous systematic review reporting that the majority of health promotion programs among university students were participated in by a majority of females [43]. However, considering that females were less active than males across the lifespan, the intervention is promising to attract such a vulnerable population [44]. Providing points based on intensity for each completion of PA could be the reason for the high interest of participants who are less active and less fit. At a similar relative intensity, less trained participants can reach similar points than more trained participants even if they reach either a lower step count or a lower distance than their reference in a similar duration. This is because untrained participants can reach similar relative intensity to more trained individuals by conducting PA at a lower speed or lower load than the more trained ones [40,45,46]. On the other hand, point calculation based on relative intensity calculated using heart rate introduced some burden to the participants reflected by participants' concern about the accuracy of the heart rate measurement, and it could also be easily falsified. Considering integration with wearable technology as suggested by participants, or integrating advanced technology with machine learning systems to measure personalized relative intensity could be considered in future development [47].

From a sample of participants, we identified app incompatibility problems experienced by 10.96% of the sample. Among the sample participants that could join the challenge, they often had problems measuring heart rate using the app. The bad user interface, app errors, and crash problems also emerged. While the development of the intervention was already using rigorous approaches from the public health and behavioral perspective by embedding it with framework and theory, the development of the mobile app lacked framework and theory from information system perspectives. The rise of information system-related problems in this co-creation process should be minimized by collaborating with information system researchers and embedding with framework and guidelines from an information system perspective before releasing the app to the public [48,49].

4.1. Strengths and limitations

Developing a PA intervention using the BCW and co-creation framework helped design potential intervention functions that address barriers and facilitators to university students' physical activity. Embedding theory into this process also potentially improved the effectiveness. Reporting the component of intervention based on the TiDieR checklist and the BCT taxonomy also allows replication of this process. However, the whole process was time-consuming, which was in accordance with several previous implementation studies using the BCW and the co-creation framework [22,50–52]. The potential use of artificial intelligence and machine learning in implementation science could be a promise in the future [53].

The evaluation process in our pilot study lacked a systematic approach and control group, which limited the internal and external validity of the findings. Pragmatic use of the RE-AIM Framework could help transparently evaluate the internal and external validity of the developed intervention while not overburdening evaluation resources [54,55]. The challenge of implementing a controlled study design in a "real-world" intervention was also faced by several previous studies [56–58]. Cluster randomized controlled trial (RCT) using watchlist control in a nationwide program could be considered to minimize selection bias, chronological bias, unknown confounders, and contamination which can neither be addressed using a non-randomized controlled design nor individual RCT [59,60].

5. Conclusions

After describing how a virtually-delivered physical activity intervention incorporating a smartphone app was developed using the BCW and co-creation framework, we found that the intervention obtained high interest from university students and could potentially increase their physical activity and improve their mental health. Several technical problems regarding the app should be considered for future development. Future research should consider the implementation of machine learning to mitigate the time-consuming process. There are also several considerations to improve the internal and external validity of the evaluation process in future research.

Declarations

Ethics approval and consent to participate

Ethics approval was granted from the Medical and Health Research Ethics Committee of the Faculty of Medicine, Public Health and Nursing, Universitas Gadjah Mada (KE/0783/08/2020). Participants provide written informed consent. All research procedures have been performed in accordance with the World Medical Association (WMA) Declaration of Helsinki for medical research involving human subjects.

Consent for publication

Not applicable.

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Authors' contributions

All authors have read and approved the manuscript. ZMS: Conceived and designed the experiments, Wrote the paper. RAW: Conceived and designed the experiments, Analyzed and interpreted the data, Contributed reagents, materials, analysis tools or data, Wrote the paper. WW: Conceived and designed the experiments, Contributed reagents, materials, analysis tools or data, Wrote the paper. AFK: Conceived and designed the experiments, Wrote the paper. PSU: Conceived and designed the experiments, Analyzed and interpreted the data, Wrote the paper. FME: Analyzed and interpreted the data, Wrote the paper. REP: Performed the experiments. EA: Performed the experiments. JS: Performed the experiments, Analyzed and interpreted the data, Contributed reagents, materials, analysis tools or data. TCC: Performed the experiments, Analyzed and interpreted the data. MIP: Performed the experiments. DA: Analyzed and interpreted the data, Wrote the paper.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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