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Effectiveness of socioecological model-guided, smart device-based, and self-management-oriented lifestyle (3SLIFE) intervention on healthy lifestyles and metabolic syndrome risk in community residents: a cluster-randomized controlled trial

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Abstract

Background Mobile health (mHealth) lifestyle interventions have showed promise in improving healthy lifestyles and reducing metabolic syndrome (MetS) risk, yet most studies adopt isolated frameworks. The 3SLIFE model—integrating the socioecological model, smart devices, and self-management strategies—provides a holistic approach to sustained behavioral change. It considers environmental influences, empowers individuals in goal-setting and engagement, and leverages smart devices for monitoring and feedback. Despite its potential, evidence on this integrated approach remains scarce. This study applies 3SLIFE to community-dwelling adults, aiming to improve healthy lifestyles.

Methods In this parallel, cluster-randomized controlled trial, 20 communities in Southwestern China were randomly assigned 1:1 to either the intervention or control group. Participants in the intervention group received the 3SLIFE intervention for 6 months, while those in the control group received routine management. The healthy lifestyle score was calculated for each participant based on smoking, alcohol intake, physical activity, dietary habits, and overweight/obesity. The primary outcome was the change in the healthy lifestyle score at the end of the 6-month trial. Differences in the score between groups were estimated using generalized linear mixed-effects models in the intention-to-treat population at 3, 6, and 12 months of follow-up.

Results From April to July 2023, 383 community-dwelling adults (mean age: 57.64 ± 11.32 years; 42.30% male) were recruited—190 in the intervention group and 193 in the control group. After the 6-month intervention, the increase in the healthy lifestyle score was slightly higher in the intervention group (13.22 ± 3.30 to 13.40 ± 2.88) than in the

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control group (13.34 ± 3.10 to 12.79 ± 3.32), with a mean difference of 0.77 (95% CI, 0.17 to 1.38). A higher proportion in the intervention group reduced at least one unhealthy lifestyle compared to the control group (31.48% vs. 19.64%, $P = 0.016$). However, no significant difference in score change was observed between groups at 12-month follow-up.

Conclusions This study provides evidence that the 3SLIFE intervention could modestly improve healthy lifestyles in a community-based population, but the effects were not sustained at the 12-month follow-up. A further refinement is needed to enhance the intervention's long-term effectiveness in promoting sustainable lifestyle changes and reduce MetS risk in communities.

Trial registration Chinese Clinical Trial Registry Identifier: ChiCTR2300070575.

Keywords Metabolic syndrome, MHealth, Lifestyles, Randomized controlled trial

Background

Metabolic syndrome (MetS) is a cluster of metabolic dysfunctions, including hypertension, central obesity, dyslipidemia, and impaired glucose tolerance. Its global prevalence is increasing, presenting a significant public health challenge, particularly in China, where about 31.1% of adults are affected [1]. MetS and its components are well-recognized risk factors for cardiovascular diseases (CVDs), even prior to the development of hyperglycaemia and type 2 diabetes mellitus, leading to increased healthcare costs and socioeconomic burdens [2–4]. As MetS progresses, the likelihood of developing CVD increases, making early risk reduction essential. A continuous MetS risk score can help assess CVD risk and serve as an early intervention tool to prevente future CVD events and mortality [5–7]. Lifestyle interventions have proven efficient in preventing the onset and progression of MetS in adults [8, 9]. However, despite these benefits, 89.6% of Chinese community-dwelling adults exhibit at least one unhealthy lifestyle behavior [10]. Some individuals may also have a high MetS risk without formal diagnosis [6]. Early lifestyles modifications in these individuals could significantly lower their risk. Improvements in risk scores may also serve as motivation, reinforcing sustained behavioral changes. Promoting healthy lifestyle interventions across all risk levels would enhance public health efforts to prevent MetS and reduce CVD in communities [11, 12]. Therefore, accessible and scalable intervention strategies are needed to improve healthy behaviors, reduce MetS risk, and support early-stage CVD prevention for better population health.

While community-based lifestyle interventions are effective in promoting healthier behaviors and managing metabolic diseases such as diabetes [13] and hypertension [14], they often struggle to address the complexity of MetS. Offline interventions may lack focus due to the multifactorial nature of MetS [11, 15]. As a result, they often lead to low compliance and unsustainable behavioral changes [16, 17]. In contrast, mobile health (mHealth) interventions offer an innovative and efficient solution. These interventions leverage smart devices to deliver short videos, text messages, images, and health monitoring data. By implementing comprehensive lifestyle management strategies at scale, they become more accessible to broader populations [18, 19]. Moreover, mHealth provide flexibility and personalization which could enhance adherence and support long-term behavioral changes [20, 21].

Despite the potential of mHealth, previous randomized controlled trials (RCTs) on reducing MetS through mobile interventions have often focused on specific lifestyle behaviors, such as physical activity or dietary changes. Most of these studies have been conducted in individuals with MetS, obesity, diabetes, and/or hypertension (Additional file 1: Figure S1, Tables S1) [9, 22–48]. As a result, evidence on the effectiveness of multi-component lifestyle interventions using mHealth in community-dwelling adults remain limited, reducing the generalizability of findings. This lack of generalizable data is critical, as many community-dwelling adults, while not diagnosed with MetS, exhibit unhealthy behaviors or insufficient healthy behaviors [10], increasing their risk of developing MetS. Early preventive interventions addressing a broader range of lifestyle factors are essential to effectively reduce MetS risk and improve community health. Moreover, healthy lifestyles and chronic diseases are influenced by multi-level environmental factors, including individual, community, and policy-level determinants [49–51]. These muti-level influences make lifestyle management more complex and challenging for community-dwelling residents than for clinical populations. Thus, effective theoretical models are needed to enhance the effectiveness of interventions.

The socio-ecological model, which emphasizes multilevel influences on lifestyles, offers a valuable framwork for guiding complex interventions that promote multiple healthy behaviors in a community-based setting [52, 53]. However, it has been criticized for not adequately considering individual decision-making and self-management strategies [53, 54]. In contrast, empowerment models emphasize self-management by fostering individual skills, social engagement, and personalized goal-setting [55]. Yet, these models often overlook the broader environmental factors that shape behaviors [56]. Combining self-management strageties with the socio-ecological models could create a more comphrehensive approach for smart device-based, self-management-oriented lifestyle interventions in community settings [57]. However, the application of this integrated approach in mHealth interventions aimed at promoting healthy lifestyles and reducing MetS risk remains understudied.

To address these gaps, the socioecological model-guided, smart device-based, and self-management-oriented lifestyle (3SLIFE) intervention was designed as a two-arm, cluster-randomized controlled trial. Conducted in a community setting in Southwest China, this study aimed to evaluate the effectiveness of mHealth-based lifestyle interventions in promoting multiple healthy lifestyle behaviors and reducing the risk of MetS among community residents.

Methods

Study design

The 3SLIFE study is a two-arm, parallel, cluster-RCT aimed at promoting healthy lifestyles based on the socioecological model. The intervention was delivered through a smart device-based approach, targeting community residents in China. The study is part of the China Multi-Ethnic Cohort (CMEC) [58] and is prospectively registered in the Chinese Clinical Trials Registry (ChiCTR2300070575, https://www.chictr.org.cn). The study protocol has been previously published [59], and the updated version can be found in Additional file 2: Study protocol. The design and implementation of this cluster-RCT adhered to the extension of the SPIRIT 2013 statement [60]. The trial was reported in accordance with the Consolidated Standards of Reporting Trials- Patient-Reported Outcomes (CONSORT PRO) [61], which is an extension of CONSORT 2010 statement [62] with guidance on reporting patient-reported outcomes (Additional file 3: CONSORT PRO).

Eligibility of participants

Four towns were randomly selected as the study sites from the CMEC [58] that had undergone two waves of surveys. From each town, five communities or villages were further randomly selected, based on criteria including: 1) having undergone two waves of CMEC; 2) having no previous or ongoing intervention programs; 3) having a minimum of five eligible participants; and 4) being at least 2 km away from other included communities or villages. Participants were community-dwelling adults recruited from eligible communities between April 30 and July 30, 2023. To be eligible for this RCT, participants were needed to 1) be 18 years of age or older; and 2) have access to the internet via a smartphone. Exclusion criteria included: 1) a history of major psychiatric illnesses; 2) major surgery in the past year; 3) current cancer treatment; and 4) pregnancy.

Ethics

This trial was conducted in compliance with the study protocol, the Declaration of Helsinki, and good clinical practice. Ethical approval for this study was obtained from the Ethics Committee of the West China School of Public Health and West China Fourth Hospital (Gwll2022096). All participants provided written informed consent before entering the RCT.

Randomization, masking, and group management

Twenty eligible communities or villages were randomized using a computer-based random number generator (www.random.org) and assigned to either the intervention group or the control group, with ten villages in each group. Randomization was performed using a covariate adaptive procedure to minimize the P value from a joint F test (1000 iterations), ensuring balanced covariates [63]. Covariates considered for randomization included the number, mean age, and sex ratio of residents.

Allocation concealment was performed by central randomization, where an independent statistician generating block randomization sequences with randomly permuted block size and with a 1:1 allocation ratio. The study center used these sequences to recruit villages, and the labels of the random sequences were revealed to the trial team responsible for delivering the interventions. A single-blind design was employed, with participants, assessors, and statisticians remaining blinded throughout the trial. The timeline cluster diagram was in Additional file 1: Figure S2.

Following randomization, participants in each community or village were assigned to a WeChat group, a widely used messaging and social media platform in China that enables real-time communication, multimedia sharing, and group interaction. This resulted in 10 WeChat groups each for the intervention and control groups. Each group was managed by a trained group manager and a local medical doctor or nurse. For the intervention groups, a panel of five medical professionals (specialized in nutrition or rehabilitation) was responsible for developing intervention materials, such as videos, images and online courses. These materials were used consistently across all intervention groups.

Interventions

The lifestyle intervention was based on the socioecological model and multi-dimensional self-management strategies. It comprised both smart device-based and offline interventions at the individual, family, and community levels [64], as previously described in detail [59]. This intervention group received a 6-month healthy lifestyle intervention, while the control group received a 6-month routine management. According to the 3SLIFE, interventions took place at three levels, including individual-, family- and community-level (Table 1).

At the individual level (microsystem), the intervention group received daily healthy lifestyle information and skills, including healthy diet, adequate physical activity, tobacco cessation, alcohol reduction, improvement of sleep quality, and medical adherence. These information was provided by homemade videos, weblinks to videos, and pictures in intervention WeChat group. Healthy lifestyle skills were delivered via homemade health coaching videos and a live streaming platform (e.g., online courses on diet) twice a week in the WeChat group. Participants received one-on-one medical consultations via WeChat or phone when needed. Over the 6-month intervention, the manager of each intervention group provided an average of 156 healthy recipe pictures and 151 healthy lifestyle information and skills pictures or videos (i.e., 24 for diet, 26 for physical activity, 25 for smoking, 27 for drinking, 23 for sleep quality, and 26 for medical adherence). Additionally, 52 live-streamed lifestyle sessions were held, and participants were encouraged to document their daily lifestyles online to improve self-management based on multi-dimensional empowerment theory. Group manager provided online communication once a week to remind unhealthy lifestyle modification or healthy lifestyle maintenance according to their documents. Participants demonstrating good performance were rewarded with gifts (e.g., soap and laundry detergent, valued under $2 USD) each month.

At the family level (mesosystem), group managers in the panel communicated with family members via WeChat, phone, and face-to-face meetings each quarter. Together with the family members, the group managers developed a healthy lifestyle improvement plan during the first month post-intervention. Family members were encouraged to assist participants in documenting their daily lifestyles to enhance self-management.

At the community level (macrosystem), we conducted a series of online (e.g., online quiz activities) and offline activities to improve the supportive environment. Over the 6-month intervention, group managers organized a total of 22 weekly online quiz activities, where questions on healthy lifestyle knowledge and skills from participants were answered, and three offline activities, which involved sharing healthy lifestyle experiences among peers. These efforts aimed to foster a healthier environment and improve self-management. All participants were invited to the local medical center in their town to attend offline intervention sessions delivered by group managers, physicians, and nurses from tertiary and local hospitals. During these sessions, participants received fitness aids such as elastic bands and pillboxes, as well as printed materials about healthy lifestyles and free medication consultations.

Participants in the control group received information unrelated to healthy lifestyles (e.g., prevention of pulmonary tuberculosis) once a week through the WeChat group, as well as free medication consultations when needed and community health activities unrelated to healthy lifestyles (e.g., healthcare reimbursement).

Data collection

Demographic data (age, sex, marital status, and educational level), lifestyle factors (smoking status, alcohol intake, physical activity, dietary habits, and obesity), healthy lifestyle-related self-efficacy, waist circumference, blood pressure (BP), body fat (body fat mass, and percent body fat), blood biochemical markers (triglycerides [TG], high-density lipoprotein cholesterol [HDL-C], and fasting blood glucose [FBG]), and medication use were

Table 1 3SLIFE framework for intervention

Levels	Interventions	Description
Individual	Knowledge	Regular healthy lifestyle information and skills
	Skill	Health coaching and medical consultation
	Empowerment	Self-management of healthy lifestyles with encouragement, self-supervision and rewards
Family	Communication	Communication with family members
	Empowerment	Family co-supervision to promote participants' self-management of healthy lifestyles
Community	Mutual support	Community health activities
	Environments	Instructions on creating healthy environments
	Empowerment	Professional medical consultation and peer encouragement for participants' self-management of healthy lifestyles

3SLIFE, socioecological model-guided, smart device-based, and self-management-oriented lifestyle collected at baseline, 3, 6 and 12 months. Detailed information of physical measurements were in Additional file 1: Table S2.

Lifestyle factors, including smoking status, alcohol intake, physical activity, dietary habit, and overweight and obesity, were selected to construct the healthy lifestyle score, based on the European Prospective Investigation into Cancer and Nutrition cohort study [65]. Smoking status was assessed based on the average number of cigarettes smoked per day [65]. Alcohol intake was assessed by examining drinking frequency and beverage type (beer, grape wine, rice wine, spirits with < 40% alcohol content, and spirits with ≥ 40% alcohol content), and the amount typically consumed per drinking occasion to calculate average daily alcohol intake. Physical activity level was assessed using metabolic equivalent of task (MET) scores based on the International Physical Activity Questionnaire [66]. Dietary habits were assessed using modified relative Mediterranean diet (mrMED) Score based on the Food Frequency Questionnaire [67, 68]. Overweight/obesity was measured by body mass index (BMI). Each lifestyle factor was quantified into a score, with specific details provided in Additional file 1: Table S3 [65–67, 69–71]. The healthy lifestyle score was the sum of individual lifestyle scores, ranging from 0 to 20, with a higher score indicating a healthier lifestyle [65]. For reasons of simplicity, each lifestyle will also be coded as a dichotomous variable, with 0 indicating absence, 1 indicating presence of a particular unhealthy lifestyle (Additional file 1: Table S3). Besides, healthy lifestyle-related self-efficacy was estimated using a modified 10-item self-efficacy scale [72], with each item scored from 0 to 4, yielding a total score of 0 to 40.

According to the criteria of the 2018 Chinese Guidelines for Prevention and Treatment of Hypertension [73], MetS was defined as the presence of three or more of the five common MetS components: 1) high BP (systolic blood pressure [SBP] ≥ 130 mmHg and/or diastolic blood pressure [DBP] ≥ 85 mmHg, or receiving antihypertensive medication); 2) elevated waist (≥ 90 cm in males and ≥ 85 cm in females); 3) elevated TG (≥ 1.7 mmol/l [150 mg/dl]), or reduced low HDL-C (< 1.04 mmol/l [40.2 mg/dl], or receiving medication for dyslipidemia); 4) FBG (≥ 6.1 mmol/l [110 mg/dl], or receiving medication for diabetes). In addition, we calculated a continuous metabolic syndrome risk score (MetS Z score) based on the continuous measures of the five MetS components (SBP, waist, TG, HDL-C, and FBG) for each participant at baseline and follow-up waves. This score was developed using data from the US National Health and Nutrition Examination Survey [74]. A Chinese age-sex-ethnicity-specific MetS Z score (Chinese MetS Z score) was also calculated for each participant, which was developed with the data from CMEC and validated in different geographical regions of China [6]. A higher MetS Z score indicates greater risk of MetS. The equations for the two MetS Z scores were shown in Additional file 1: Table S4 [6, 74]. Medication use was estimated by self-reported use of any cardiometabolic disease medication (i.e., lipid-lowering drugs, antidiabetic drugs, antihypertensive drugs).

For the intervention group, we also conducted an evaluation at the end of the intervention to assess participants' adherence and satisfaction to recommended recipes, health education, live online courses, online quiz activities, and offline communication events.

Outcomes

The primary outcome was the mean difference in change of healthy lifestyle score between the intervention and control groups at 6 months compared to baseline in the total sample. The primary outcome also included the reduction of unhealthy lifestyles, with a decrease in at least one unhealthy lifestyle at 6 months considered a favorable outcome (coded 1) and any other outcome unfavorable (coded 0).

Secondary outcomes that were most relevant to the primary research question were reported, including the mean difference in healthy lifestyle score change at 3 and 12 months; the difference in proportion of favorable outcome (reduction of unhealthy lifestyles) at 3 and 12 months; the difference in changes in lifestyle factors (including current smoker, alcohol intake, physical activity, mrMED score, and BMI), body composition, and healthy lifestyle-related self-efficacy at 3, 6, and 12 months. As exploratory analyses, we reported the difference in changes in the MetS Z score, the Chinese MetS Z score, and the changes in MetS and its components (i.e., SBP, DBP, waist circumference, TG, HDL-C, and FBG) at 3, 6, and 12 months from baseline.

Statistical analysis

The statistical analysis plan was developed before the completion of data collection and any analyses. Drawing on findings from the previous two CMEC survey waves, we estimated that a 2% of the control group participants would achieve a favorable outcome. We assumed a 10% increase in favorable outcome in the intervention group, resulting in a 10% minimally important difference.

We used a chi-squared test of independence to calculate the sample size. To achieve a power of 0.80 for detecting a statistically significant difference ($\alpha \le 0.05$) between $p1 = 0.02$ and $p2 = 0.12$, the sample size is estimated to be 204 (102 per group). To account for an estimated 20% attrition rate, the recruitment target is 128 participants per group, resulting in a total sample size of 256 participants for assessment and evaluation. We also accounted for clustering effects [75, 76], and the sample size was calculated to be 142 per group, assuming cluster size of 10, a correlation coefficient of 0.05 [77], and design effect estimated at 1.45. To account for an estimated 15% participant attrition, the recruitment target is set at 167 participants per group, leading to a total sample of 334 participants for assessment and evaluation. For the MetS Z score, we aimed to detect a 0.2 change in MetS Z score with 80% power, 0.05 significance, and a standard deviation of 0.48 for the between-group difference [9, 78], requiring 90 participants per group, with a total of 307 to account for design effects and attrition.

The analysis for all outcomes was conducted according to the intention-to-treat (ITT) principle. Change in the mean or percentage was estimated from the observed differences, and the differences in change between the intervention and control groups were estimated using generalized linear mixed effects models. The model included the groups (intervention and control), time (baseline, 3, 6, and 12 months), time × group interactions, and a random intercept for participants and potential confounding variables (sex, age, locations and baseline outcomes). The time × group interaction term indicated the different changes between groups from baseline to 3 months, the end (6 months) of the trial or 12 months follow-up. For continuous variables, the mean differences in change between the intervention group and control group (intervention effect) were estimated. For categorical variables, such as the prevalence of MetS, the corresponding odds ratios (OR) were estimated. The 95% confidence intervals (CIs) were calculated for both the mean differences and OR values. For the favorable outcome (reduction of unhealthy lifestyles), we used the chi-square test to compare the differences between the control and intervention groups.

Sex, age and medication use at baseline may influence the efficacy of intervention for healthy lifestyle and MetS [6, 79]. Therefore, a post hoc subgroup analysis was conducted by adding the subgroup variable (sex, age and medication use) along with its two-way interactions with both time and group (subgroup variable × group, subgroup variable × time), as well as its three-way interaction with time and group (subgroup variable × time × group). The fixed effect of the three-way interaction was assessed using analysis of variance with type III sum of squares, with the results presented as P value < 0.05, indicating a significant difference in intervention effects across subgroups.

To assess the robustness of the intervention effect on the outcomes, we performed five sensitivity analyses: 1) an ITT analysis after imputing missing values of the incompleted data; 2) a per-protocol (PP) analysis, with participants who completed baseline and end trial assessments, and adhered to the protocol-required intervention measures; 3) recalculating the healthy lifestyle score after excluding alcohol intake from the mrMED score calculation, as alcohol was also assessed in the mrMED; 4) calculating the healthy lifestyle score using quintile thresholds based on log-transformed values of physical activity and mrMED for each time point, considering the right-skewed distribution may lead to unstable thresholds; and 5) calculating the healthy lifestyle score by summing the scores of all dichotomous lifestyle factors (with the total score reversed, ranging from 0 to 5) to validate the robustness of the results.

Data analyses were performed using R version 4.2.1 for Windows. All analyses were two-sided, and P value of < 0.05 was considered significant. More details can be found in Additional file 4: Statistical analysis plan [63, 75, 76, 80, 81].

Results

Characteristics of participants

We recruited 438 participants from 20 communities/villages (10 in each group), of whom a total of 383 participants met the criteria and completed the baseline survey (Table 2). The mean age was 57.64 ± 11.32 years, and 162 (42.30%) were male. A total of 190 participants (from 10 communities/villages) and 193 participants (from 10 communities/villages) were allocated to the intervention and control groups, respectively. At baseline, the mean healthy lifestyle scores were 13.22 ± 3.30 and 13.34 ± 3.10 in the intervention and control groups, respectively; and the mean MetS Z scores were 0.15 ± 0.97 in the intervention group and 0.05 ± 0.88 in the control group. The baseline characteristics of participants were similar between the intervention and control groups. There were no significant differences in baseline characteristics between participants who were lost to follow-up and those who completed the study, except for sampling regions (Additional file 1: Table S5). At the end of the 6-month follow-up, 53 (13.84%) participants were lost to follow-up, and by the end of the 12-month follow-up, a total of 93 (24.28%) participants were lost to follow-up, primarily due to reasons such as work commitments, travel, or visiting relatives (Fig. 1). No important harms or unintended effects were observed in each group.

Among participants in the intervention group, 167 received an intervention adherence and satisfaction evaluation at the end of the 6-month trial. Of these, 30 (17.96%) reported no exposure to or adherence to the recommended recipes, 31 (18.56%) to healthy lifestyle education, 42 (25.15%) to online live courses, 45 (26.95%) to online quiz activities, and 33 (19.76%) to offline communication events. A total of 8 (4.75%) participants reported no exposure or non-adherence to any of the intervention

Table 2 Baseline characteristics of participants

Variables	n (%) or mean ± SD		
	Overall *n* = 383	**Control group *n* = 193**	**Intervention group *n* = 190**
Age at baseline (years)	57.64 ± 11.32	57.31 ± 12.33	57.98 ± 10.22
Sex			
Male	162 (42.30)	80 (41.45)	82 (43.16)
Female	221 (57.70)	113 (58.55)	108 (56.84)
Marital status			
Unmarried/widowed/divorced	32 (8.36)	14 (7.25)	18 (9.47)
Married	351 (91.64)	179 (92.75)	172 (90.53)
Educational level			
Primary school or below	125 (32.64)	68 (35.23)	57 (30.00)
Junior school or above	258 (67.36)	125 (64.77)	133 (70.00)
Location [a]			
Town A	78 (20.37)	47 (24.35)	31 (16.32)
Town B	95 (24.80)	48 (24.87)	47 (24.74)
Town C	124 (32.38)	62 (32.12)	62 (32.63)
Town D	86 (22.45)	36 (18.65)	50 (26.32)
Lifestyles			
Current Smoker (%) [b]	70 (18.28)	32 (16.58)	38 (20.00)
Alcohol intake (g/d)	10.20 ± 40.73	6.54 ± 19.22	13.93 ± 54.32
Physical activity (METs-h/d) [c]	26.01 ± 12.01	25.64 ± 11.36	26.40 ± 12.67
mrMED score	8.48 ± 2.23	8.38 ± 2.23	8.58 ± 2.22
BMI (kg/m^2)	24.99 ± 3.43	25.26 ± 3.50	24.71 ± 3.34
Healthy lifestyle score	13.28 ± 3.20	13.34 ± 3.10	13.22 ± 3.30
MetS and its components			
MetS Z score	0.10 ± 0.93	0.05 ± 0.88	0.15 ± 0.97
Chinese Mets Z score	0.37 ± 1.02	0.37 ± 1.03	0.38 ± 1.02
MetS			
No	276 (72.06)	141 (73.06)	135 (71.05)
Yes	107 (27.94)	52 (26.94)	55 (28.95)
SBP (mmHg)	135.28 ± 19.42	135.70 ± 20.88	134.86 ± 17.87
DBP (mmHg)	82.95 ± 11.00	82.68 ± 10.94	83.22 ± 11.08
Waist circumference (cm)	87.21 ± 8.96	87.53 ± 9.15	86.89 ± 8.77
TG (mmol/L)	1.85 ± 1.81	1.83 ± 1.82	1.87 ± 1.80
HDL-C (mmol/L)	1.49 ± 0.39	1.49 ± 0.41	1.49 ± 0.36
FBG (mmol/L)	5.75 ± 1.68	5.67 ± 1.54	5.83 ± 1.81
Medication use [d]			
No	298 (77.81)	156 (80.83)	142 (74.74)
Yes	85 (22.19)	37 (19.17)	48 (25.26)
Body fat			
Body fat mass (kg)	20.62 ± 6.11	21.11 ± 6.45	20.12 ± 5.72
Percent body fat (%)	32.90 ± 6.98	33.09 ± 7.06	32.71 ± 6.90

BMI body mass index, *DBP* diastolic blood pressure, *FBG* fasting blood glucose, *HDL-C* high density lipoprotein, *MetS* Metabolic syndrome, *MET* metabolic equivalent of task, *mrMDS* modified relative Mediterranean Diet Score, *SBP* systolic blood pressure, *SD* standard deviation, *TG* triglyceride

[a] The four towns were study sites selected from the China Multi-Ethnic Cohort

[b] Current smoker was defined as an individual who consumes any amount of tobacco at the time of assessment, excluding those who have never smoked or have ceased smoking for at least 6 months

[c] Metabolic equivalent tasks across four activity domains: occupational physical activity, transportation physical activity, physical activity for housework, and sports and leisure-time physical activity

[d] Medication use was estimated by self-reported use of any cardiometabolic disease medication (i.e., lipid-lowering drugs, antidiabetic drugs, antihypertensive drugs) at baseline

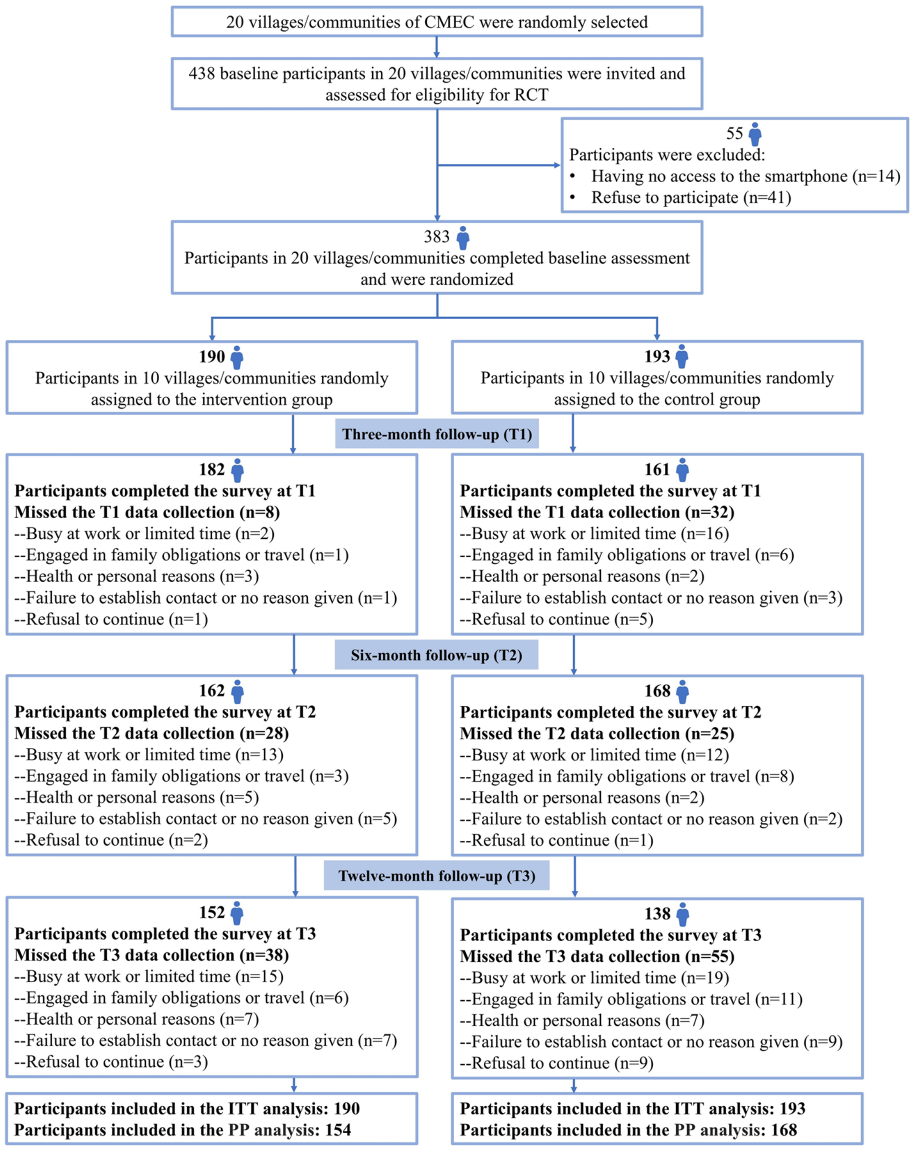

Fig. 1 Study flowchart. At 6 months, eight participants in the intervention group reported no exposure or non-adherence to any of the intervention measures at the end of trial, and the PP analysis sample size was 154. CMEC, the China Multi-Ethnic Cohort; ITT, intention-to-treat; PP, per-protocol; RCT, randomized controlled trial

measures. Additionally, 129 (77.25%) reported satisfaction with the recommended recipes, 125 (74.85%) with healthy lifestyle education, 122 (73.05%) with online live courses, 111 (66.47%) with online quiz activities, and 123 (73.66%) with offline communication events (Additional file 1: Table S6).

Changes in healthy lifestyles and related self-efficacy

A significant difference was observed in the change in healthy lifestyle score between the intervention and control groups at 6 months, with a slightly increased mean difference of 0.77 (95% CI, 0.17 to 1.38); however, no significant differences were found at 3 (mean difference: 0.47 [95% CI, −0.14 to 1.07]) and 12 months (0.20 [95% CI, −0.43 to 0.84]) (Table 3, Fig. 2, Additional file 1: Figure S3). At 6 months, significant differences were observed in the changes between the intervention and control groups in alcohol intake (−9.28 g/d [95% CI, −16.05 g/d to −2.50 g/d]), and BMI (−0.24 kg/m^2 [95% CI, −0.47 kg/m^2 to −0.01 kg/m^2]). Additionally, the proportion of participants with an improvement in heathy lifestyle score greater than one point (29.47% vs. 18.13%, $P=0.013$), two points (28.94% vs. 15.03%, $P=0.002$), and five points (5.26% vs. 1.04%, $P=0.037$) was higher

Table 3 Effect of the 3SLIFE intervention on healthy lifestyle score and specific lifestyle factors

Variables	Control group		Intervention group		Difference in change or OR (95% CI) (Intervention effect)[a]	*P* value
	n (%) or mean ± SD	Change in the mean or percentage (95%CI)	n (%) or mean ± SD	Change in the mean or percentage (95%CI)		
Healthy lifestyle score						
Baseline	13.34 ± 3.10	Ref	13.22 ± 3.30	Ref	Ref	
At 3-month	12.89 ± 3.31	−0.45 (−1.12, 0.22)	13.32 ± 3.13	0.10 (−0.55, 0.75)	0.47 (−0.14, 1.07)	0.133
At 6-month	12.79 ± 3.32	−0.55 (−1.21, 0.12)	13.40 ± 2.88	0.18 (−0.47, 0.83)	**0.77 (0.17, 1.38)**	**0.013**
At 12-month	12.78 ± 3.50	−0.56 (−1.29, 0.17)	13.29 ± 3.17	0.07 (−0.62, 0.76)	0.20 (−0.43, 0.84)	0.534
Current smoker (%)[b]						
Baseline	32 (16.58)	Ref	38 (20.00)	Ref	Ref	
At 3-month	31 (19.25)	2.67 (−5.37, 10.71)	35 (19.23)	−0.77 (−08.84, 7.30)	0.26 (0.02, 4.31)	0.343
At 6-month	30 (17.86)	1.28 (−6.54, 9.10)	33 (20.37)	0.37 (−8.05, 8.79)	0.23 (0.01, 4.25)	0.322
At 12-month	29 (21.01)	4.43 (−4.16, 13.02)	27 (17.76)	−2.24 (−10.56, 6.08)	0.19 (0.01, 4.06)	0.284
Alcohol intake (g/d)						
Baseline	6.54 ± 19.22	Ref	13.93 ± 54.32	Ref	Ref	
At 3-month	8.19 ± 22.08	1.65 (−2.71, 6.01)	7.51 ± 18.64	−6.42 (−14.60, 1.76)	**−7.96 (−14.67, −1.24)**	**0.020**
At 6-month	10.01 ± 25.31	3.47 (−1.22, 8.16)	8.94 ± 26.79	−4.99 (−13.75, 3.77)	**−9.28 (−16.05, −2.50)**	**0.007**
At 12-month	9.43 ± 25.80	2.89 (−2.20, 7.98)	10.33 ± 23.57	−3.60 (−12.18, 4.98)	−3.00 (−10.05, 4.05)	0.404
Physical activity (METs-h/d)[c]						
Baseline	25.64 ± 11.36	Ref	26.40 ± 12.67	Ref	Ref	
At 3-month	22.54 ± 15.72	−3.10 (−6.01, −0.19)	22.90 ± 13.79	−3.50 (−6.19, −0.81)	−0.17 (−4.23, 3.88)	0.932
At 6-month	22.42 ± 11.51	−3.22 (−5.59, −0.85)	24.50 ± 12.50	−1.90 (−4.54, 0.74)	1.24 (−2.80, 5.27)	0.548
At 12-month	19.70 ± 19.50	−5.94 (−9.57, −2.31)	23.08 ± 20.43	−3.32 (−7.03, 0.39)	1.20 (−3.00, 5.41)	0.575
mrMED score						
Baseline	8.38 ± 2.23	Ref	8.58 ± 2.22	Ref	Ref	
At 3-month	8.32 ± 2.39	−0.06 (−0.55, 0.43)	8.48 ± 2.26	−0.10 (−0.56, 0.36)	0.02 (−0.54, 0.57)	0.954
At 6-month	8.47 ± 2.21	0.09 (−0.37, 0.55)	8.36 ± 2.34	−0.22 (−0.70, 0.26)	−0.31 (−0.87, 0.25)	0.278
At 12-month	8.47 ± 2.21	0.09 (−0.39, 0.57)	8.60 ± 2.42	0.02 (−0.48, 0.52)	−0.04 (−0.62, 0.54)	0.887
BMI (kg/m^2)						
Baseline	25.26 ± 3.50	Ref	24.71 ± 3.34	Ref	Ref	
At 3-month	25.16 ± 3.52	−0.10 (−0.83, 0.63)	24.43 ± 3.48	−0.28 (−0.97, 0.41)	−0.20 (−0.42, 0.03)	0.092
At 6-month	25.15 ± 3.42	−0.11 (−0.83, 0.61)	24.42 ± 3.27	−0.29 (−0.98, 0.40)	**−0.24 (−0.47, −0.01)**	**0.042**
At 12-month	24.86 ± 3.00	−0.40 (−1.10, 0.30)	24.24 ± 3.54	−0.47 (−1.21, 0.27)	−0.16 (−0.40, 0.08)	0.186

BMI body mass index, *CI* confidence interval, *mrMDS* modified relative Mediterranean Diet Score, *MET* metabolic equivalent of task, *OR* odds ratio, *SD* standard deviation, *3SLIFE* socioecological model-guided, smart device-based, and self-management-oriented lifestyle

[a] Comparison between intervention and control groups in the changes from baseline to 3-, 6-, and 12-month follow-up. Positive values indicate that the intervention group had a greater increase or less decrease from baseline to follow-up than the control group; negative values indicate that the intervention group had a greater decrease or smaller increase from baseline to follow-up than the control group. Intervention effects were presented as mean differences with 95% CIs for continuous variables and as ORs with 95% CIs for categorical variables. All analyses were adjusted for age, sex, location and lifestyle factors (i.e., smoking status, alcohol intake, physical activity, mrMED score, and BMI) at baseline. Bolded values denote statistical significance

[b] Current smoker was defined as an individual who consumed any amount of tobacco at the time of assessment, excluding those who had never smoked or had ceased smoking for at least 6 months

[c] Metabolic equivalent tasks across four activity domains: occupational physical activity, transportation physical activity, physical activity for housework, and sports and leisure-time physical activity

in the intervention group than in the control group at 6 months (Additional file 1: Table S7). Besides, the proportion of participants who reduced at least one unhealthy lifestyle was higher in the intervention group than in the control group at 6 months (31.48% vs. 19.64%, $P = 0.016$) (Additional file 1: Table S8). No significant differences were observed in the changes in current smoker, physical activity and mrMED score between the two groups at 3, 6, and 12 months (Table 3, Additional file 1: Figure S4).

As for body fat, significant differences were observed in the changes in body fat mass and percent body fat between the intervention and control groups at 6

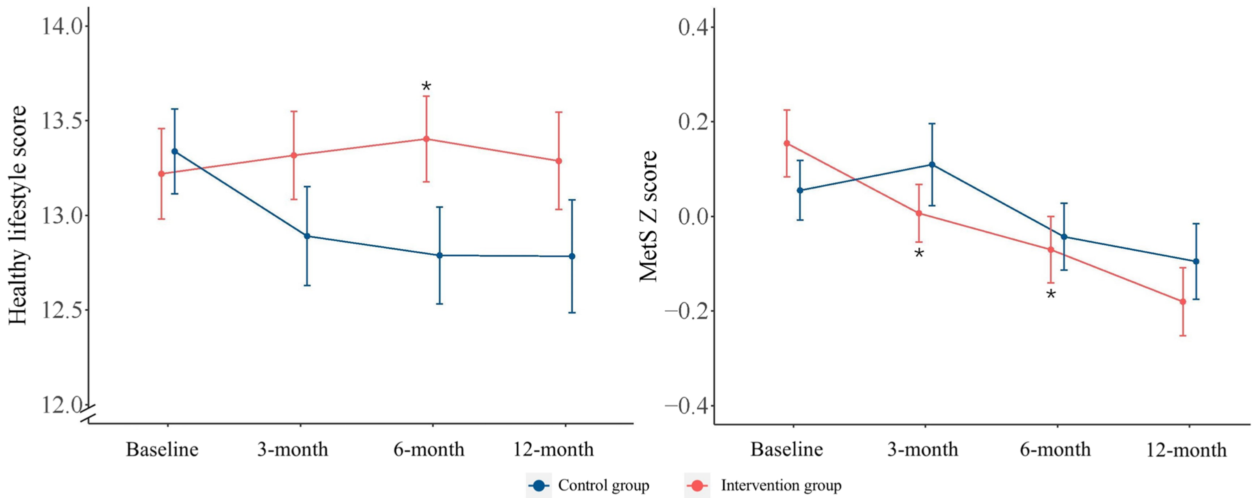

Fig. 2 Effect of the 3SLIFE intervention on healthy lifestyle score and MetS Z score. *Significant difference in changes of outcomes between groups. The error bars denote the standard error of the mean. MetS, metabolic syndrome; 3SLIFE, socioecological model-guided, smart device-based, and self-management-oriented lifestyle

months, with mean differences of −0.61 kg (95%CI, −1.11 kg, −0.11 kg) and −0.88% (95%CI, −1.54% to −0.23%), respectively (Additional file 1: Table S9). Healthy lifestyle-related self-efficacy increased in the intervention group and exceeded that of the control group by the end of the trial, although the changes were not significant (Additional file 1: Table S10).

Exploration analyses: change in MetS Z score, MetS prevalence and components

The mean MetS Z score in the intervention group was modestly reduced compared with the control group at 3 months (mean difference: −0.20 [95% CI, −0.36 to −0.04]) and 6 months (−0.17 [95% CI, −0.33 to −0.01]), but no significant reduced was observed at 12 months. A modestly significant difference in the changes in the Chinese MetS Z score was also observed between the two groups at 3 months (mean difference: −0.25 [95% CI, −0.44 to −0.06]) and 12 months (mean difference: −0.21 [95% CI, −0.40 to −0.01]), but no significant difference was observed at 6 months (Table 4).

At baseline, the prevalence of MetS was 28.95% in the intervention group and 26.94% in the control group (Table 4, Additional file 1: Figure S5). The intervention significantly reduced the proportion of participants with MetS by the end of the trial (17.90% versus 26.19%; OR = 0.35 [95% CI, 0.14 to 0.92]), although no significant difference was found at 3 and 12 months. For MetS components, a significant difference in the change in TG was found between groups at 3 months (mean difference: −0.47 mmol/L [95% CI, −0.86 mmol/L to −0.09 mmol/L]), but no significant difference was found at 6 and 12 months. Significant differences in the changes in waist circumference were observed between groups at 3, 6, and 12 months, with mean differences of −1.48 cm (95% CI, −2.46 cm to −0.50 cm), −1.16 cm (95% CI, −2.15 cm to −0.17 cm) and −1.52 cm (95% CI, −2.55 cm to −0.49 cm), respectively.

Subgroup analyses

By subgroup analysis of age, a significant difference in the change in healthy lifestyle score was observed between the intervention and control groups at 6 months in both age subgroups, whereas no significant differences were found in the changes in the MetS Z score at 3, 6, and 12 months (Fig. 3a). Among male participants, there were significant differences in the changes in healthy lifestyle score between groups at 6 months (Fig. 3b), and significant differences in the changes in both the MetS Z score and the Chinese MetS Z score were observed at 3 and 12 months. Among participants using medication, a significant difference in the changes in Chinese MetS Z score was observed between groups at 3 months. Among those not using medication, significant differences in the changes in healthy lifestyle score were observed at 6 months, and in MetS Z score at 6 and 12 months (Fig. 3c). However, no significant interaction effect of age, sex, and medication use with the intervention effect on the changes in healthy lifestyle score and MetS Z score was observed.

Sensitivity analyses

The intervention effect on the healthy lifestyle score between the intervention and control groups remained

Table 4 Effect of the 3SLIFE intervention on MetS Z score and MetS components

Variables	Control group		Intervention group		Difference in change or OR (95% CI) (Intervention effect)[a]	*P* value
	n (%) or mean ± SD	Change in the mean or percentage (95%CI)	n (%) or mean ± SD	Change in the mean or percentage (95%CI)		
MetS Z score						
Baseline	0.05 ± 0.88	Ref	0.15 ± 0.97	Ref	Ref	
At 3-month	0.10 ± 1.09	0.05 (−0.16, 0.26)	0.01 ± 0.82	−0.15 (−0.33, 0.03)	**−0.20 (−0.36, −0.04)**	**0.012**
At 6-month	−0.04 ± 0.91	−0.09 (−0.28, 0.10)	−0.07 ± 0.90	−0.23 (−0.43, −0.03)	**−0.17 (−0.33, −0.01)**	**0.037**
At 12-month	−0.09 ± 0.93	−0.14 (−0.34, 0.06)	−0.18 ± 0.89	−0.34 (−0.54, −0.14)	−0.15 (−0.31, 0.02)	0.084
Chinese MetS Z score						
Baseline	0.37 ± 1.03	Ref	0.38 ± 1.02	Ref	Ref	
At 3-month	0.50 ± 1.54	0.13 (−0.15, 0.41)	0.25 ± 0.85	−0.13 (−0.32, 0.06)	**−0.25 (−0.44, −0.06)**	**0.009**
At 6-month	0.16 ± 1.02	−0.21 (−0.42, 0.00)	0.05 ± 0.83	−0.33 (−0.52, −0.14)	−0.18 (−0.37, 0.01)	0.068
At 12-month	0.19 ± 1.05	−0.18 (−0.41, 0.05)	−0.04 ± 0.75	−0.42 (−0.61, −0.23)	**−0.21 (−0.40, −0.01)**	**0.042**
MetS (%)						
Baseline	52 (26.94)	Ref	55 (28.95)	Ref	Ref	
At 3-month	45 (27.95)	1.01 (−8.33, 10.35)	41 (22.53)	−6.42 (−15.27, 2.43)	0.53 (0.21, 1.31)	0.170
At 6-month	44 (26.19)	−0.75 (−9.88, 8.38)	29 (17.90)	−11.05 (−19.79, −2.31)	**0.35 (0.14, 0.92)**	**0.032**
At 12-month	25 (18.12)	−8.82 (−17.79, 0.15)	24 (15.79)	−13.16 (−21.83, −4.49)	0.78 (0.28, 2.16)	0.630
SBP (mmHg)						
Baseline	135.70 ± 20.88	Ref	134.86 ± 17.87	Ref	Ref	
At 3-month	133.48 ± 21.60	−2.22 (−6.67, 2.23)	132.31 ± 19.21	−2.55 (−6.32, 1.22)	−0.80 (−3.75, 2.14)	0.593
At 6-month	132.61 ± 20.57	−3.09 (−7.37, 1.19)	129.82 ± 16.14	−5.04 (−8.59, −1.49)	−1.49 (−4.47, 1.49)	0.327
At 12-month	124.36 ± 19.52	−11.34 (−15.73, −6.95)	121.19 ± 15.18	−13.67 (−17.17, −10.17)	−1.00 (−4.11, 2.10)	0.526
DBP (mmHg)						
Baseline	82.68 ± 10.94	Ref	83.22 ± 11.08	Ref	Ref	
At 3-month	83.96 ± 10.40	1.28 (−0.95, 3.51)	83.96 ± 9.45	0.74 (−1.35, 2.83)	−0.89 (−2.52, 0.74)	0.285
At 6-month	79.52 ± 9.84	−3.16 (−5.30, −1.02)	79.12 ± 9.50	−4.10 (−6.25, −1.95)	−1.13 (−2.78, 0.52)	0.179
At 12-month	79.05 ± 9.33	−3.63 (−5.82, −1.44)	77.96 ± 9.11	−5.26 (−7.4, −3.12)	−1.11 (−2.83, 0.60)	0.204
Waist circumference (cm)						
Baseline	87.53 ± 9.15	Ref	86.98 ± 8.77	Ref	Ref	
At 3-month	86.20 ± 8.88	−1.33 (−3.21, 0.55)	84.24 ± 8.24	−2.74 (−4.47, −1.01)	**−1.48 (−2.46, −0.50)**	**0.003**
At 6-month	84.60 ± 8.87	−2.93 (−4.79, −1.07)	82.88 ± 8.19	−4.10 (−5.87, −2.33)	**−1.16 (−2.15, −0.17)**	**0.021**
At 12-month	85.03 ± 8.96	−2.5 (−4.48, −0.52)	82.62 ± 9.61	−4.36 (−6.33, −2.39)	**−1.52 (−2.55, −0.49)**	**0.004**
TG (mmol/L)						
Baseline	1.83 ± 1.82	Ref	1.87 ± 1.80	Ref	Ref	
At 3-month	2.26 ± 2.99	0.43 (−0.10, 0.96)	1.81 ± 1.14	−0.06 (−0.36, 0.24)	**−0.47 (−0.86, −0.09)**	**0.016**
At 6-month	1.69 ± 1.59	−0.14 (−0.49, 0.21)	1.58 ± 1.03	−0.29 (−0.59, 0.01)	−0.22 (−0.61, 0.17)	0.269
At 12-month	1.80 ± 1.66	−0.03 (−0.41, 0.35)	1.57 ± 0.74	−0.30 (−0.58, −0.02)	−0.32 (−0.72, 0.08)	0.120
HDL-C (mmol/L)						
Baseline	1.49 ± 0.41	Ref	1.49 ± 0.36	Ref	Ref	
At 3-month	1.47 ± 0.44	−0.02 (−0.11, 0.07)	1.48 ± 0.40	−0.01 (−0.09, 0.07)	0.01 (−0.06, 0.08)	0.756
At 6-month	1.54 ± 0.41	0.05 (−0.03, 0.13)	1.57 ± 0.43	0.08 (0.01, 0.16)	0.04 (−0.03, 0.12)	0.232
At 12-month	1.52 ± 0.44	0.03 (−0.06, 0.12)	1.58 ± 0.40	0.09 (0.01, 0.17)	0.05 (−0.03, 0.12)	0.228
FBG (mmol/L)						
Baseline	5.68 ± 1.54	Ref	5.83 ± 1.81	Ref	Ref	
At 3-month	5.65 ± 1.77	−0.03 (−0.38, 0.32)	5.54 ± 1.18	−0.29 (−0.60, 0.02)	−0.25 (−0.54, 0.05)	0.098
At 6-month	5.85 ± 1.32	0.17 (−0.13, 0.47)	5.87 ± 1.45	0.04 (−0.30, 0.38)	−0.15 (−0.45, 0.15)	0.321
At 12-month	5.71 ± 1.19	0.03 (−0.26, 0.32)	5.65 ± 1.69	−0.18 (−0.55, 0.19)	−0.01 (−0.31, 0.31)	0.996

CI confidence interval, *DBP* diastolic blood pressure, *FBG* fasting blood glucose, *HDL-C* high density lipoprotein, *MetS* Metabolic syndrome, *OR* odds ratio, *SBP* systolic blood pressure, *SD* standard deviation, *TG* triglyceride, *3SLIFE* socioecological model-guided, smart device-based, and self-management-oriented lifestyle

[a] Comparison between intervention and control groups in the changes from baseline to 3-, 6-, and 12-month follow-up. Positive values indicate that the intervention group had a greater increase or less decrease from baseline to follow-up than the control group; negative values indicate that the intervention group had a greater decrease or smaller increase from baseline to follow-up than the control group. Intervention effects were presented as mean differences with 95% CIs for continuous variables and as ORs with 95% CIs for categorical variables. All analyses were adjusted for age, sex, location and MetS components (i.e., SBP, DBP, Waist circumference, TG, HDL-C, and FBG) at baseline. Bolded values denote statistical significance

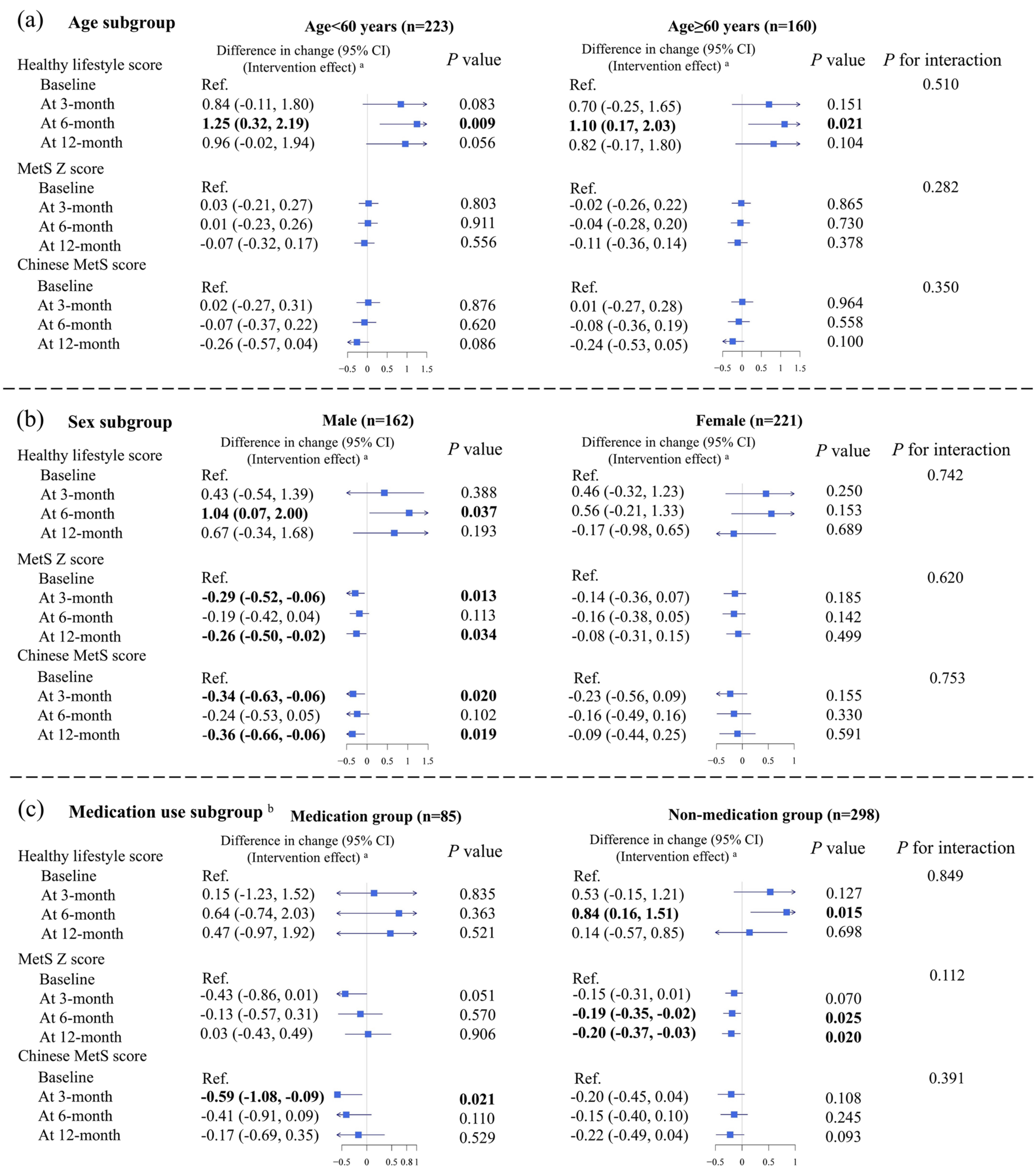

Fig. 3 Effect of the 3SLIFE intervention by age, sex, and drug intake status. [a]Comparison between intervention and control groups in the changes from baseline to 3-, 6- and 12-month follow-up. Positive values indicate the intervention group had a greater increase or less decrease from baseline to follow-up than the control group, while negative values indicate a greater decrease or smaller increase. Intervention effects were presented by mean difference with 95% CIs for continuous variables and by ORs with 95% CIs for categorical variables. All analyses were adjusted for age, sex, location, and baseline outcome (either lifestyle factors or MetS components), except for the variable used for subgroup analysis. The bolded values indicate statistical significance. [b]Medication use was estimated by self-reported use of any cardiometabolic disease medication (i.e., lipid-lowering drugs, antidiabetic drugs, antihypertensive drugs) at baseline. CI, confidence interval; MetS: Metabolic syndrome; 3SLIFE, socioecological model-guided, smart device-based, and self-management-oriented lifestyle

essentially unchanged when incomplete data were included in the analysis, with a mean difference of 0.85 (95% CI, 0.29 to 1.41) at 6 months in improving the healthy lifestyle score (Additional file 1: Table S11). The intervention effect was significant in reducing the MetS Z score (at 3 months: −0.18 [95% CI, −0.33 to −0.04]; 6 months: −0.19 [95% CI, −0.34 to −0.04]), the Chinese MetS Z score (3 months: −0.25 [95% CI, −0.44 to −0.06]; 12 months: −0.21 [95% CI, −0.40 to −0.01]), and the prevalence of MetS at 6 months (18.95% vs. 28.50%; OR = 0.37 [95% CI, 0.16 to 0.85]) (Additional file 1: Table S12).

For the PP analysis, a modestly significant intervention effect was found in improving the healthy lifestyle score (mean difference: 0.84 [95% CI, 0.24 to 1.44]) at 6 months (Additional file 1: Table S13). Besides, a significant intervention effect was observed in reducing the MetS Z score by −0.20 (95% CI, −0.38 to −0.03), reducing the Chinese MetS Z score by −0.21 (95% CI, −0.39 to −0.03), and lowering the prevalence of MetS (14.94% vs. 26.19%, OR = 0.28 [95% CI, 0.11 to 0.71]) at 6 months (Additional file 1: Table S14).

After excluding alcohol intake from the mrMED score calculation, calculating healthy lifestyle score using log-transformed values of physical activity and mrMED, and calculating the healthy lifestyle score by summing up the dichotomous lifestyle factors, the intervention effect on the healthy lifestyle score between the intervention and control groups remained robust (Additional file 1: Table S15).

Discussion

Our study investigated the effect of a socioecological model-guided, smart device-based, self-management-oriented lifestyle intervention on promoting healthy lifestyles and reducing MetS risk among community residents. To our knowledge, this is one of the few RCTs assessing the effects of community-based, multilevel mHealth lifestyle interventions on these outcomes. Our findings indicate that the 6-month lifestyle intervention led to a modest improvement in overall healthy lifestyle behaviors and slightly reduced MetS risk and prevalence. However, the effects were not sustained at the 12-month follow-up.

In a community setting, this 3SLIFE study adds evidence that implementing smart device-based healthy lifestyle interventions at individual, family, and community levels can modestly improve healthy lifestyles and reduce the MetS risk among community residents. According to the ‘prevention paradox’[82], most disease cases in a population occur in individuals at low or moderate risks, which means that even a slight improvement of the intervention in a community population could lower the risk of a considerable number of people and have important public health implications [83]. Given that lifestyle behaviors often cluster and act synergistically to increase the risk of multiple chronic diseases such as MetS, multilevel lifestyle interventions may be more conducive to improving overall health outcomes [17, 83, 84,]. Similar to previous studies that focused on one or two specific lifestyles [85, 86], the effectiveness of our intervention, which takes a comprehensive lifestyle approach, can be explained across these multi-levels. At the individual level, we provided medical consultations, health knowledge, and practical skills. A web-based mHealth trial focusing on tailored physical activity and dietary behaviors similarly showed that multiple lifestyle interventions could reduce the risk of impaired FBG and elevated TG [87]. In the Chinese culture, unhealthy behavior changes cannot disregard the impact of family and community environments. Chinese families often dine and engage in activities together [88], making individual-focused interventions less effective. By establishing a supportive environment at the family and community levels, our intervention enhanced self-management through shared improvement plans, quizzes, and peer support in WeChat groups. Such supportive environments helped encourage participants to adopt and maintain healthier lifestyles.

Comparing the two groups, we observed a modest effect of the intervention on improving healthy lifestyle scores by the end of the trial, particularly in terms of alcohol consumption. This may be attributed to the increasing public perception in China that alcohol poses a more immediate health risk, closely linked to chronic conditions like coronary artery disease and cancers [69, 89]. However, we found that the intervention did not lead to large changes in healthy lifestyle scores overall. This may be due to varying levels of interest in health information and proficiency in using mobile phones in community residents, especially among the elderly [90], which could hinder implementation and reduce the effectiveness of mHealth interventions. From within-group changes, no anticipated lifestyle improvement was observed among participants, possibly due to seasonal transitions (summer to winter) or holiday influencing health behavior patterns [91–93]. However, this RCT demonstrated that the intervention at least supported the maintenance of healthy behaviors in the intervention group, where a higher proportion of participants showed an improvement in their healthy lifestyle scores. Additionally, we did not observe a significant change in healthy lifestyle scores between groups during the post-intervention follow up, which might be insufficient long-term supports to sustain behavior change over time. This is a common challenge in health interventions, particularly in community-based settings, where maintaining healthy behaviors often requires ongoing self-management and supportive environment at the family and community levels [94, 95]. Furthermore, although the intervention did not significantly improve self-efficacy, there was an increase in self-efficacy scores in the intervention group compared to the control group by the end of the trial, which may have intuitively contributed to lifestyle modifications.

Our 6-month intervention among community residents led to a mean reduction of −0.17 in the MetS Z score. In contrast, two previous offline physical activity interventions targeting community residents, each lasting 12 weeks or longer, did not report significant changes in a composite metabolic risk score [96, 97]. The effectiveness of the 3SLIFE intervention may be attributed to its comprehensive nature and the use of mHealth. However, a modest reduction was observed only in waist circumference and TG, which is less favorable compared to a prior exercise training program among employed adults with MetS, where the mean difference in MetS Z score was reduced by −0.26 after a 6-month intervention [9]. Barriers to implementing community-based health programs may stem from contextual and infrastructural challenges [98]. Community residents may lack the organizational structure found in workplaces, where health interventions have demonstrated success [99]. The adoption of healthy behaviors often results from influential members and peer encouragement at the community level [100]. Although the supportive environment and guidance from medical staff were present, the lack of peer supervision within WeChat groups may have limited the intervention's effectiveness. Additionally, the fixed intervention model may have decreased its appeal over time, resulting in diminished effectiveness at the post-intervention follow-up. A meta-analysis showed that the effect of fixed behavioral interventions tended to weaken after 6 months [101]. The lack of adherence has been a well-known issue in mHealth intervention, and adaptive interventions using real-time data and just-in-time adjustments could promote long-term adherence to healthy lifestyles [102, 103]. However, the adaptive interventions may face challenges due to the need for more wearable devices, user-friendly apps, and sufficient digital literacy among participants [21, 104]. Future efforts are warranted to explore the applicability of adaptive interventions in more broad community populations, to better understand their accessibility and feasibility in different contexts. Future research should also explore the feasibility of integrating adaptive and passive data-driven interventions in diverse settings. Passive data, such as location, weather, or app usage, can enhance personalization without requiring active user input, thereby improving accessibility for individuals with lower digital literacy.

Our post hoc analysis revealed that intervention effects on healthy lifestyles were more pronounced among males, likely attributable to the higher prevalence of heavy alcohol consumption and smoking in men [105]. Additionally, we found that participants not using medication exhibited a significant improvement in the healthy lifestyle score and reduction in MetS Z score at 6-month intervention. In contrast, no significant reduction was observed among those using medication. Similar to the findings from a previous RCT, a greater beneficial effect of a 12-month physical activity intervention was observed in reducing MetS prevalence among participants not taking any medication for treating MetS [97]. As suggested by previous studies [106, 107], lifestyle modification is primarily conditioned by a person's health status. Long-standing unresolved health conditions and medication use may override the effectiveness of lifestyle intervention in reducing MetS risk. However, the results of post hoc subgroup analyses should be interpreted with caution due to the limited sample size within each subgroup.

Given the rising prevalence of MetS that affects over a billion individuals worldwide [108, conducting healthy lifestyle interventions among community residents holds public health implications, especially for those with high MetS risk who may remain undiagnosed. The 3SLIFE intervention, implemented using smart mobile health technologies in real-world setting, offers an effective and scalable solution for regions with limited chronic disease intervention services. Moreover, the 3SLIFE intervention framework provides new evidence for promoting healthy lifestyles across communities. Its application has the potential to benefit a broad spectrum of individuals, including those with and without unhealthy behaviors, by promoting healthier lifestyle practices. This could reduce MetS risk across populations, serving as an early CVD preventive measure and supporting health policy aimed at improving overall population health.

Several limitations in this study should be acknowledged. First, numerous unknown factors beyond the self-reported lifestyle behaviors might have influenced the measured outcomes. To mitigate potential biases, such as social expectancy bias in questionnaire responses, we assured participants of full anonymity. Second, the study was conducted in a community setting in Southwest China, which may limit its applicability to other sociocultural contexts. Further multi-center studies are warranted to clarify the applicability of this study. Third, the slight improvements in healthy lifestyles and the non-significant findings in some lifestyle components may be due to information overload caused by the inclusion of too many elements in the 3SLIFE intervention, which may have challenged the participants' adherence to the intervention. Besides, our intervention period was relatively short, though we observed modest changes in biomarkers, such as TG, which has been known to respond sensitively to lifestyle changes [109]. These initial findings should be considered preliminary and interpreted with caution. Fourth, although we used mixed-effects models to account for within-subject correlation, multiple statistical tests may still increase the risk of type I errors. The interpretation of these results should be approached with caution. Fifth, although subgroup analyses investigate the potential differences by sex, age and medication use, the small sample sizes within these subgroups may limit the statistical power and reliability of the observed effects. Future research with larger and more balanced samples is needed to validate these findings and improve the robustness of subgroup analyses. Sixth, although we conducted a sensitivity analysis by log-transforming the physical activity and dietary habits, the small sample size may lead to unstable or non-generalizable thresholds of log-transformed values, as the quintile categorization is highly sensitive to outliers or random variations. Seventh, the healthy lifestyle score as a dichotomous variable, which is somewhat arbitrary and may not fully capture the nuances of the data over time. Lastly, although this study evaluated the outcomes at 12 months to observe the sustainability of the intervention, it did not include the 9-month follow-up, which deviates from the protocol. This limitation may affect the completeness of the follow-up results, and restrict the capture the dynamic effects after the intervention ended. Future research should incorporate more follow-up assessments to comprehensively assess the durability of the intervention.

Conclusions

The 3SLIFE intervention, an mHealth lifestyle intervention program applicable to the community setting, led to only modest improvements in healthy lifestyle behaviors and a slight reduction in MetS risk. However, the effects on maintaining healthy lifestyle changes and reducing MetS risk were not sustained at the 12-month follow-up. While the impact was limited, the findings still provide valuable insights into the feasibility of implementing such interventions in real-world community settings, where small, population-wide behavioral shifts can still have meaningful public health implications. Nevertheless, a further refinement is needed to enhance both the long-term effectiveness of the intervention and its ability to drive more substantial and sustained improvements in MetS risk reduction.

Abbreviations

BMI	Body mass index
BP	Blood pressure
CIs	Confidence intervals
CMEC	China Multi-Ethnic Cohort
CONSORT PRO	Consolidated Standards of Reporting Trials- Patient-Reported Outcomes
CVDs	Cardiovascular diseases
DBP	Diastolic blood pressure
FBG	Fasting blood glucose
HDL-C	High-density lipoprotein cholesterol
ITT	Intention-to-treat
MET	Metabolic equivalent of task
MetS	Metabolic syndrome
mHealth	Mobile health
mrMED	Mediterranean diet
OR	Odds ratios
PP	Per-protocol
RCTs	Randomized controlled trials
SBP	Systolic blood pressure
SD	Standard deviation;
TG	Triglycerides
3SLIFE	Socioecological model-guided, smart device-based, and self-management-oriented lifestyle

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-04135-6.

Additional file 1: Supplementary tables and figures. Figure S1–Study inclusion and exclusion flowchart; Table S1–Characteristics of included studies; Figure S2–Timeline cluster diagram; Table S2–Summary of collected variables; Table S3–Components of healthy lifestyle score; Table S4–The equations for MetS Z scores and Chinese MetS Z score; Table S5–Baseline characteristics of participants who completed the trial and those lost to follow-up at the end of the 6-month intervention for the primary outcome; Table S6–Participants' satisfaction with 3SLIFE intervention; Figure S3–Effect of the 3SLIFE intervention on healthy lifestyle score with Y-axis starting from 0; Table S7–Number and proportion of individuals with improvements of the healthy lifestyle score at 6 months between the intervention and control groups; Table S8–Effect of the 3SLIFE intervention on the reduction of unhealthy lifestyles; Figure S4–Effect of the 3SLIFE intervention on healthy lifestyle score and specific lifestyle factors; Table S9–Effect of the 3SLIFE intervention on body fat; Table S10–Effect of the 3SLIFE intervention on heathy lifestyle-related self-efficacy; Figure S5–Effect of the 3SLIFE intervention on MetS and its components; Table S11–Effect of the 3SLIFE intervention on healthy lifestyle score with imputing missing values of incomplete data; Table S12–Effect of the 3SLIFE intervention on MetS Z score and MetS components with imputing missing values of incomplete data; Table S13–Effect of the 3SLIFE intervention on healthy lifestyle score for the per-protocol population; Table S14–Effect of the 3SLIFE intervention on MetS Z score and MetS components for the per-protocol population; Table S15–Sensitive analysis of the effect of the 3SLIFE intervention on healthy lifestyle score.

Additional file 2: Study protocol.

Additional file 3: CONSORT PRO. Checklist of information to include when reporting a randomised trial.

Additional file 4: Statistical analysis plan.

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Authors' contributions

SY and BY designed the study. BY, SY and CM performed the data analysis; SY, QD, and BY prepared the data. SY, BY, and YL wrote the paper. BY, SY, QD, CM, HZ, XY, ML, CC, YF, ZH, TP, QT, FY, and TY conducted investigation and sample collection. SY, LY, JDR, and PJ provided comments and revision. SY, PJ, and QD provided supervision. All authors read and approved the final manuscript.

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Data availability
All investigators and implementation staff will have unrestricted access to the full data set for verification interpretation purposes. Data will be made available to the public after publication of study findings upon request from the corresponding author.

Declarations

Ethics approval and consent to participate
This trial was conducted in compliance with the study protocol, the Declaration of Helsinki, and good clinical practice. Ethical approval for this study was obtained from the Ethics Committee of the West China School of Public Health and West China Fourth Hospital (Gwll2022096). All participants provided written informed consent before entering the RCT.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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