Empowering weight loss through a self-regulation app-based program on weight loss among young adults with excess body weight: A pragmatic randomized controlled trial

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Abstract

Background: By 2035, over half of the global population may be obese, driving significant health and economic burdens. Although lifestyle modification is a preferred approach to weight management, it requires substantial support to be effective.

Objective: This study aimed to test the effectiveness of a 12-weeks standalone self-regulation weight loss Temporal Self-Regulation Theory (TST)-based app integrating self-regulation, food logging, and dietary nudging in improving weight loss among young adults with excess body weight.

Methods: A two-arm parallel 1:1 randomized controlled trial was conducted and reported according to the CONSORT-Outcomes 2022 Extension reporting guideline with participants recruited using convenience sampling. Participants completed a face-to-face body composition analysis and online questionnaires on their sociodemographic profile, self-regulation of eating behaviour, overeating habit, time perspective, eating phenotype, nutrition knowledge, and psychological flexibility. Participants in the intervention group joined a 12-weeks app-based program called the eating trigger response inhibition program 2.0 (eTRIP 2.0) while participants in the control group did not receive any active intervention. Both groups were required to return for follow-up measurements at weeks 12 and 24.

Results: A total of 165 participants were recruited from 14 Nov 2023 to 27 March 2024. The mean body weight differences between the two groups at weeks 0, 12 and 24 were 0.29 kg (95% CI -3.69 kg to 4.28 kg), -1.76 kg (95% CI -5.96 kg to 2.43kg), -1.6 kg (95% CI -5.92 kg to 2.65 kg. A significantly higher improvements of small-to-medium effect sizes with a significant group?time interactions were observed in the intervention compared to control group at week 12 for weight (-0.89 kg, 95% CI -1.51 kg to -0.27 kg, p=0.005), BMI (-0.32 kg/m2, 95% CI -0.55 kg/m2 to -0.10 kg/m2, p=0.005), waist circumference (-1.50cm, 95% CI -2.80 cm to -0.19cm, p=0.03), waist-hip ratio (-0.01, 95% CI -0.011 to <0.001, p=0.04) and BRI (-0.18, 95% CI -0.34 to -0.02, p=0.02). No significant differences were found in anthropometric change between the two groups from weeks 12 to 24 (when app access was ceased) and from weeks 0 to 24. A slightly higher number of participants preferred to lose weight through physical activity over diet across the 24 weeks.

Conclusions: This study provides evidence supporting the effectiveness of TST-based app in improving anthropometric outcomes indicative of cardiometabolic risk including weight, BMI, waist circumference, waist-hip ratio and BRI and psychological constructs of depression, perceived health and eating self-regulation. There is potential for scalability in both population and primary health settings. Clinical Trial: Clinicaltrials.gov (NCT05969639)

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Abstract

Background

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Conclusion

This study provides evidence supporting the effectiveness of TST-based app in improving anthropometric outcomes indicative of cardiometabolic risk including weight, BMI, waist circumference, waist-hip ratio and BRI and psychological constructs of depression, perceived health and eating self-regulation. There is potential for scalability in both population and primary health settings.

Trial Registration: Clinicaltrials.gov (NCT05969639)

Keywords: Weight management, self-regulation, obesity, excess adiposity, artificial intelligence, app

Introduction

In 2022, approximately one in eight of the global population of adults live with obesity, one of the leading risk factors of cardiometabolic diseases such as hypertension, dyslipidaemia, and type 2 diabetes.[1,2] By 2035, more than half of the global population is expected to live with overweight and obesity, costing an estimated $4.32 trillion. [3] Lifestyle modification is typically adopted as the first-line obesity management strategy over more effective options such as obesity management medications (OMM) and bariatric surgery often due to concerns about side effects, perceived ineffectiveness of available treatments, weight stigma, and high cost. [4-7] However, the process of achieving and sustaining lifestyle modification requires substantial internal and external regulation, without which reduces the chances of weight loss success. [8,9] While clinical weight management services do provide lifestyle modification counselling and health coaching, the need for close follow-up and engagement for successful lifestyle modification renders these options manpower intensive and difficult to sustain. Moreover, most individuals prefer to manage their weight on their own, with one study reporting only 11% of individuals intending to use weight-related care. [10]

With an increasing global smartphone penetration of 69% and 97% in developed countries like Singapore, [11] there is a strong potential for using smartphone apps to support weight management especially among people with excess body weight. Moreover, app-based support for weight loss reduces the manpower needed to guide weight management as compared to clinical weight management programs especially those led by a multidisciplinary team. A systematic review of 12 studies found that using mobile phone apps for weight management led to notable reductions in both body weight (-1.04 kg) and BMI (-0.43 kg/m²) compared to control groups. [12] Similarly, a recent meta-analysis of 34 studies demonstrated that smartphone app interventions – featuring key functions such as food logging and calorie counting – resulted in substantial weight loss, with an average reduction of 1.99 kg at 3 months and 2.80 kg at 6 months compared to control groups. [13] Further improvement in weight loss outcomes could be achieved by integrating such apps with elements that enhance self-regulation in dietary behaviours. The Temporal Self-Regulation Theory (TST) offers insights into how self-regulation can impact health behaviour change, suggesting that immediate feedback and goal-setting could strengthen users' motivation to adhere to weight loss interventions. [14] However, the current literature on mobile apps that incorporate motivational and self-regulation related constructs for the purposes of weight management remain limited. [15,16]

Therefore, we developed an app that integrates a self-regulation training framework with image-based food logging, dietary check-in nudging, obesity psychoeducational resources and an app-based social forum into a smartphone app to support weight loss among young adults with excess body weight. The image-based food logging and dietary check-in nudging had previously been shown to improve eating habits, physical activity and mental well-being. [17] The self-regulation framework was tested to be effective in improving heart failure self-care behaviours such as improving diet and exercise. [18] Through this study, we aimed to test the effectiveness of a 12-weeks standalone self-regulation weight loss app in improving weight loss among young adults with excess body weight. We hypothesized that the group that received the app would achieve a higher amount of weight loss as compared to individuals in the control group who do not receive any intervention at week 12.

Methodology

Study design and sampling method

A two-arm parallel 1:1 randomized controlled trial was conducted and reported according to the CONSORT-Outcomes 2022 Extension [19] reporting guideline alongside the template for intervention description and replication (TIDieR) checklist. [20] Participants were recruited using convenience sampling from the community through social media advertisements (e.g. telegram). Potential participants were included if they (1) had a body mass index (BMI) ≥23kg/m^2; (2) were between the ages of 21 and 35 years old; (3) could understand and read the English language; (4) used a smartphone that could download apps; (5) were willing to travel to the National University Singapore for body composition analysis. Participants were excluded if they (1) were pregnant or lactating; (2) were participating in a structured weight loss program; (3) were planning or receiving pharmacotherapy or bariatric surgery within the next 6 months; (4) were diagnosed with a severe mental disorder.

Sample size

Based on a power analysis using the G* power 3.1 software, at least 150 participants were needed for the study to have a 80% power and two-tailed significance level of 0.05 to detect a group difference of 2.5kg (SD 5.4) at week 12. [21] Attrition rate was not factored in as drop-outs by week 12 were replaced.

Procedure

Once a potential participant registers their interest to participate in the study by contacting the research assistant, the research assistant explained the study in detail and collected written informed consent. Next, participants were required to undergo a face-to-face body composition analysis at the National University of Singapore and complete a set of online questionnaires through the university-endorsed survey platform (Qualtrics) on their sociodemographic profile, self-regulation of eating behaviour, overeating habit, time perspective, eating phenotype, nutrition knowledge, and psychological flexibility. Data collection was conducted by a research assistant (JWN) trained by the principal investigator (PI, HSJC) through repeat demonstrations. Participants were then randomly assigned by the research assistant to either the intervention or control group using a computer-generated random list of numbers generated by the PI who was not involved in the data collection process to maintain allocation concealment. Participants in the intervention group were onboarded to a novel 12-weeks app-based program called the eating trigger response inhibition program 2.0 (eTRIP 2.0), of which access was ceased at week 12. Both groups were required to return for follow-up measurements at weeks 12 and 24 by a research assistant. Participants were reimbursed $30 for completing the intervention at week 12 and $10 for completing each follow-up outcome measurement session. Drop-outs at the week 12 follow-up were replaced to ensure sufficient power to detect a group difference at week 12 to assess the app effectiveness on weight loss. However, due to the limited timeframe of the grant, four drop-outs from the intervention group could not be replaced in time.

Ethical consideration

This study was approved by the National University of Singapore Institutional Review Board (NUS-IRB-2022-650) and registered with the Clinicaltrials.gov (NCT05969639). This study conformed with the ethical guidelines of the 1975 Declaration of Helsinki.

Control group

Participants in the control group did not receive any active intervention besides the outcome measurements at weeks 0, 12 and 24.

Intervention group: eating trigger response inhibition program 2.0 (eTRIP 2.0)

The eTRIP 2.0 is a behaviour change weight management app that was developed based on the Temporal Self-regulation Theory (TST), which posits that an intention is influenced by time perspective (i.e. the extent to which one considers about future consequences) and connectedness beliefs (i.e. the extent to which one believes in the association between behaviours and consequences). Additionally, an intention-behaviour gap is influenced by behavioural prepotency (i.e. habits) and self-regulation capacity (i.e. ability to self-regulate thoughts, feelings and behaviours). [14] As an upgrade from the basic image-based food-logging and dietary check-in nudging app (eTRIP 1.0) [17] we added infographics and animated images on the constituents of a healthy diet using the national guideline on “My healthy plate” (based on a plate of 10 inch diameter, quarter to be filled with wholegrains, quarter to be filled with proteins and half with fruits and vegetables), [22] portion size estimation, and emotional regulation. Techniques on emotional regulation were illustrated using animated image on observing and accepting instances negative emotions as natural responses that may pass and need not be compensated by actions such as eating. At every participant’s pre-set meal timing, a prompt was pushed to each participant’s phone, nudging them to take a photograph of their food item(s) and answer a set of questions related to their pre-meal activities (takes around 1-2 minutes). Food images were recognized using a locally developed food image recognition system of which calorie counts were automatically generated and logged backend. At the end of every week, participants were prompted weekly to review their food logs and complete a weekly reflection on their dietary problems, goals, thoughts and feelings on their progress over the past week. They will then make use of a set of previously developed self-regulation strategies and framework using the if-then logic model to develop psychological flexibility through adaptive self-regulation strategies as the action plan for the following week. [18] As the delivery of the intervention was computer pre-programmed; intervention fidelity was ensured.

Outcomes

All measurements were taken at baseline, week 12 and week 24.

Weight (primary outcome), BMI, body fat mass, body fat percentage, basal metabolic rate, waist-hip ratio, and visceral fat level were assess using the InBody 120 (Seoul, Korea) Body composition analyser (BCA), which has been used in various studies for BCA measurements. [23,24] **Height** was assessed only at baseline using a measuring tape stuck to the wall. The research assistant ensured that the body composition analyser was calibrated to zero at every weigh-in to ensure outcome data quality. **Body Roundness Index (BRI)**, which has been shown to be a better predictor of all-cause mortality using a visceral-to-subcutaneous fat area ratio than BMI as a reflection of overall adiposity, was calculated using the following formula: [25]

$$364.2-365.5\times\sqrt{1-\left(\frac{waist\,circumference\,(cm)}{2\pi}\right)^{2}/¿¿}$$

Nutrition knowledge was assessed using the General Nutrition Knowledge Questionnaire-Revised (GNKQ-R) which comprises 88 questions scored against an answer sheet. The questions can be categorised into five subscales – Dietary recommendations, Food groups, Food choices, Food labels and Diet, disease and weight association. Each correct answer received a score of one point, adding up to a total maximum score of 88. [26] Higher scores represent higher level of nutrition knowledge. The GNKQ-R demonstrated high internal reliability (Cronbach's α = .93) and test–retest reliability, with intraclass correlation coefficients ranging from 0.72 to 0.89 across subscales, indicating strong consistency and stability. Validity was confirmed through known-groups and convergent validity methods, with significantly higher scores among dietetics students than English students (effect size d = 1.2, p < 0.001). [26] The tool was contextualised by changing the example of a healthy diet guideline in section 1 question 9 from "Eatwell guide" to "My healthy Plate" and "starchy foods" to "whole grains". The right answer for section 4 question 14 on the BMI classification of 23kg/m^2 was also contextualised from "normal" to "overweight" to suit the Asian cut-off scores.

Psychological flexibility was assessed using the Acceptance and Action Questionnaire for Weight-Related Difficulties (AAQW) which comprises of 22 items measured on a 7-point Likert scale. [27] An example of an AAQW item is, "if I'm overweight, I can't live the life I want to". The scores for all items were summed to calculate the final score. Lower scores represent higher psychological flexibility. In a sample of mostly middle-aged Caucasian females, the AAQW demonstrated good internal consistency (α = .88*)*. Validity was supported by significant correlations with related constructs, including the AAQ (r = .58, p < .001), obesity-related quality of life (ORWELL, r = .64, p < .001), general psychological distress (GHQ, r = .40, p < .001), and BMI (r = .39, p < .001). It also correlated with behavioural indicators, such as weekly binge frequency (r = .36, p < .01), exercise frequency (r = -.30, p < .01), and selecting healthy meals when eating out (r = -.40, p < .01). [27]

Eating Behaviour was assessed using the Three-Factor Eating Questionnaire (TFEQ) which has three subscales – Uncontrolled Eating Scale with nine items, Cognitive Restraint Scale with six items, and Emotional Eating Scale with three items. [28] An example of a TFEQ item is, "when I feel nervous, I find myself eating.". Raw scale scores are calculated for each subscale by taking the mean of all items in each scale multiplied by the number of items in the scale. Raw scores are then transformed to a zero to 100 scale, where higher values indicate more Uncontrolled Eating, Cognitive Restraint or Emotional Eating. Initially developed for an obese population, the TFEQ has demonstrated high internal consistency (α = 0.85 to 0.93) and strong test-retest reliability (α = 0.80 to 0.93). Validity has been confirmed through correlations with binge eating and overeating in response to emotional and social cues. [28]

Self-regulation of eating behaviour was assessed using the Self-regulation of Eating Behaviour Questionnaire (SREBQ). It comprises of five main items measured on a 5-point Likert scale. The total mean score was calculated, and higher scores represent higher levels of self-regulation. Mean scores categorize self-regulation into low (less than 2.8), medium (2.8 to 3.6), and high (greater than 3.6). [29] An example item is, 'I'm good at resisting tempting food.' The SREBQ also includes four screening questions on healthy diet intentions (e.g., 'Do you intend to have a healthy diet?'). With reference to a UK adult population, reliability of the SREBQ is high, with a α of 0.75, and test-retest reliability at 0.77. Construct validity is well-supported by positive correlations with general self-regulation measures and negative correlations with food responsiveness and emotional overeating ($p < 0.001$). [29] Three questions were added and analysed separately (did not contribute to scoring) to further assess the participants intentions, perceptions and preferences in weight management. These questions were, "Do you intent to change your eating behaviours to lose weight?"; "Do you think a healthy diet leads to a healthy weight?"; and "Would you rather control your diet or increase your physical activity to lose weight? (choose only one option)?"

Time perspective was assessed using the Consideration of Future Consequences Scale 6-item (CFCS-6). It has two subscales – CFC-Immediate and CFC-Future, each with three items measured on a 7-point Likert scale. The scores of CFC-Immediate subscales will be reverse coded and added to the CFC-Future subscale scores. The total mean score was then calculated and taken as the final score, where lower scores indicate that participants focus more on their immediate needs and concerns and are expected to act to satisfy these immediate needs, while higher scores indicate that participants are expected to consider future implications of their behaviour and use their distant goals to guide their current actions. [30] An example of a CFC-6 item is, "My behavior is generally influenced by future consequences". With reference to online samples of U.S and Singapore adults, the CFCS-6 demonstrates strong reliability (CFC-Future: α = 0.77; CFC-Immediate: α = 0.83) and predictive validity, with both subscales effectively correlating with behaviours involving delayed gratification, self-control, and health-oriented decisions. [30]

Anxiety was assessed using the Generalised Anxiety Disorder 2-item (GAD-2). Each item has a scale range of zero to three, with total scores ranging from zero to six. Higher scores represent higher levels of anxiety. [31] An example of a GAD-2 item is, "Over the last 2 weeks, how often have you been bothered by the following problems? (Feeling nervous, anxious or on edge)." With reference to adults in Australia, the GAD-2 has demonstrated good reliability (α = 0.81) and test-retest reliability of 0.81. Validity is supported by its correlation with the GAD-7 and its ability to discriminate between individuals with and without an anxiety diagnosis, showing acceptable sensitivity and specificity at a cut-off score of ≥3 (sensitivity = 0.71, specificity = 0.69).[32]

Depression was assessed using the Patient Health Questionnaire 2-item (PHQ-2). Each item has a scale range of zero to three, with total scores ranging from zero to six. Higher scores represent higher levels of depression. [33] An example of a PHQ-2 item is, "Over the last 2 weeks, how often have you been bothered by any of the following problems? (Feeling down, depressed, or hopeless)". When evaluated on medical outpatients in Germany, the PHQ-2 has demonstrated good internal consistency (α = 0.83). Its criterion validity is supported by a sensitivity of 87% and a specificity of 78% for detecting major depressive disorder at a cut-off score of ≥3, in comparison with the Structured Clinical Interview for DSM-IV. [34]

Automaticity or habit of overeating behaviour was assessed using the Self-Report Behavioural Automaticity Index (SRBAI), which comprises four items measured on a 7-point Likert scale. The mean score across all items were calculated and taken as the final score, where higher scores suggest a stronger habit of overeating. [35] An example of an SRBAI item is, “Behaviour ___ is something I do automatically”. In a more recent validation study, the SRBAI shows high reliability (α = 0.93) and excellent validity, with each item being strongly correlated (r = .85 to .94, p < .05) with the overall scale and behavior frequency, confirming its effectiveness in measuring automaticity in habits. [36]

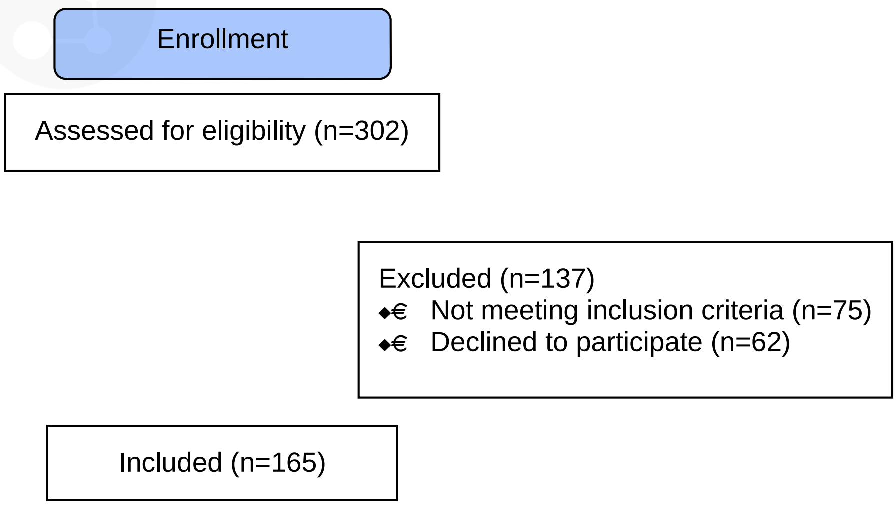
Data analysis

Data analysis was conducted using IBM SPSS 29 [37]and R. [38] Data entry was verified by 2 independent study team members to ensure data quality. Sociodemographic characteristics were summarized using mean (standard deviation, SD) and count (percentage, %). Baseline group differences were assessed using Chi-square test of independence for categorical variables and independent sample t-test for continuous variables. Per protocol (PP) approach was used over an intention-to-treat (ITT) to test the effectiveness of eTRIP 2.0 rather than the effectiveness of intervention assignment as retention in weight management programs has been shown to affect the effectiveness of such programs. [39] Group differences on outcome measures were analyzed at week 12 (to test for app effectiveness) and week 24 (to test for app effectiveness sustainability) using independent sample t-test. Group×time interaction on primary and secondary outcomes were assessed using Generalised Estimating Equations (GEE) to account for repeated measures correlations. Predictors of weight were analysed using multiple linear regression. All statistical analyses were conducted based on two-sided hypotheses at 0.05 level of significance.

Results

Baseline characteristics

302 participants were assessed for eligibility with 137 of them excluded with reasons (Figure 1). A total of 165 participants were recruited from 14 Nov 2023 to 27 March 2024 (Figure 1). At baseline, the mean age, weight, BMI, waist circumference and BRI of the participants were 25.9 ± 4.11 years old, 76.8 ± 12.9 kg, 27.2 ± 3.55 kg/m^2, 87.1 ± 8.80 cm and 3.76 ± 0.95. According to the Asian BMI cut-off scores recommended by the World Health Organization, most of the participants were classified as overweight (63%).[40] The sociodemographic characteristics, baseline anthropometric and psychological construct measures are shown in Tables 1 and 2 respectively. As this was a study on young adults in a developed country aged 21 to 35 years old, our sample comprised mostly of participants who were single (97%), had a university education (69.1%), employed full-time (28.5%) and earning a per capita household income of Singapore $5,001 to 10,000. Only 17% and 46.1% of the participants had experience with using weight loss apps and smartwatches respectively. There was a slightly higher representation of Chinese (84.8%) in our sample as compared to our national demographic of 75.6%. [41] There were no significant differences between the participants who completed and did not complete the study (Appendix 3) and no significant baseline differences between the participants in the intervention and control group (Tables 1 and 2). The trial ended according to the funding timeline.



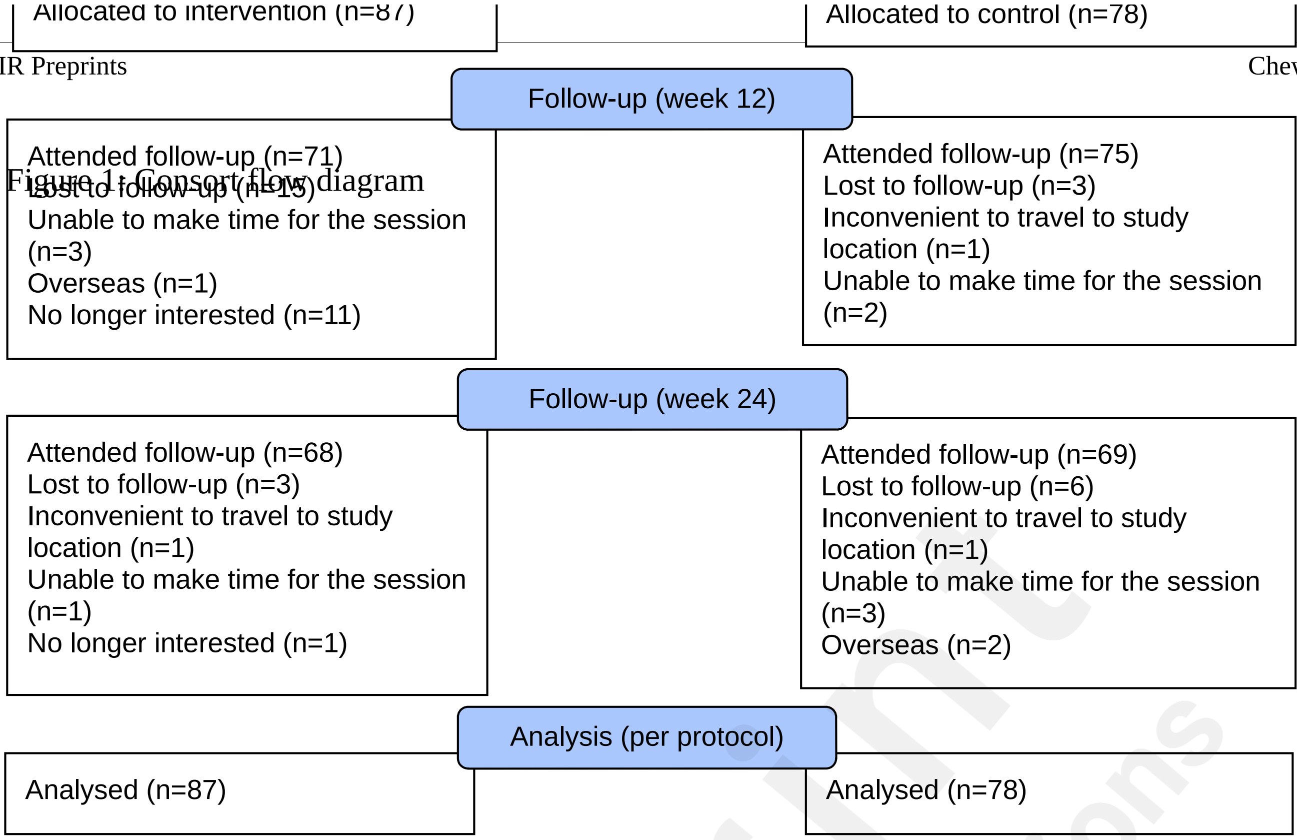


Figure 1: Consort flow diagram

Table 1: Sociodemographic characteristics, experience with using apps and smartwatches of the 165 participants who completed the study and group differences between the intervention and control groups.

Characteristics	**Mean ± SD / Frequency (%)**			**Test-statistic, p-value**
	All (N=165)	**Intervention group (n=87)**	**Control group (n=78)**	
Age, years	25.9 ± 4.11	26.3 ± 4.29	25.5 ± 3.87	[a]1.16, 0.25
Sex				[b]0.10, 0.75
Males	91 (55.2)	49 (56.3)	42 (53.8)	
Females	74 (44.8)	38 (43.7)	36 (46.2)	
Race				[b]0.37, 0.95
Chinese	140 (84.8)	74 (85.1)	66 (84.6)	
Indian	11 (6.7)	6 (6.9)	5 (6.4)	
Malay	9 (5.5)	4 (4.6)	5 (6.4)	
Others	5 (3.0)	3 (3.4)	2 (2.6)	
Marital status				[b]0.11, 0.74
Single	160 (97.0)	84 (96.6)	76 (97.4)	
Married	5 (3.0)	3 (3.4)	2 (2.6)	
Religion				[b]0.82, 0.98
Buddhism	40 (24.2)	20 (23)	20 (25.6)	
Christianity	46 (27.9)	23 (26.4)	23 (29.5)	
Hinduism	6 (3.6)	3 (3.4)	3 (3.8)	
Islam	10 (6.1)	5 (5.7)	5 (6.4)	
Free Thinker	58 (35.2)	33 (37.9)	25 (32.1)	
Others	5 (3.0)	3 (3.4)	2 (2.6)	
Highest education level				[b]0.51, 0.48
Pre-university	51 (30.9)	29 (33.3)	22 (28.2)	
University	114 (69.1)	58 (66.7)	56 (71.8)	
Per capita household income (S$/month)				[b]1.1, 0.90
<1,000	14 (8.5)	8 (9.2)	6 (7.7)	
1,000 – 3,000	38 (23.0)	19 (21.8)	19 (24.4)	
3,001 – 5,000	40 (24.2)	21 (24.1)	19 (24.4)	
5,001 – 10,000	47 (28.5)	27 (31)	20 (25.6)	
>10,000	26 (15.8)	12 (13.8)	14 (17.9)	
Employment				[b]0.72, 0.70
Full-time	97 (58.8)	51 (58.6)	46 (59.0)	
Part-time	14 (8.5)	6 (6.9)	8 (10.3)	
Unemployed	54 (32.7)	30 (34.5)	24 (30.8)	
Experienced using weight loss apps				[b]0.86, 0.35
Yes	28 (17.0)	17 (19.5)	11 (14.1)	
No	137 (83.0)	70 (80.5)	67 (85.9)	
Apps used				
MyFitnessPal	18 (50.0)	-	-	
Fitness Tracker	2 (5.6)	-	-	
LumiHealth	2 (5.6)	-	-	
Calorie counter	1 (2.8)	-	-	
Fastic	1 (2.8)	-	-	
Healthify	1 (2.8)	-	-	
Home Fitness for weight loss	1 (2.8)	-	-	
Joggo	1 (2.8)	-	-	
Lifesum	1 (2.8)	-	-	
LoseIt	1 (2.8)	-	-	
Madfit	1 (2.8)	-	-	
My Diet Coach	1 (2.8)	-	-	
National Steps Challenge	1 (2.8)	-	-	
Noom	1 (2.8)	-	-	
SMARTWOD	1 (2.8)	-	-	
Weightfit	1 (2.8)	-	-	

Zero for Intermittent Fasting	1 (2.8)	-	-	
Experienced using smartwatches				[b]0.08, 0.77
Yes	76 (46.1)	41 (47.1)	35 (44.9)	
No	89 (53.9)	46 (52.9)	78 (55.1)	
Smartwatches used				
Apple smartwatch	31 (40.3)	-	-	
Fitbit	13 (16.9)	-	-	
Garmin	9 (11.7)	-	-	
Tracker for National Steps Challenge	7 (9.1)	-	-	
Samsung watch	6 (7.8)	-	-	
Huawei watch	3 (3.9)	-	-	
Polar	2 (2.6)	-	-	
Actxa Tempo 4C	1 (1.3)	-	-	
Amazfit Bip	1 (1.3)	-	-	
Haylou Solar	1 (1.3)	-	-	
Pebble time 2	1 (1.3)	-	-	
Titan smartwatch	1 (1.3)	-	-	
Xiaomi	1 (1.3)	-	-	

Notes: SD=standard deviation; IQR=interquartile range; BMI=Body Mass Index (kg/m^2); ABSI= A Body Shape Index (ABSI); BRI=Body Roundness Index; [a]t-test; [b]X^2-test; degrees of freedom for [a]t- and [b]X^2-test=163; $p<0.05$*; $p<0.01$**; $p<0.001$***

Table 2: Baseline anthropometric and psychological construct measures of the 165 participants who completed the study and group differences between the intervention and control groups.

Characteristics	Mean ± SD / Frequency (%)			Test-statistic, p-value
	All (N=165)	Intervention group (n=87)	Control group (n=78)	
Anthropometric measures				
Weight, kg	76.8 ± 12.9	77.0 ± 13.7	76.7 ± 12.0	0.15, 0.88
Height, cm	168 ± 9.07	168 ± 8.84	168 ± 9.39	0.05, 0.96
BMI, kg/m^2	27.2 ± 3.55	27.2 ± 3.73	27.2 ± 3.36	0.03, 0.98
BMI classifications				
Overweight (23.0-27.4kg/m^2; moderate risk)	104 (63)	56 (64.4)	48 (61.5)	
Obese I (27.5-32.4kg/m^2; high risk)	47 (27.9)	25 (28.7)	21 (26.9)	
Obese II (32.5-37.4kg/m^2; very high risk)	11 (6.7)	3 (3.4)	8 (10.3)	
Obese III (≥37.4kg/m^2; very high risk)	4 (2.4)	3 (3.4)	1 (1.3)	
Waist circumference, cm	87.13 ± 8.80	87.75 ± 8.9	86.43 ± 8.69	0.2, 0.84
Body fat mass, kg	22.84 ± 8.16	22.82 ± 8.3	22.87 ± 8.05	0.74, 0.46
Body fat %	29.71 ± 8.65	29.6 ± 8.6	29.82 ± 8.77	0.08, 0.94
Skeletal Muscle Mass, kg	30.31 ± 6.65	30.39 ± 6.9	30.22 ± 6.4	1.7, 0.09
Basal Metabolic rate, kcal	1535.93 ± 234.85	1539.45 ± 243.32	1532 ± 226.55	1.06, 0.29
Waist-Hip Ratio	0.91 ± 0.04	0.91 ± 0.04	0.9 ± 0.03	0.96, 0.34
Visceral fat level	9.56 ± 3.91	9.59 ± 3.98	9.54 ± 3.86	-0.04, 0.97
BRI	3.76 ± 0.95	3.83 ± 0.99	3.68 ± 0.9	0.16, 0.87
Psychological constructs				
Nutrition knowledge (GNKQ-R)	61.5 ± 9.1	61.61 ± 9.83	61.45 ± 8.28	0.11, 0.91
Psychological flexibility (AAQW)	80.5 ± 21.0	81.79 ± 21.73	79.14 ± 20.1	0.81, 0.42
Eating phenotypes (TFEQ)				
Uncontrolled eating	47.4 ± 22.1	48.49 ± 22.04	46.2 ± 22.27	0.66, 0.51
Cognitive restraint	45.0 ± 19.5	44.06 ± 19.77	46.01 ± 19.31	-0.64, 0.52
Emotional eating	45.8 ± 30.2	46.49 ± 30.29	45.01 ± 30.28	0.31, 0.76
Eating self-regulation (SREBQ)	2.96 ± 0.57	2.89 ± 0.59	3.04 ± 0.55	-1.72, 0.09
Overeating habit (SRBAI)	3.63 ± 1.70	3.71 ± 1.69	3.54 ± 1.71	0.62, 0.53
Time perspective (CFC-6)	4.3 ± 1.06	4.31 ± 1.11	4.38 ± 1.02	-0.42, 0.68
Immediate thinking	3.89 ± 1.53	3.91 ± 1.57	3.86 ± 1.5	0.2, 0.84
Future thinking	4.79 ± 1.11	4.7 ± 1.23	4.89 ± 0.96	-1.09, 0.28
Anxiety (GAD-2)	2.26 ± 1.84	2.32 ± 1.88	2.19 ± 1.81	0.45, 0.65
Depression (PHQ-2)	1.61 ± 1.70	1.8 ± 1.68	1.38 ± 1.7	1.6, 0.11

Notes: SD=standard deviation; GNKQ-R=General Nutrition Knowledge Question-revised; AAQW=The Acceptance and Active Questionnaire for Weight-Related Difficulties; TFEQ=The Three-Factor Eating Questionnaire; SREBQ=Self-regulation of Eating Behaviour Questionnaire; SRBAI=Self-Report Behavioural Automaticity Index; CFC-6=Consideration of Future Consequences Scale 6-item; GAD-2=Generalized Anxiety Disorder 2-item; PHQ-2=Patient Health Questionnaire 2-item; degrees of freedom for [a]t- and [b]X^2-test=163; p<0.05*; p<0.01**; p<0.001***; BMI classification was derived from the recommended Asian cut-off scores.

Anthropometric changes

Anthropometric changes are detailed in Table 3 and Figure 2. Mean differences between the two groups at weeks 0, 12 and 24 for weight as our primary outcome were 0.29 kg (95% CI -3.69 kg to 4.28 kg), -1.76 kg (95% CI -5.96 kg to 2.43kg), -1.6 kg (95% CI -5.92 kg to 2.65 kg. The minimum and maximum among of weight change ranged from -13.3kg to 9kg. From weeks 0 to 12, significantly higher improvements of small-to-medium effect sizes were observed in the intervention compared to control group for weight (-0.89 kg, 95% CI -1.51 kg to -0.27 kg, p=0.005), BMI (-0.32 kg/m^2, 95% CI -0.55 kg/m^2 to -0.10 kg/m^2, p=0.005), waist circumference (-1.50cm, 95% CI -2.80 cm to -0.19cm, p=0.03), waist-hip ratio (-0.01, 95% CI -0.011 to <0.001, p=0.04) and BRI (-0.18, 95% CI -0.34 to -0.02, p=0.02). No significant differences were found in anthropometric change between the two groups from weeks 12 to 24 (when app access was ceased) and from weeks 0 to 24. Similarly, significant group￼time interactions were found at week 12 but not at week 24.

Table 3: Mean differences and group time interaction on anthropometric and psychological constructs changes between intervention and control group at from week 0-12, week 12-24 and week 0-24.

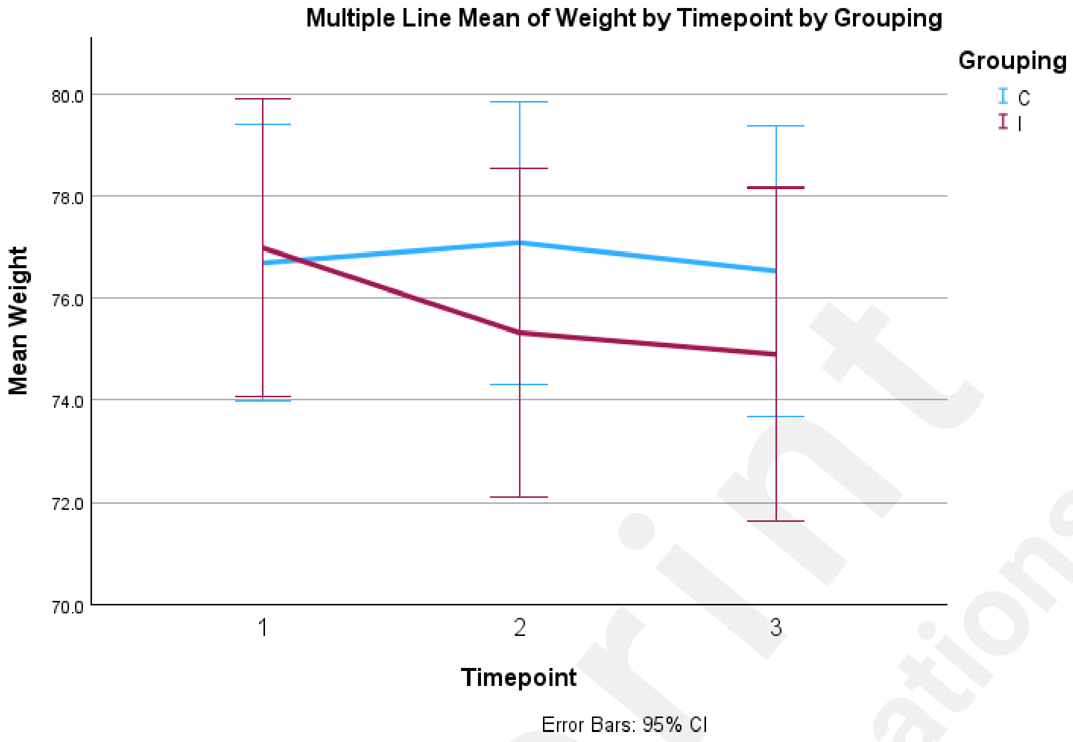
	Intervention group mean ± SD (n=71)	Control group mean ± SD (n=75)	Mean difference (95% CI)	t-value, df	p-value	Group time interaction	d (95% CI)
Anthropometric changes (week 0-12)							
Weight, kg	-0.64 ± 2.11	0.25 ± 1.67	-0.89 (-1.51, -0.27)	-2.82, 144	0.005**	0.004**	-0.47 (-0.80, -0.14)
BMI, kg/m^2	-0.24 ± 0.76	0.09 ± 0.59	-0.32 (-0.55, -0.10)	-2.88, 144	0.005**	0.003**	-0.48 (-0.81, -0.15)
Waist circumference, cm	-1.62 ± 3.84	-0.12 ± 4.10	-1.5 (-2.80, -0.19)	-2.27, 144	0.03*	0.02*	-0.38 (-0.70, -0.05)
Body fat mass, kg	-0.55 ± 2.07	-0.13 ± 1.70	-0.42 (-1.04, 0.20)	-1.35, 144	0.18	0.16	-0.22 (-0.55, 0.10)
Body fat %, %	-0.46 ± 2.21	-0.26 ± 1.86	-0.2 (-0.87, 0.46)	-0.60, 144	0.55	0.53	-0.1 (-0.42, 0.23)
Skeletal muscle mass, kg	-0.01 ± 0.87	0.22 ± 0.86	-0.24 (-0.52, 0.05)	-1.65, 144	0.10	0.09	-0.27 (-0.60, 0.05)
Basal metabolic rate	-1.87 ± 31.44	8.09 ± 31.11	-9.97 (-20.20, 0.27)	-1.93, 144	0.06	0.05	-0.32 (-0.65, 0.01)
Waist-Hip Ratio	-0.004 ± 0.016	0.002 ± 0.017	-0.01 (-0.011, <0.001)	-2.13, 144	0.04*	0.03*	-0.35 (-0.68, -0.03)
Visceral fat level	-0.30 ± 1.02	-0.01 ± 0.99	-0.28 (-0.61, 0.05)	-1.70, 144	0.09	0.08	-0.28 (-0.61, 0.05)
BRI	-0.17 ± 0.45	0.01 ± 0.50	-0.18 (-0.34, -0.02)	-2.27, 144	0.02*	0.02*	-0.38 (-0.70, -0.05)
Psychological constructs changes (week 0-12)							
Nutrition knowledge	1.33 ± 5.76	1.16 ± 5.59	0.18 (-1.68, 2.04)	-0.19, 144	0.85	0.85	0.031 (-0.29, 0.36)
Dietary recommendations	-0.08 ± 1.89	0.09 ± 2.47	-0.18 (-0.90, 0.54)	-0.49, 144	0.63	-	-0.08 (-0.41, 0.24)
Food groups	0.55 ± 3.68	0.77 ± 3.16	-0.22 (-1.34, 0.90)	-0.40, 144	0.69	-	-0.07 (-0.39, 0.26)
Food choices	0.23 ± 1.59	0.39 ± 1.63	-0.16 (-0.69, 0.36)	-0.61, 144	0.55	-	-0.1 (-0.43, 0.23)
Food labels	0.14 ± 0.83	0.00 ± 0.82	0.14 (-0.13, 0.41)	1.03, 144	0.31	-	0.17 (-0.16, 0.50)
Diet, disease and weight association	0.51 ± 2.15	-0.09 ± 2.62	0.6 (-0.19, 1.39)	1.51, 144	0.13	-	0.25 (-0.08, 0.57)
Perceived health	-0.10 ± 0.66	-0.01 ± 0.63	-0.09 (-0.30, 0.13)	-0.80, 143	0.43	0.08	-0.13 (-0.46, 0.19)
Psychological flexibility	-3.75 ± 12.16	-0.44 ± 12.84	-3.31 (-7.40, 0.79)	-1.60, 144	0.11	0.08	-0.26 (-0.59, 0.06)
Eating phenotypes							()
Uncontrolled eating	-1.10 ± 14.53	-0.05 ± 15.09	-1.05 (-5.90, 3.80)	-0.43, 144	0.67	0.62	-0.07 (-0.40, 0.25)
Cognitive restraint	5.24 ± 17.44	3.26 ± 14.95	1.98 (-3.32, 7.29)	0.74, 144	0.46	0.53	0.12 (-0.20, 0.45)
Emotional eating	3.13 ± 18.61	2.67 ± 16.83	0.46 (-5.33, 6.26)	0.16, 144	0.88	0.88	0.03 (-0.30, 0.35)
Overeating habit	-0.19 ± 1.46	0.08 ± 1.38	-0.27 (-0.73, 0.19)	-1.15, 144	0.25	0.25	-0.19 (-0.52, 0.14)
Eating self-regulation	0.03 ± 0.55	-0.06 ± 0.42	0.09 (-0.07, 0.25)	1.08, 144	0.28	0.23	0.18 (-0.15, 0.50)
Time perspective	0.04 ± 0.75	0.06 ± 0.81	-0.02 (-0.28, 0.24)	-0.16, 144	0.88	0.93	-0.03 (-0.35, 0.30)
Immediate thinking	-0.0047 ± 1.22	0.06 ± 1.30	-0.07 (-0.48, 0.35)	-0.32, 144	0.75	-	-0.05 (-0.38, 0.27)
Future thinking	0.08 ± 1.11	0.05 ± 1.07	0.03 (-0.33, 0.38)	0.15, 144	0.89	-	0.02 (-0.30, 0.35)
Anxiety	0.00 ± 1.59	-0.28 ± 1.70	0.28 (-0.26, 0.82)	1.03, 144	0.31	0.42	0.17 (-0.16, 0.50)
Depression	-0.27 ± 1.25	0.25 ± 1.25	-0.52 (-0.93, -0.11)	-2.51, 144	0.01*	0.008**	-0.42 (-0.74, -0.09)

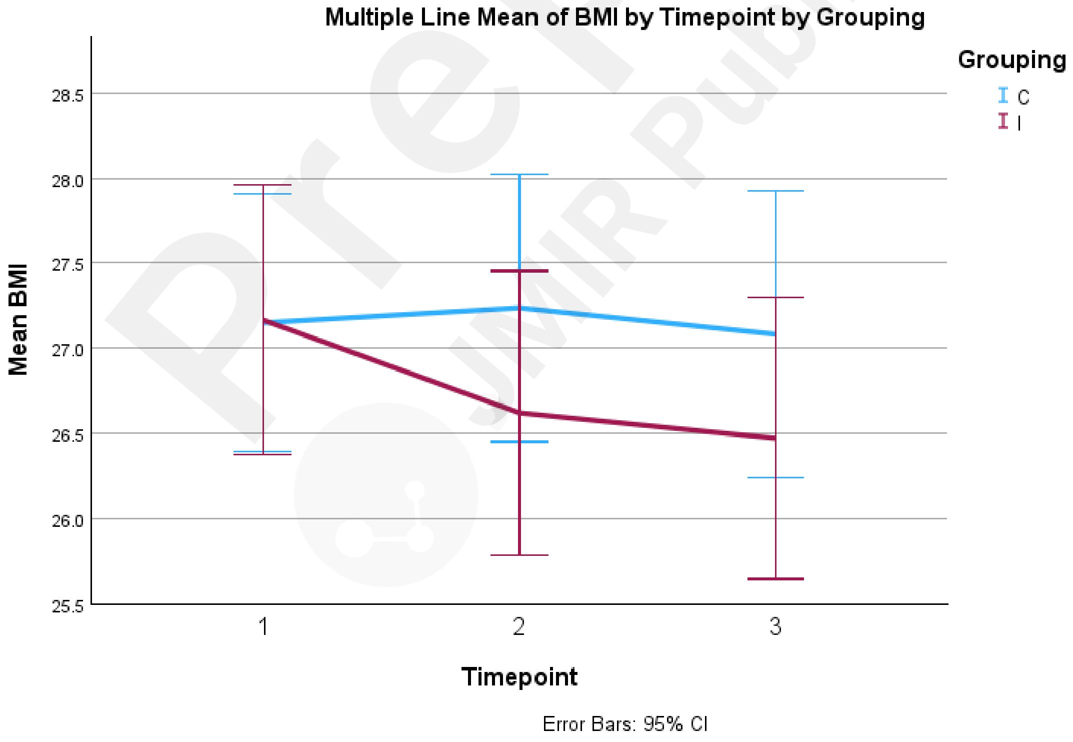
	Intervention group mean ± SD (n=68)	**Control group mean ± SD (n=70)**	**Mean difference (95% CI)**	**t-value, df**	**p-value**	**[a]Group × time interaction p-value**	d (95% CI)
Anthropometric measures (week 12-24)							
Weight, kg	-0.36 ± 2.31	-0.55 ± 2.31	0.19 (-0.59 ± 0.97)	0.49, 136	0.63	0.13	0.08 (-0.25, 0.42)
BMI, kg/m^2	-0.13 ± 0.82	-0.19 ± 0.81	0.06 (-0.22 ± 0.33)	0.41, 136	0.69	0.10	0.07 (-0.26, 0.40)
Waist circumference, cm	-1.02 ± 3.25	-1.11 ± 3.59	0.09 (-1.06 ± 1.24)	0.16, 136	0.88	0.07	0.03 (-0.31, 0.36)
Body fat mass, kg	-0.27 ± 2.09	-0.15 ± 2.03	-0.12 (-0.81 ± 0.57)	-0.34, 136	0.74	0.18	-0.06 (-0.39, 0.28)
Body fat %, %	-0.18 ± 1.98	0.01 ± 2.24	-0.19 (-0.91 ± 0.52)	-0.54, 136	0.59	0.31	-0.09 (-0.43, 0.24)
Skeletal muscle mass, kg	-0.06 ± 0.79	-0.25 ± 0.99	0.19 (-0.12 ± 0.49)	1.21, 136	0.23	0.67	0.21 (-0.13, 0.54)
Basal metabolic rate	-2.21 ± 28.61	-8.81 ± 35.5	6.61 (-4.26 ± 17.48)	1.20, 136	0.23	0.50	0.2 (-0.13, 0.54)
Waist-Hip Ratio	0.00 ± 0.02	0.00 ± 0.01	-0.0008 (-0.007 ± 0.005)	-0.30, 136	0.77	0.03	-0.05 (-0.38, 0.28)
Visceral fat level	-0.15 ± 1.19	-0.07 ± 1.09	-0.080 (-0.46 ± 0.31)	-0.39, 136	0.70	0.08	-0.07 (-0.40, 0.27)
BRI	-0.12 ± 0.37	-0.13 ± 0.45	0.0003 (-0.14 ± 0.14)	0.04, 136	0.97	0.06	0.01 (-0.33, 0.34)
	Intervention group mean ± SD (n=68)	**Control group mean ± SD (n=69)**	**Mean difference (95% CI)**	**t-value, df**	**p-value**	**Group × time interaction**	d (95% CI)
Psychological constructs (week 12-24)							
Nutrition knowledge (GNKQ-R)	0.22 ± 5.77	0.75 ± 5.91	-0.53 (-2.51, 1.44)	-0.53, 135	0.59	0.75	-0.09 (-0.43, 0.24)
Dietary recommendations	0.41 ± 2.25	0.17 ± 1.96	0.24 (-0.48, 0.95)	0.66, 135	0.51	-	0.11 (-0.22, 0.45)
Food groups	-0.04 ± 2.63	0.07 ± 3.50	-0.12 (-1.16, 0.93)	-0.22, 126.2	0.83	-	-0.04 (-0.37, 0.30)
Food choices	0.13 ± 1.89	0.13 ± 1.37	0.0019 (-0.56, 0.56)	0.01, 135	1.00	-	0.001 (-0.33, 0.34)
Food labels	0.00 ± 0.77	0.09 ± 0.78	-0.09 (-0.35, 0.18)	-0.66, 135	0.51	-	-0.11 (-0.45, 0.22)
Diet, disease and weight association	-0.29 ± 2.28	0.29 ± 2.40	-0.57 (-1.36, 0.22)	-1.43, 135	0.16	-	-0.24 (-0.58, 0.09)
Perceived health	0.18 ± 0.60	-0.06 ± 0.54	0.24 (0.04, 0.43)	2.40, 134	0.02*	0.08	0.41 (0.07, 0.75)
Psychological flexibility	-0.28 ± 11.15	-0.54 ± 13.70	0.26 (-3.97, 4.48)	0.12, 135	0.90	0.14	0.02 (-0.31, 0.36)
Eating phenotypes							
Uncontrolled eating	-1.25 ± 13.12	-3.06 ± 15.92	1.81 (-3.13, 6.74)	0.72, 135	0.47	0.88	0.12 (-0.21, 0.46)
Cognitive restraint	-3.10 ± 15.58	-0.72 ± 16.19	-2.38 (-7.75, 2.99)	-0.88, 135	0.38	0.74	-0.15 (-0.49, 0.19)
Emotional eating	-1.14 ± 17.92	-0.16 ± 21.93	-0.98 (-7.76, 5.79)	-0.29, 135	0.78	0.87	-0.05 (-0.38, 0.29)
Overeating habit	0.13 ± 1.19	-0.23 ± 1.14	0.36 (-0.03, 0.75)	1.81, 135	0.07	0.71	0.31 (-0.03, 0.65)
Eating self-regulation	0.17 ± 0.57	0.003 ± 0.43	0.17 (-0.0027, 0.34)	1.95, 135	0.05*	0.001**	0.33 (-0.01, 0.67)
Time perspective	0.00 ± 0.80	-0.09 ± 0.79	0.09 (-0.18, 0.36)	0.66, 135	0.51	0.53	0.11 (-0.22, 0.45)
Immediate thinking	-0.01 ± 1.05	-0.03 ± 1.08	0.02 (-0.34, 0.38)	0.13, 135	0.90	-	0.02 (-0.31, 0.36)

Future thinking	0.01 ± 0.94	-0.14 ± 1.1	0.15 (-0.19, 0.50)	0.89, 135	0.38	-	0.15 (-0.18, 0.49)
Anxiety	-0.41 ± 1.57	-0.03 ± 1.63	-0.38 (-0.92, 0.16)	-1.40, 135	0.16	0.47	-0.24 (-0.58, 0.10)
Depression	-0.03 ± 1.50	-0.09 ± 1.47	0.06 (-0.44, 0.56)	0.23, 135	0.82	0.036*	0.04 (-0.30, 0.37)
	Intervention group mean ± SD (n=68)	**Control group mean ± SD (n=70)**	**Mean difference (95% CI)**	**t-value, df**	**p-value**	**Group time interaction**	**d (95% CI)**
Anthropometric measures (week 0-24)							
Weight change	-1.01 ± 3.07	-0.35 ± 2.66	-0.26 (-0.60, 0.09)	-1.37, 136	0.17	-	-0.23 (-0.57, 0.10)
BMI change	-0.37 ± 1.12	-0.11 ± 0.93	-1.42 (-3.07, 0.23)	-1.48, 136	0.14	-	-0.25 (-0.59, 0.08)
Waist circumference change	-2.70 ± 4.64	-1.28 ± 5.13	-0.49 (-1.33, 0.35)	-1.71, 136	0.09	-	-0.29 (-0.63, 0.05)
Body fat mass change	-0.86 ± 2.57	-0.37 ± 2.42	-0.33 (-1.15, 0.48)	-1.14, 136	0.26	-	-0.2 (-0.53, 0.14)
Body fat % change	-0.69 ± 2.38	-0.36 ± 2.46	-0.07 (-0.41, 0.27)	-0.81, 136	0.42	-	-0.14 (-0.47, 0.20)
Skeletal muscle mass change	-0.05 ± 1.02	0.02 ± 1.01	-3.94 (-16.03, 8.15)	-0.40, 136	0.69	-	-0.07 (-0.40, 0.27)
Basal metabolic rate change	-3.34 ± 36.21	0.60 ± 35.62	-0.01 (-0.01, 0.00)	-0.64, 136	0.52	-	-0.11 (-0.44, 0.22)
Waist-Hip Ratio change	-0.01 ± 0.02	0.00 ± 0.02	-0.31 (-0.74, 0.12)	-1.74, 136	0.08	-	-0.3 (-0.63, 0.04)
Visceral fat level change	-0.46 ± 1.27	-0.14 ± 1.29	0 (0.00, 0.00)	-1.43, 136	0.15	-	-0.24 (-0.58, 0.09)
BRI change	-0.30 ± 0.52	-0.12 ± 0.68	-0.26 (-0.60, 0.09)	-1.81, 136	0.07	-	-0.31 (-0.64, 0.03)
Psychological constructs (week 0-24)	**Intervention group mean ± SD (n=68)**	**Control group mean ± SD (n=69)**	**Mean difference (95% CI)**	**t-value, df**	**p-value**	-	**d (95% CI)**
Nutrition knowledge (GNKQ-R)	1.67 ± 6.76	2.04 ± 5.76	-0.37 (-2.49, 1.75)	-0.34, 135	0.73	-	-0.06 (-0.39, 0.28)
Dietary recommendations	0.35 ± 2.16	0.13 ± 2.66	0.22 (-0.60, 1.04)	0.54, 135	0.59	-	0.09 (-0.24, 0.43)
Food groups	0.57 ± 3.67	1.03 ± 3.53	-0.46 (-1.67, 0.76)	-0.74, 135	0.46	-	-0.13 (-0.46, 0.21)
Food choices	0.31 ± 1.89	0.61 ± 1.89	-0.3 (-0.94, 0.34)	-0.93, 135	0.36	-	-0.16 (-0.49, 0.18)
Food labels	0.15 ± 0.72	0.13 ± 0.77	0.02 (-0.23, 0.27)	0.13, 135	0.90	-	0.02 (-0.31, 0.36)
Diet, disease and weight association	0.29 ± 2.99	0.14 ± 2.20	0.15 (-0.64, 0.94)	0.374, 135	0.71	-	0.06 (-0.27, 0.40)
Perceived health	0.06 ± 0.67	-0.07 ± 0.61	0.13 (-0.08, 0.35)	1.21, 133	0.23	-	0.21 (-0.13, 0.55)
Psychological flexibility (AAQW)	-3.35 ± 13.06	-1.28 ± 15.17	-2.08 (-6.86, 2.71)	-0.86, 135	0.39	-	-0.15 (-0.48, 0.19)
Eating phenotypes (TFEQ)						-	
Uncontrolled eating	-1.74 ± 14.11	-2.47 ± 17.85	0.73 (-4.72, 6.17)	0.26, 135	0.79	-	0.05 (-0.29, 0.38)
Cognitive restraint	2.04 ± 14.33	2.25 ± 18.21	-0.21 (-5.75, 5.33)	-0.08, 135	0.94	-	-0.01 (-0.35, 0.32)

Emotional eating	1.80 ± 16.02	1.77 ± 21.27	0.03 (-6.34, 6.40)	0.01, 135	0.99	-	0.001 (-0.33, 0.34)
Overeating habit (SRBAI)	-0.03 ± 1.34	-0.11 ± 1.38	0.08 (-0.38, 0.54)	0.34, 135	0.73	-	0.06 (-0.28, 0.39)
Eating self-regulation (SREBQ)	0.18 ± 0.55	-0.06 ± 0.47	0.24 (0.06, 0.41)	2.72, 135	0.007*	-	0.47 (0.13, 0.80)
Time perspective (CFC-6)	0.04 ± 0.72	-0.03 ± 0.81	0.07 (-0.19, 0.33)	0.54, 135	0.59	-	0.09 (-0.24, 0.43)
Immediate thinking	-0.03 ± 1.27	-0.02 ± 1.16	-0.01 (-0.42, 0.41)	-0.03, 135	0.98	-	-0.004 (-0.34, 0.33)
Future thinking	0.12 ± 1.13	-0.03 ± 1.05	0.15 (-0.22, 0.52)	0.79, 135	0.43	-	0.13 (-0.20, 0.47)
Anxiety (GAD-2)	-0.34 ± 1.45	-0.26 ± 1.40	-0.08 (-0.56, 0.40)	-0.32, 135	0.75	-	-0.05 (-0.39, 0.28)
Depression (PHQ-2)	-0.26 ± 1.42	0.13 ± 1.44	-0.4 (-0.88, 0.09)	-1.61, 135	0.11	-	-0.28 (-0.61, 0.06)

Notes: d=Cohen's d effect size


Multiple Line Mean of Weight by Timepoint by Grouping
Grouping
C
I
Mean Weight
80.0
78.0
76.0
74.0
72.0
70.0
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of BMI by Timepoint by Grouping
Grouping
C
I
Mean BMI
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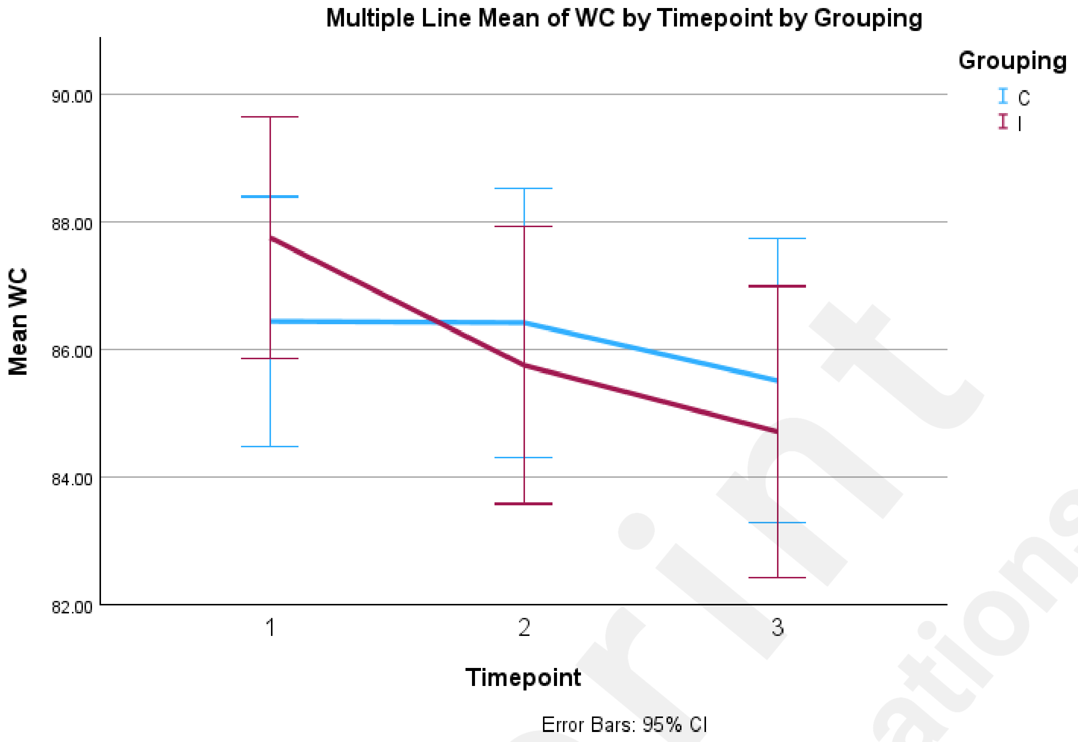
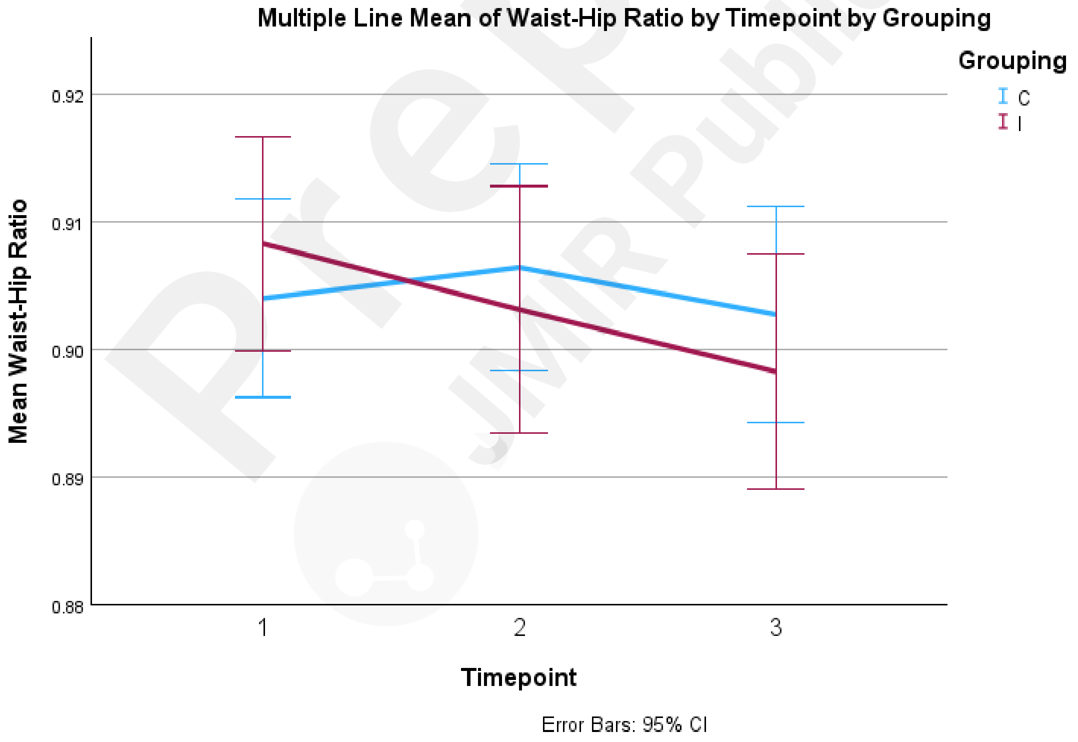
28.0
27.5
27.0
26.5
26.0
25.5
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of WC by Timepoint by Grouping
Grouping
C
I
Mean WC
90.00
88.00
86.00
84.00
82.00
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of Waist-Hip Ratio by Timepoint by Grouping
Grouping
C
I
Mean Waist-Hip Ratio
0.92
0.91
0.90
0.89
0.88
1
2
3
Timepoint
Error Bars: 95% CI

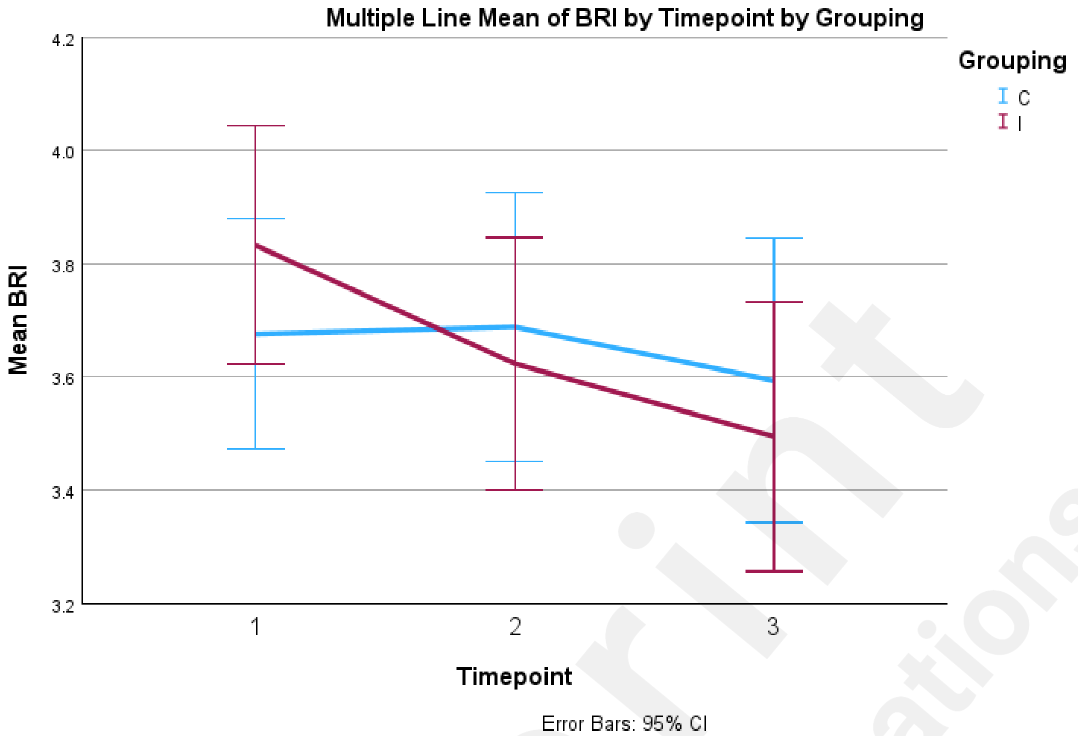
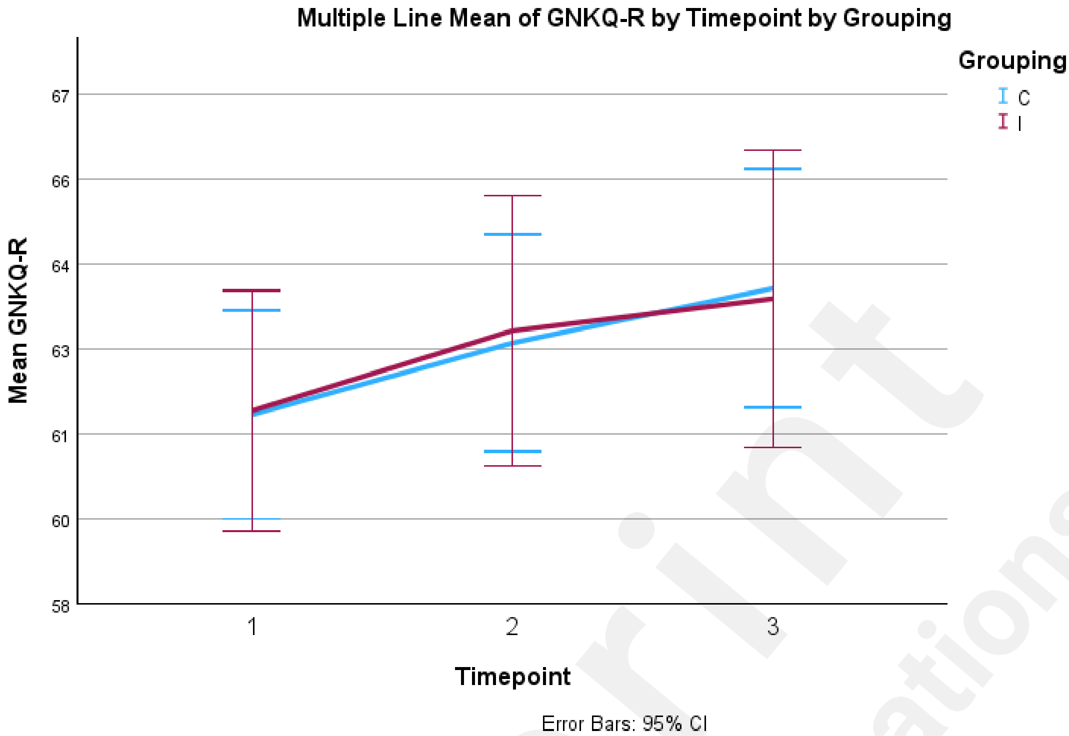


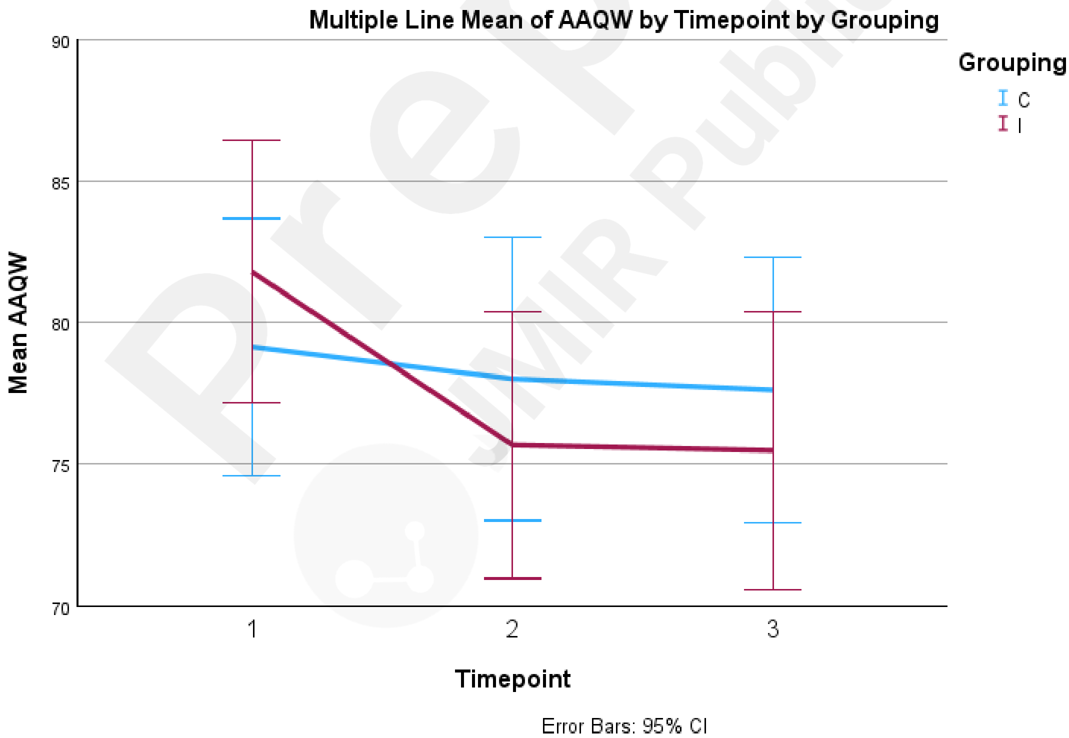
Figure 2: Graphics of the mean changes in weight, body mass index (BMI), waist circumference, waist-to-hip ratio and body roundness index (BRI) over weeks 0, 12 and 24.

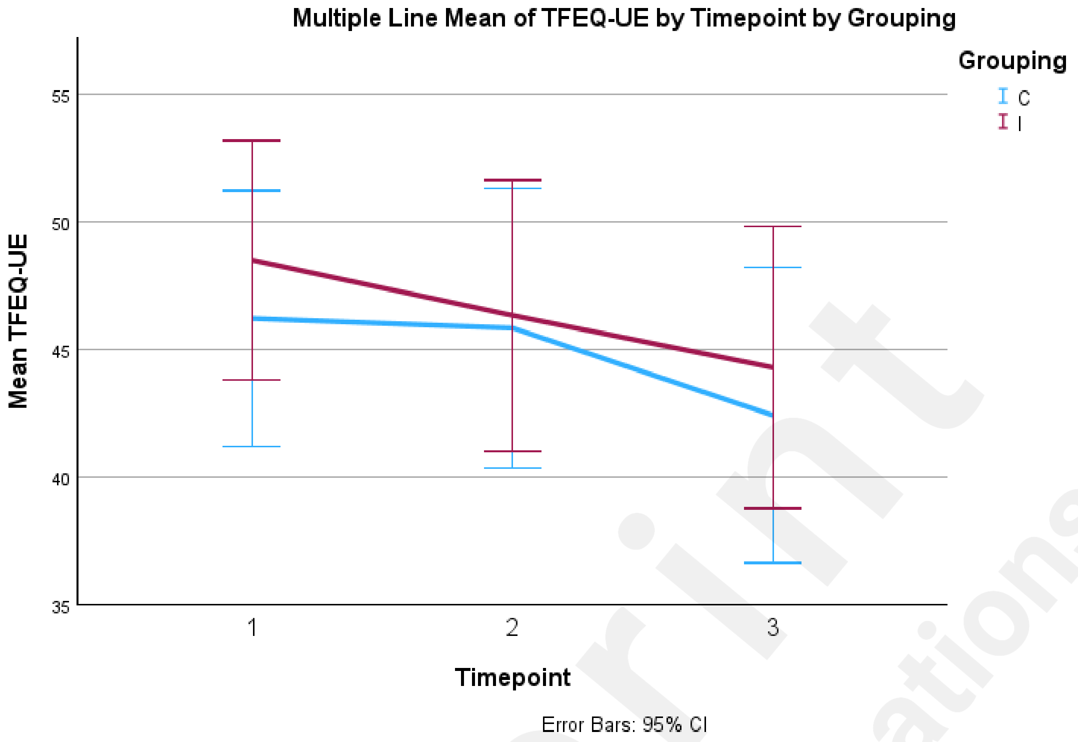
It is noteworthy that from weeks 0 to 12, there was an inverse trend in anthropometric changes between the two groups where mean anthropometric measurements improved in the intervention group while that of the control group worsened. From weeks 12 to 24, both groups experienced a general improvement in anthropometric measurements, potentially due to the motivational effect of the previous body composition analysis report that was given to the participants that encouraged both groups of participants to improve their anthropometric measurements. This was evident in the process evaluation that we had conducted through a feedback form at the end of the study.

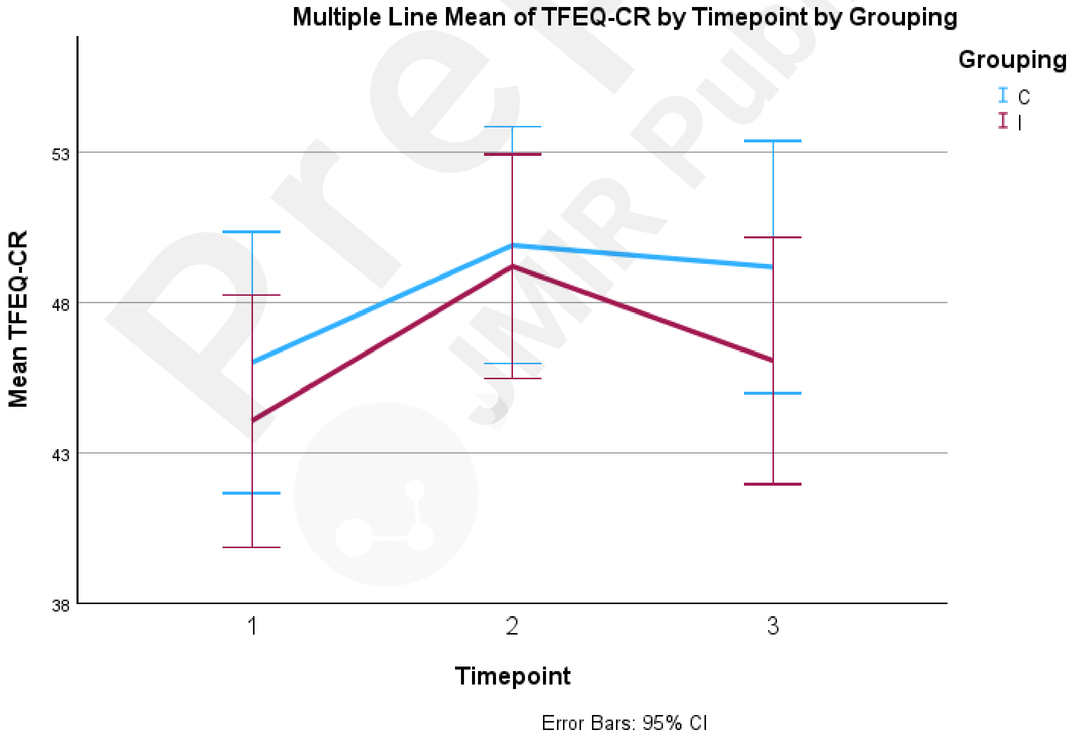
Psychological constructs changes

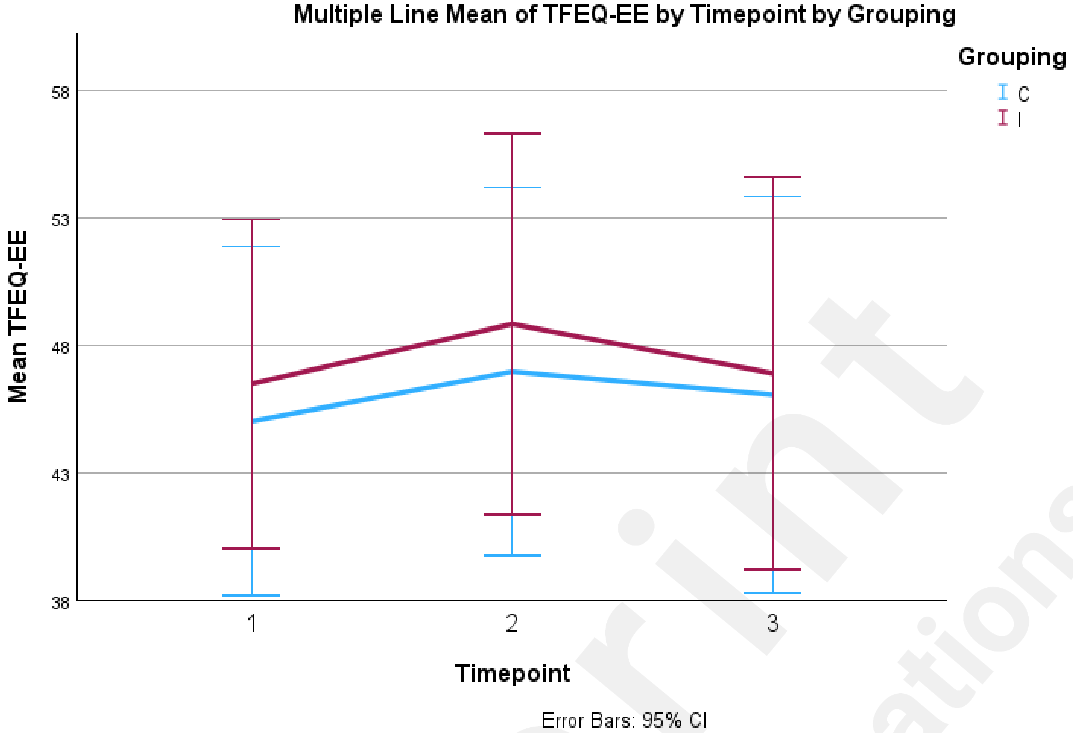
Psychological constructs changes are detailed in Table 3 and Figure 3. From weeks 0 to 12, we observed a general improvement in nutrition knowledge, psychological flexibility, uncontrolled eating, cognitive restraint, overeating habit, future-oriented thinking, and anxiety among both groups. Except for a significantly higher improvement in the intervention compared to control group for depression scores, no significant differences were observed between the two groups for other psychological constructs. From weeks 12 to 24, significantly higher improvements in perceived health and eating self-regulation were found in the intervention compared to control group while only the improvement in self-regulation remained statistically significant over the 24 weeks. Significant group×time interactions were found for the group differences that were statistically significant.


Multiple Line Mean of GNKQ-R by Timepoint by Grouping
Grouping
C
I
Mean GNKQ-R
67
66
64
63
61
60
58
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of AAQW by Timepoint by Grouping
Grouping
C
I
Mean AAQW
90
85
80
75
70
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of TFEQ-UE by Timepoint by Grouping
Grouping
C
I
Mean TFEQ-UE
55
50
45
40
35
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of TFEQ-CR by Timepoint by Grouping
Grouping
C
I
Mean TFEQ-CR
53
48
43
38
1
2
3
Timepoint
Error Bars: 95% CI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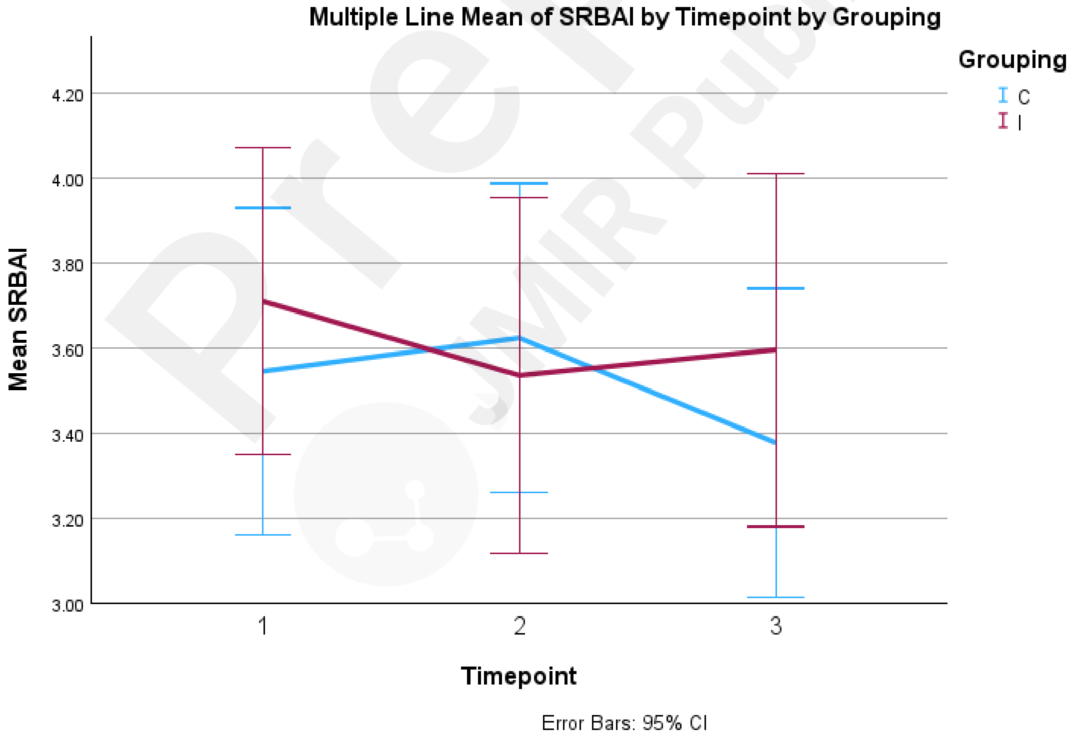
Grouping
C
I
Mean TFEQ-EE
58
53
48
43
38
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of SRBAI by Timepoint by Grouping
Grouping
C
I
Mean SRBAI
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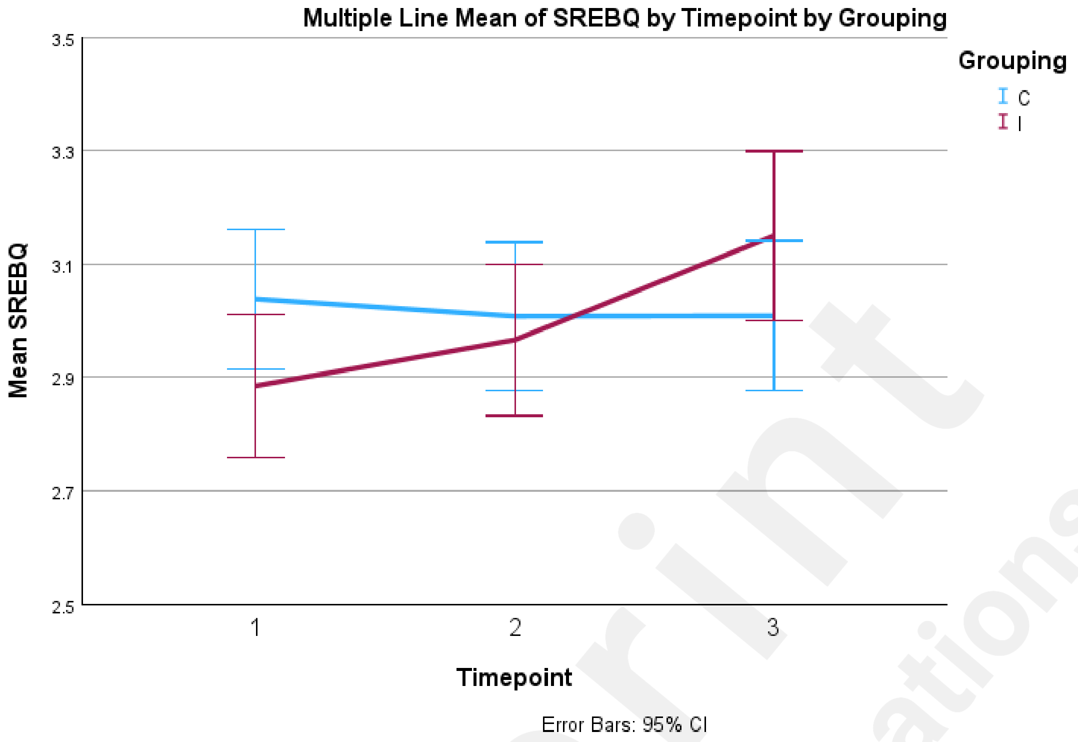
4.00
3.80
3.60
3.40
3.20
3.00
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of SREBQ by Timepoint by Grouping
Grouping
C
I
Mean SREBQ
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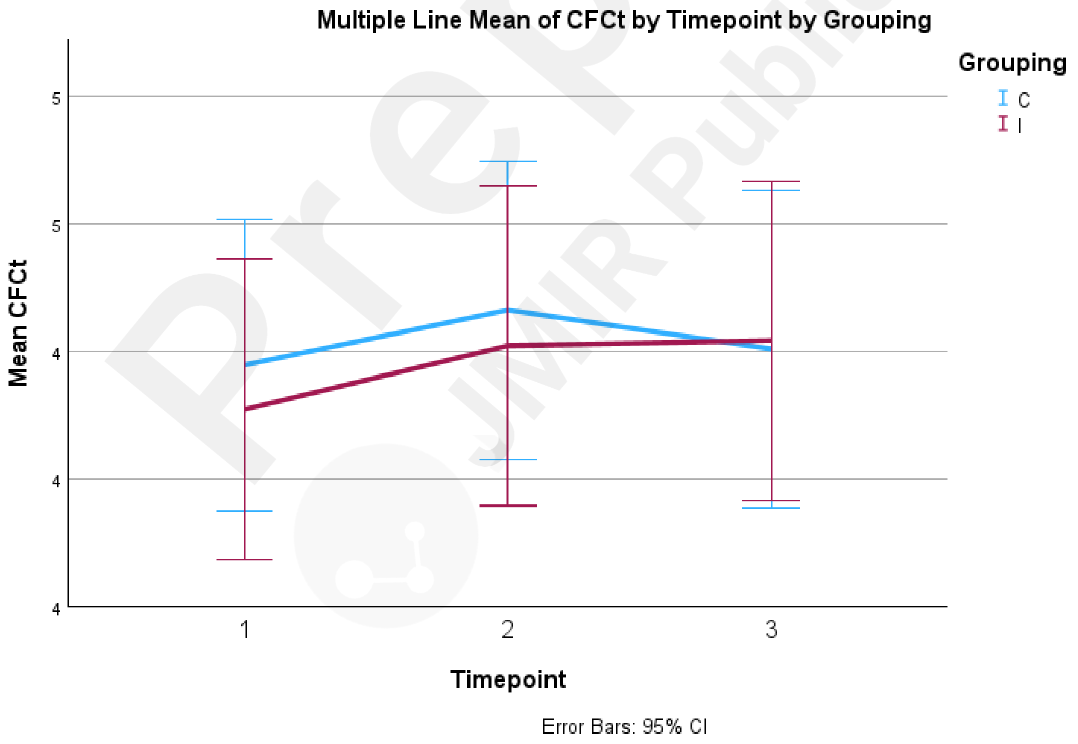
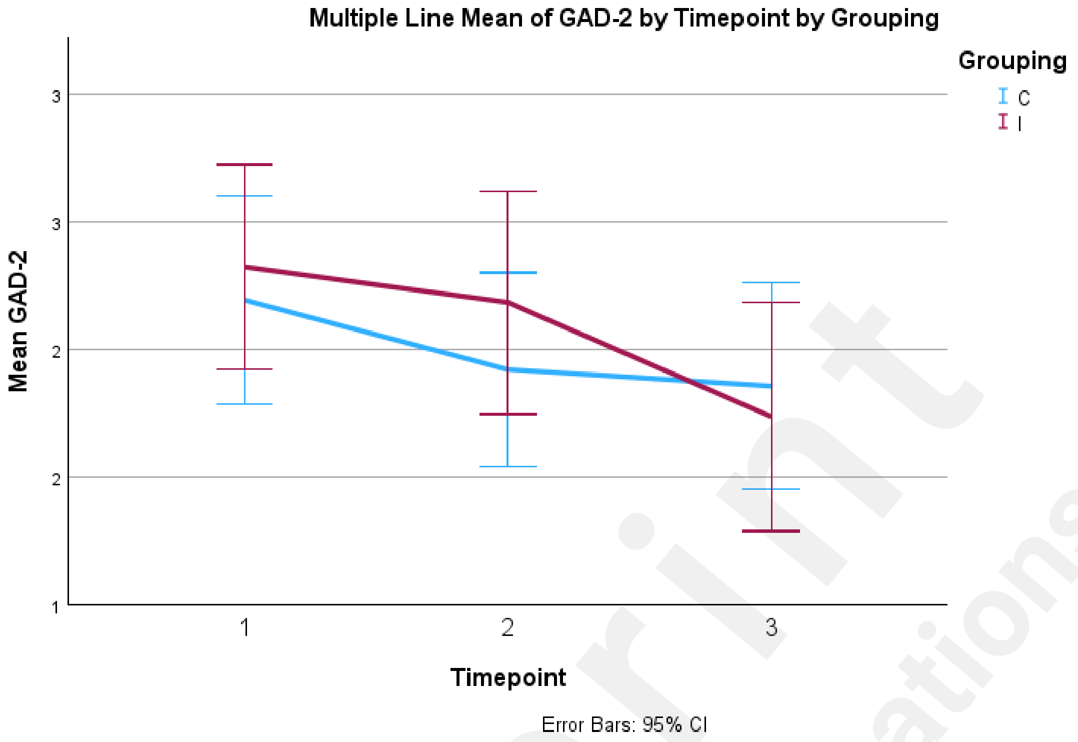
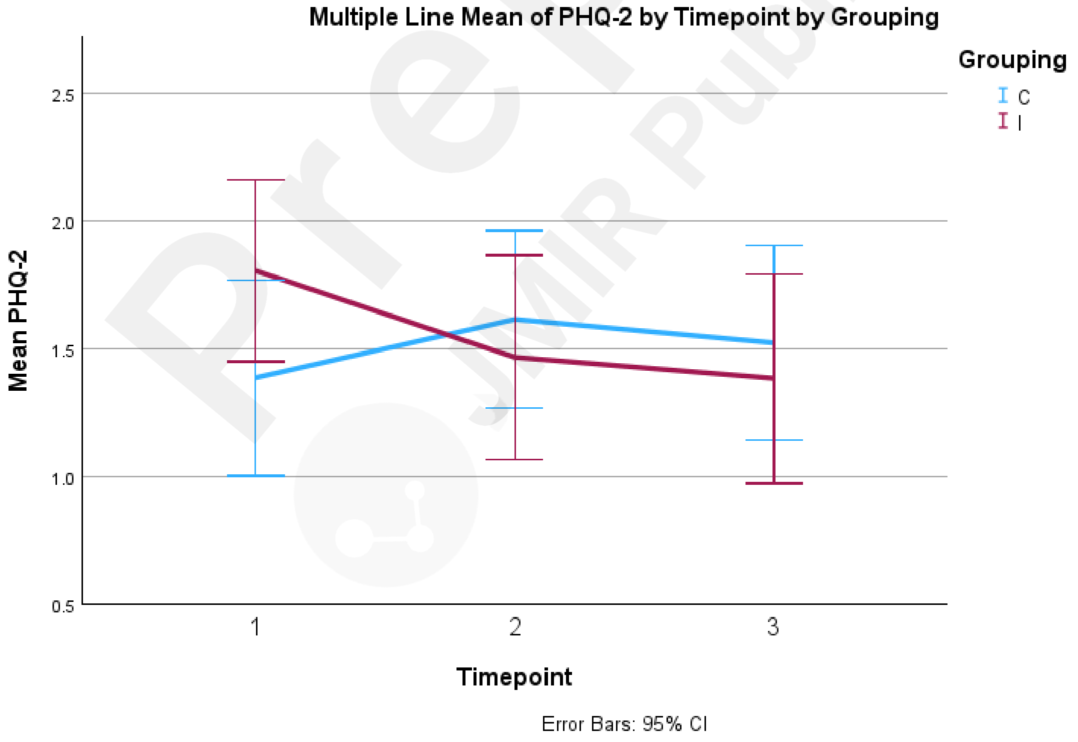
3.3
3.1
2.9
2.7
2.5
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of CFCt by Timepoint by Grouping
Grouping
C
I
Mean CFCt
5
5
4
4
4
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of GAD-2 by Timepoint by Grouping
Grouping
C
I
Mean GAD-2
3
3
2
2
1
1
2
3
Timepoint
Error Bars: 95% CI


Multiple Line Mean of PHQ-2 by Timepoint by Grouping
Grouping
C
I
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1.5
1.0
0.5
1
2
3
Timepoint
Error Bars: 95% CI

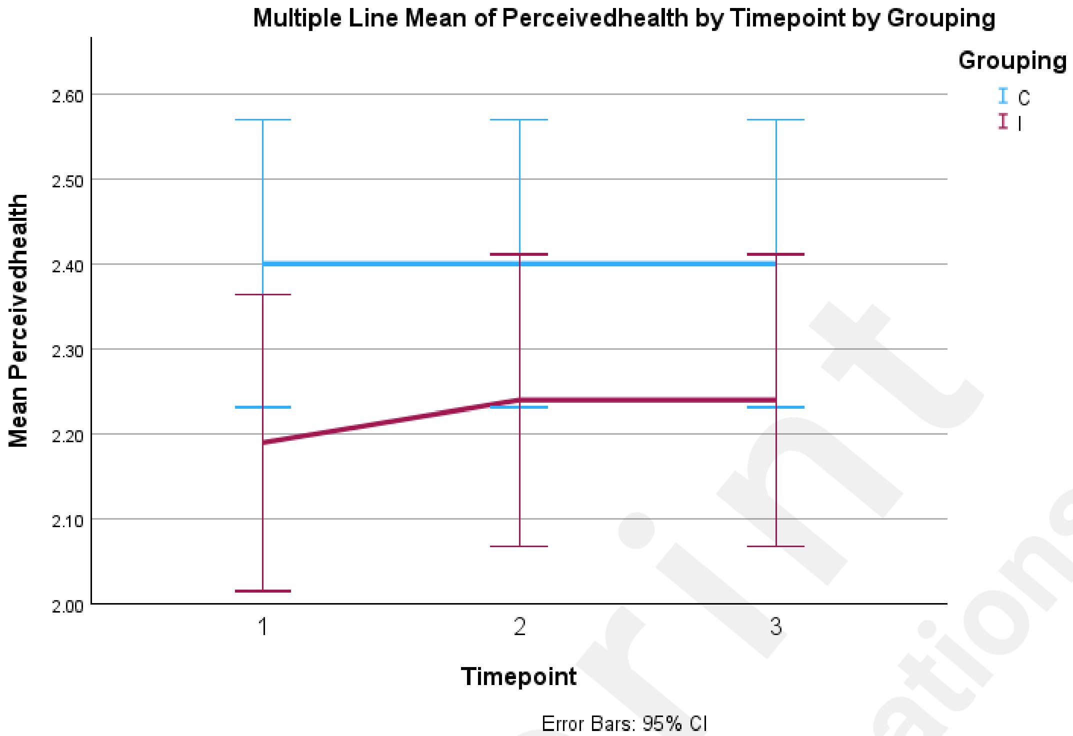

Figure 3: Graphics of the mean changes in psychological constructs over weeks 0, 12 and 24.

Changes in intention, perceptions and preferences for weight management

Detailed in Table 4. 83% to 97.2% of the participants had an intention to avoid tempting foods, intention to change eating habits to lose weight, intention to have a healthy diet and perceived the connection between a healthy diet and healthy weight across the 24 weeks although there were no significant differences between the groups. A slightly higher number of participants preferred to lose weight through physical activity over diet across the 24 weeks.

Table 4: Changes in intention, perceptions and preferences for weight management.

Additional questions	Question options	Frequency (%)					
		Week 0		Week 12		Week 24	
		Intervention group (n=87)	Control group (n=78)	Intervention group (n=71)	Control group (n=75)	Intervention group (n=68)	Control group (n=69)
Intention to avoid tempting foods	Yes	74 (85.1)	65 (83.3)	63 (88.7)	64 (85.3)	59 (86.8)	55 (79.7)
	No	13 (14.9)	13 (16.7)	8 (11.3)	11 (14.7)	9 (13.2)	14 (20.3)
Intention to change eating habits to lose weight	Yes	78 (89.7)	70 (89.7)	62 (87.3)	67 (89.3)	56 (82.4)	63 (91.3)
	No	9 (10.3)	8 (10.3)	9 (12.7)	8 (10.7)	12 (17.6)	6 (8.7)
Intention to have a healthy diet	Yes	81 (93.1)	73 (93.6)	70 (98.6)	72 (96)	64 (94.1)	65 (94.2)
	No	6 (6.9)	5 (6.4)	1 (1.4)	3 (0.4)	4 (5.9)	4 (5.8)
Perception of healthy diet leading to healthy weight	Yes	80 (92)	75 (96.2)	68 (95.8)	78 (98.7)	65 (95.6)	67 (97.1)
	No	7 (0.8)	3 (3.8)	3 (4.2)	1 (1.3)	3 (4.3)	2 (2.9)
Preference to control diet or increase physical activity to lose weight	Diet	42 (48.3)	33 (42.3)	31 (43.7)	30 (40.0)	35 (51.5)	32 (46.4)
	Physical activity	45 (51.7)	45 (57.7)	40 (56.3)	45 (60.0)	37 (48.5)	33 (53.6)
		Week 0 - 12		Week 12 - 24		Week 0 - 24	
		Intervention group (n=87)	Control group (n=78)	Intervention group (n=71)	Control group (n=75)	Intervention group (n=68)	Control group (n=69)
Intention to avoid tempting foods	Decreased	4 (5.6)	6 (8.0)	2 (2.9)	4 (5.8)	4 (5.9)	6 (8.7)
	Maintained	63 (88.7)	64 (85.3)	62 (91.2)	57 (82.6)	58 (85.3)	55 (79.7)
	Increased	4 (5.6)	5 (6.7)	4 (5.9)	8 (11.6)	6 (8.8)	8 (11.6)
Intention to change eating habits to lose weight	Decreased	2 (2.8)	2 (2.7)	1 (1.5)	6 (8.7)	1 (1.5)	7 (10.1)
	Maintained	65 (91.5)	71 (94.7)	63 (92.6)	58 (84.1)	60 (88.2)	57 (82.6)
	Increased	4 (5.6)	2 (2.7)	4 (5.9)	5 (7.2)	7 (10.3)	5 (7.2)
Intention to have a healthy diet	Decreased	3 (4.2)	4 (5.3)	0 (0.0)	1 (1.4)	2 (2.9)	4 (5.8)
	Maintained	68 (95.8)	69 (92.0)	65 (95.6)	65 (94.2)	64 (94.1)	62 (89.9)
	Increased	0 (0.0)	2 (2.7)	3 (4.4)	3 (4.3)	2 (2.9)	3 (4.3)
Perception of a	Decreased	3 (4.2)	3 (4.0)	1 (1.5)	1 (1.4)	2 (2.9)	3 (4.5)

link of healthy diet leading to healthy weight	Maintained	68 (95.8)	71 (94.7)	66 (97.1)	66 (95.7)	66 (97.1)	64 (92.8)
	Increased	0 (0.0)	1 (1.3)	1 (1.5)	2 (2.9)	0 (0.0)	2 (2.9)
Preference to control diet or increase physical activity to lose weight	Change from preferring increase in physical activity to control diet	8 (11.3)	12 (16.0)	12 (17.6)	11 (15.9)	15 (22.1)	13 (18.8)
	Remained the same	57 (80.3)	49 (65.3)	49 (72.1)	51 (73.9)	45 (66.2)	44 (63.8)
	Change from preferring to control diet to increase in physical activity	6 (8.5)	14 (18.7)	7 (10.3)	7 (10.1)	8 (11.8)	12 (17.4)

Note: Using chi-square tests, no significant differences were detected

Self-regulation and overeating habit as predictors of body weight

At week 24, self-regulation (B=3.08, t= 3.95, p=0.005) and overeating (B=6.11, t= 2.84, p<0.001) habit were found to be significant predictors that explained 10.7% of the variance in body weight at week 24, of which explainability increased to 31.6% after accounting for age and sex (Table 5).

Table 5: Multiple linear regression results on regression of body weight on self-regulation, overeating habit, age and sex at week 24.

Models		B	Std. Error	t	Sig.
1	SRBAI (wk24)	3.08	0.78	3.95	<.001
	SREBQ (wk24)	6.11	2.15	2.8	.005
2	SRBAI (wk24)	2.70	0.70	3.87	<.001
	SREBQ (wk24)	3.11	1.96	1.59	.115
	Age	0.130	0.221	.59	.556
	Sex	-11.9	1.9	-6.16	<.001

Discussion

In this study, we tested the effectiveness of a standalone behavioural change weight management app on changes in anthropometric and psychological construct outcomes using a RCT design as the gold standard to test for causal interventional effects. In general, the app was effective in improving anthropometric outcomes indicative of cardiometabolic risk including weight, BMI, waist circumference, waist-hip ratio and BRI and psychological constructs of depression, perceived health and eating self-regulation.

Improvements in anthropometric outcomes

Contrary to existing literature that observed no statistically significant body weight loss in standalone weight management apps, [42] we found a significantly higher amount of weight loss (-0.89kg) at week 12 among individuals who received the eTRIP app as compared to those in the control group. This could be due to the incorporation of self-regulation training, which seemed to have improved self-regulation based on the significantly higher self-regulation scores in the intervention group over time. Moreover, self-regulation and overeating habit were found to be independent predictors of body weight, which coincides with the TST that both factors are crucial in closing the intention-behaviour gap. [14] Similarly, another study showed that participants who received a 12-week psychoeducational intervention on weight management observed a 0.87 kg higher amount of weight loss compared to those in the control group. [43] Changes in self-regulation and automaticity of healthy behaviours were found to have mediated the relationship between group differences and weight loss. [43] Motivation has been shown to be one of the most challenging aspects for individuals attempting to self-manage their weight. [44] Incorporating of self-regulation training and the use of app-based social forum seem to help provide motivational support which is lacking in typical weight loss campaigns. [44] The adoption of food image recognition technology also helps to reduce the inconvenience associated with calorie counting which was seen as a barrier for users. [45] Therefore, our findings add to a dearth of evidence on the effectiveness of a standalone self-regulation weight loss on obesity management and the importance of incorporating self-regulation training in weight management programs.

While the eTRIP app improved anthropometric outcomes from weeks 0 to 12, it did not show a sustained effect when removed, as expected. According to a systematic review, weight loss from weight management apps tend to peak at 3 months and taper off with time. [46] While this is commonly seen as a limitation of weight loss apps, using a standalone app could reduce the obesity disease burden as compared to having no interventions and the cost-effectiveness of hybrid human-app obesity management programs as compared to fully human-led programs. [47] The use of a smartphone has also been shown to significantly improve adherence rates as compared to the use of website and diaries for self-monitoring. [48] On the other hand, such apps could be used to augment and reduce the resource-intensity of health coaching, which typically requires frequent client engagements to achieve a modest amount of weight loss. Moreover, with the high smartphone penetration globally, apps are one of the most promising tools to enhance interventional access and reach at scale. [49] Future studies could consider examining the cost-effectiveness of app-enhanced weight management interventions to inform the development and implementation of such interventions as a population health solution.

Improvements in behavioural and psychological outcomes

From weeks 0 to 12, we found a significantly higher improvement in the intervention group for depression scores, likely associated with the higher weight loss observed. Studies have shown the bidirectional relationship between weight and depression through psychological and biological mechanistic pathways such as the mood regulatory and hypothalamic-pituitary-adrenal (HPA) axis pathways. [50] Other studies including the landmark Look AHEAD RCT study which examined the effects of intentional weight loss in people with obesity have shown that lifestyle modification and weight loss improves depression symptoms compared to controls, contrary to the belief that intentional weight loss reduces mental well-being. [51]

Interestingly, while we observed a simultaneous app effectiveness on anthropometric and depression outcomes from weeks 0 to 12, we observed a delayed effect of the app on perceived health and eating self-regulation only from weeks 12 to 24. This could potentially be due to longer time and larger sample size needed for latent factors like the latter to reach statistical significance as compared to more observable factors like the former. [52] Nevertheless, the intersection between the two groups on scores for mean weight, BMI, waist circumference, waist-hip ratio, BRI (figure 2), psychological flexibility, overeating habit, eating self-regulation, future-oriented time perspective, anxiety and depression (figure 3) suggests potential app effectiveness through mechanisms that involve the mentioned psychological constructs, although not all were found to be significantly improved by the time the study ended.

It was surprising that we did not find significant differences between the groups for nutrition knowledge, psychological flexibility, eating phenotypes, time perspective and anxiety. This could be due to the lack of enforcement, accountability and a client-healthcare provider relationship that are common in interventions with human counselling, impeding the potential benefits that could be obtained. [53] According to a systematic review conducted, only the combination of health coaching and use of app-based intervention improves weight loss which highlights the importance of human component in weight loss intervention. [54] On the other hand, outcomes could have been contaminated by the effects of the outcome measurements, which could have served as a motivation for participants in both groups to improve psychological outcome scores. [55] Future studies could consider incorporating regular human-facilitated check-ins to reflect empathy and a human touch.

Effect of progress monitoring

While the intervention group experienced a higher improvement in anthropometric outcomes over the 24 weeks, we noticed a marked improvement in the control group's anthropometric outcomes from weeks 12-24. Based on our process evaluation feedback from all participants, the anthropometric improvement in the control group could have been due to the motivational effect of the week 12 outcomes measurement that alerted the participants of the need to improve their anthropometric outcomes. Similarly, another study reported found a positive relationship between the frequency of weighing with weight change. [56] Frequent self-weighing allows participants to observe how their behaviour affects their weight and enables them to adjust their behaviour to prevent weight gain. [56] While this can be considered as a confounding factor in the current study, it also highlights the importance of regular body composition analysis as a facilitator of weight loss as many participants indicated that they were particularly looking forward to the next outcomes measurement to monitor their progress in weight and fat loss. Weight management programs especially clinical ones could hence consider including body composition analysers into the program package to encourage self-monitoring, motivation and weight loss maintenance.

Strengths and limitations

This study has several notable strengths that adds insights to the limited literature on standalone mobile apps that incorporate motivational and self-regulation related constructs for the purposes of weight management. Firstly, while previous studies have evaluated the effectiveness of mobile app interventions, this is the first study to examine the use of a TST-guided app designed to support weight loss among young adults with excess body weight. The findings suggest significantly higher improvements of small-to-medium effect sizes in the intervention compared to control group across key anthropometric metrics including weight, waist circumference, waist-hip-ratio and BRI. This study also shows potential for scalability in both population and primary health settings, as the app-based weight loss support requires less manpower than traditional clinical weight management programs, particularly those with multidisciplinary teams. This makes it more accessible and sustainable for the healthcare system. [57] Secondly, this study offers sufficient statistical power to detect differences between the intervention and control groups, enhancing the reliability of the findings. [42]Thirdly, this study evaluates behavioural and psychological outcomes aside from anthropometric outcomes, providing a comprehensive assessment of the app's impact on various aspects of health and well-being that contribute to weight loss.

However, this study also has several limitations. With regards to sampling strategy, convenience sampling was used which might result in selection bias and limits generalisability beyond the sample. [58] Future trials could consider employing probability sampling for broader applicability. Furthermore, due to the nature of intervention, blinding of participants was not feasible. This could lead to subjective bias in patients' participation and reporting of the outcome, especially on self-report subjective measures such as nutrition knowledge, psychological reflexibility and eating behaviours. [59]

Conclusion

In conclusion, our study showed that even a standalone self-regulation app-based program provides significant benefits on anthropometric outcomes among people with excess adiposity, demonstrating its strong potential as a scalable, sustainable, resource-efficient adjuvant behaviour change intervention to existing weight management programs. Future studies could consider testing the implementation of such interventions in the community to ascertain its implementation outcomes.

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Author Credit statements:

Han Shi Jocelyn Chew: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition
Jia Wen Ngooi: Investigation, Data Curation, Project administration, Formal analysis

Ruo Chen Du: Methodology, Validation

Bin Zhu, Yu Cao, Chong Wah Ngo: Software, Resources, Writing - review & editing

Pin Zhong Chan, Miia Jansson, Roger Foo, Asim Shabbir, Dean Ho, Nick Sevdalis, Kee Yuan Ngiam: Validation, Writing - review & editing.

Conflicts of interest:

D.H. is a shareholder of KYAN Therapeutics, which has licensed intellectual property pertaining to AI-based oncology drug development. D.H. has filed a provisional patent on data-driven behaviour change.

N.S. is the director of London Safety and Training Solutions ltd, which offers training and improvement and implementation solutions to healthcare organisations and the pharmaceutical industry.

References

1. Odum EP, Asekomeh EG, Ntuen N. Cardio metabolic Risk Factors in Obese Subjects. *IOSR Journal of Dental and Medical Sciences*. 2014;13:63-67.
2. Obesity and overweight. World health Organization; 2024. Accessed 29 October 2024. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight
3. Mahase E. Global cost of overweight and obesity will hit $4.32 tn a year by 2035, report warns. British Medical Journal Publishing Group; 2023.
4. Geerling R, Gray SM, Holmes-Truscott E, Speight J. 'I need someone to believe in me and walk the journey with me': A qualitative analysis of preferred approaches to weight management discussions in clinical care among adults with type 2 diabetes. *Diabet Med*. Mar 2022;39(3):e14790. doi:10.1111/dme.14790
5. Maggard MA, Shugarman LR, Suttorp M, et al. Meta-analysis: surgical treatment of obesity. *Ann Intern Med*. Apr 5 2005;142(7):547-59. doi:10.7326/0003-4819-142-7-200504050-00013
6. Puhl RM, Himmelstein MS, Pearl RL. Weight stigma as a psychosocial contributor to obesity. *Am Psychol*. Feb-Mar 2020;75(2):274-289. doi:10.1037/amp0000538
7. Washington TB, Johnson VR, Kendrick K, et al. Disparities in Access and Quality of Obesity Care. *Gastroenterol Clin North Am*. Jun 2023;52(2):429-441. doi:10.1016/j.gtc.2023.02.003
8. Hennessy EA, Johnson BT, Acabchuk RL, McCloskey K, Stewart-James J. Self-regulation mechanisms in health behavior change: a systematic meta-review of meta-analyses, 2006-2017. *Health Psychol Rev*. Mar 2020;14(1):6-42. doi:10.1080/17437199.2019.1679654
9. Teixeira PJ, Carraça EV, Marques MM, et al. Successful behavior change in obesity interventions in adults: a systematic review of self-regulation mediators. *BMC Medicine*. 2015/04/16 2015;13(1):84. doi:10.1186/s12916-015-0323-6
10. Tol J, Swinkels IC, De Bakker DH, Veenhof C, Seidell JC. Overweight and obese adults have low intentions of seeking weight-related care: a cross-sectional survey. *BMC public health*. 2014;14:1-12.
11. Statista. Global smartphone penetration rate as share of population from 2016 to 2023. 2024. https://www.statista.com/statistics/203734/global-smartphone-penetration-per-capita-since-2005/
12. Flores Mateo G, Granado-Font E, Ferré-Grau C, Montaña-Carreras X. Mobile Phone Apps to Promote Weight Loss and Increase Physical Activity: A Systematic Review and Meta-Analysis. *J Med Internet Res*. Nov 10 2015;17(11):e253. doi:10.2196/jmir.4836
13. Antoun J, Itani H, Alarab N, Elsehmawy A. The Effectiveness of Combining Nonmobile Interventions With the Use of Smartphone Apps With Various Features for Weight Loss: Systematic Review and Meta-analysis. *JMIR mHealth and uHealth*. 2022;10
14. Hall PA, Fong GT. Temporal self-regulation theory: A model for individual health behavior. *Health Psychology Review*. 2007;1(1):6-52.
15. Semper H, Povey R, Clark-Carter D. A systematic review of the effectiveness of smartphone applications that encourage dietary self-regulatory strategies for weight loss in overweight and obese adults. *Obesity Reviews*. 2016;17:895 - 906.
16. Spring B, Champion KE, Acabchuk R, Hennessy EA. Self-regulatory behaviour change techniques in interventions to promote healthy eating, physical activity, or weight loss: a meta-review. *Health Psychology Review*. 2021;15(4):508-539.
17. Chew HSJ, Chew NW, Loong SSE, et al. Effectiveness of an Artificial Intelligence-

Assisted App for Improving Eating Behaviors: Mixed Methods Evaluation. *Journal of medical Internet research*. 2024;26:e46036.
18. Chew HSJ, Sim KLD, Choi KC, Chair SY. Effectiveness of a nurse-led temporal self-regulation theory-based program on heart failure self-care: a randomized controlled trial. *International Journal of Nursing Studies*. 2021;115:103872.
19. Butcher NJ, Monsour A, Mew EJ, et al. Guidelines for reporting outcomes in trial reports: the CONSORT-outcomes 2022 extension. *Jama*. 2022;328(22):2252-2264.
20. Hoffmann TC, Glasziou PP, Boutron I, et al. Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *Bmj*. 2014;348
21. Spring B, Duncan JM, Janke EA, et al. Integrating technology into standard weight loss treatment: a randomized controlled trial. *JAMA internal medicine*. 2013;173(2):105-111.
22. Health Promotion Board S. My Healthy Plate. Accessed 2024, https://www.healthhub.sg/programmes/nutrition-hub/eat-more
23. Cheng KYK, Chow SKH, Hung VWY, et al. Diagnosis of sarcopenia by evaluating skeletal muscle mass by adjusted bioimpedance analysis validated with dual-energy X-ray absorptiometry. *Journal of cachexia, sarcopenia and muscle*. 2021;12(6):2163-2173.
24. Liu C, Cheng KY-K, Tong X, et al. The role of obesity in sarcopenia and the optimal body composition to prevent against sarcopenia and obesity. *Frontiers in Endocrinology*. 2023;14:1077255.
25. Zhang X, Ma N, Lin Q, et al. Body Roundness Index and All-Cause Mortality Among US Adults. *JAMA Network Open*. 2024;7(6):e2415051-e2415051.
26. Kliemann N, Wardle J, Johnson F, Croker H. Reliability and validity of a revised version of the General Nutrition Knowledge Questionnaire. *Eur J Clin Nutr*. Oct 2016;70(10):1174-1180. doi:10.1038/ejcn.2016.87
27. Lillis J, Hayes SC. Measuring avoidance and inflexibility in weight related problems. *International Journal of Behavioral Consultation and Therapy*. 2007;4(1):30.
28. Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J Psychosom Res*. 1985;29(1):71-83. doi:10.1016/0022-3999(85)90010-8
29. Kliemann N, Beeken RJ, Wardle J, Johnson F. Development and validation of the Self-Regulation of Eating Behaviour Questionnaire for adults. *International Journal of Behavioral Nutrition and Physical Activity*. 2016/08/02 2016;13(1):87. doi:10.1186/s12966-016-0414-6
30. Chng S, Chew HSJ, Joireman J. When time is of the essence: Development and validation of brief consideration of future (and immediate) consequences scales. *Personality and Individual Differences*. 2022/02/01/ 2022;186:111362. doi:https://doi.org/10.1016/j.paid.2021.111362
31. Kroenke K, Spitzer RL, Williams JB, Monahan PO, Löwe B. Anxiety disorders in primary care: prevalence, impairment, comorbidity, and detection. *Annals of internal medicine*. 2007;146(5):317-325.
32. Staples LG, Dear BF, Gandy M, et al. Psychometric properties and clinical utility of brief measures of depression, anxiety, and general distress: The PHQ-2, GAD-2, and K-6. *General Hospital Psychiatry*. 2019/01/01/ 2019;56:13-18. doi:https://doi.org/10.1016/j.genhosppsych.2018.11.003
33. Kroenke K, Spitzer RL, Williams JBW. The Patient Health Questionnaire-2: Validity of a Two-Item Depression Screener. *Medical Care*. 2003;41(11):1284-1292. doi:10.1097/01.Mlr.0000093487.78664.3c

34. Löwe B, Kroenke K, Gräfe K. Detecting and monitoring depression with a two-item questionnaire (PHQ-2). *Journal of psychosomatic research*. 2005;58(2):163-171.
35. Gardner B, Abraham C, Lally P, de Bruijn G-J. Towards parsimony in habit measurement: Testing the convergent and predictive validity of an automaticity subscale of the Self-Report Habit Index. *International Journal of Behavioral Nutrition and Physical Activity*. 2012/08/30 2012;9(1):102. doi:10.1186/1479-5868-9-102
36. Gardner B, Lally P, Rebar AL. Can—and should—automaticity be self-reported using a single item? A secondary analysis of 16 datasets. *Applied Psychology: Health and Well-Being*. 2024;
37. *IBM SPSS Statistics for Windows, Version 29.0.2.0* 2023.
38. *A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing*. 2023.
39. Leung AW, Chan RS, Sea MM, Woo J. An overview of factors associated with adherence to lifestyle modification programs for weight management in adults. *International journal of environmental research and public health*. 2017;14(8):922.
40. Organization WH. The Asia-Pacific perspective: redefining obesity and its treatment. *Health Communications Australia*. 2000;
41. Division NPaT. *Population in Brief 2024*. 2024. Accessed Oct 2024. https://www.population.gov.sg/files/media-centre/publications/Population_in_Brief_2024.pdf
42. Ghelani DP, Moran LJ, Johnson C, Mousa A, Naderpoor N. Mobile apps for weight management: a review of the latest evidence to inform practice. *Frontiers in endocrinology*. 2020;11:412.
43. Kliemann N, Vickerstaff V, Croker H, Johnson F, Nazareth I, Beeken RJ. The role of self-regulatory skills and automaticity on the effectiveness of a brief weight loss habit-based intervention: secondary analysis of the 10 top tips randomised trial. *International Journal of Behavioral Nutrition and Physical Activity*. 2017;14:1-11.
44. Solbrig L, Jones R, Kavanagh D, May J, Parkin T, Andrade J. People trying to lose weight dislike calorie counting apps and want motivational support to help them achieve their goals. *Internet interventions*. 2017;7:23-31.
45. Chew HSJ, Ang WHD, Lau Y. The potential of artificial intelligence in enhancing adult weight loss: a scoping review. *Public health nutrition*. 2021;24(8):1993-2020.
46. Chew HSJ, Koh WL, Ng JSHY, Tan KK. Sustainability of weight loss through smartphone apps: systematic review and meta-analysis on anthropometric, metabolic, and dietary outcomes. *Journal of Medical Internet Research*. 2022;24(9):e40141.
47. Cleghorn C, Wilson N, Nair N, et al. Health benefits and cost-effectiveness from promoting smartphone apps for weight loss: multistate life table modeling. *JMIR mHealth and uHealth*. 2019;7(1):e11118.
48. Carter MC, Burley VJ, Nykjaer C, Cade JE. Adherence to a smartphone application for weight loss compared to website and paper diary: pilot randomized controlled trial. *Journal of medical Internet research*. 2013;15(4):e32.
49. Piette JD, List J, Rana GK, Townsend W, Striplin D, Heisler M. Mobile health devices as tools for worldwide cardiovascular risk reduction and disease management. *Circulation*. 2015;132(21):2012-2027.
50. Milaneschi Y, Simmons WK, van Rossum EF, Penninx BW. Depression and obesity: evidence of shared biological mechanisms. *Molecular psychiatry*. 2019;24(1):18-33.
51. Fabricatore AN, Wadden TA, Higginbotham AJ, et al. Intentional weight loss and changes

in symptoms of depression: a systematic review and meta-analysis. *International journal of obesity*. 2011;35(11):1363-1376.
52. Ledgerwood A, Shrout PE. The trade-off between accuracy and precision in latent variable models of mediation processes. *Journal of personality and social psychology*. 2011;101(6):1174.
53. Ryan K, Dockray S, Linehan C. Understanding how ehealth coaches tailor support for weight loss: towards the design of person-centered coaching systems. 2022:1-16.
54. Antoun J, Itani H, Alarab N, Elsehmawy A. The effectiveness of combining nonmobile interventions with the use of smartphone apps with various features for weight loss: systematic review and meta-analysis. *JMIR mHealth and uHealth*. 2022;10(4):e35479.
55. VanWormer JJ, French SA, Pereira MA, Welsh EM. The impact of regular self-weighing on weight management: a systematic literature review. *International journal of behavioral nutrition and physical activity*. 2008;5:1-10.
56. Gokee-LaRose J, Gorin AA, Wing RR. Behavioral self-regulation for weight loss in young adults: a randomized controlled trial. *International Journal of Behavioral Nutrition and Physical Activity*. 2009;6:1-9.
57. Stapelfeldt PM, Müller SA, Kerkemeyer L. Assessing the accessibility and quality of mobile health applications for the treatment of obesity in the German healthcare market. *Frontiers in Health Services*. 2024;4:1393714.
58. Acharya AS, Prakash A, Saxena P, Nigam A. Sampling: Why and how of it. *Indian journal of medical specialties*. 2013;4(2):330-333.
59. Gamerman V, Cai T, Elsäßer A. Pragmatic randomized clinical trials: best practices and statistical guidance. *Health Services and Outcomes Research Methodology*. 2019;19:23-35.

Supplementary Files