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Research Article

The role of habit in physical activity maintenance: Evidence from the LifelongU intervention

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ABSTRACT

The prevalence of physical inactivity is rising in the world and is associated with noncommunicable diseases and mental health problems. While behaviour change interventions that promote physical activity initiation have been relatively successful, lapses and relapses are frequent in these interventions. This study aims to develop and test an integrative intervention to promote physical activity habits among physically inactive university students. 36 individuals were enrolled and assigned to one of two arms. The experimental group received a 12-week LifelongU intervention, while the control group participated in a regular physical education course. Linear mixed-effects models revealed significant changes in habit over time, with a significant group × time interaction indicating that habit development trajectories differed between the experimental and control groups. Similarly, physical activity showed a significant group × time interaction, indicating more favourable and sustained trajectories in the intervention group across the study period. Together, these findings suggest that habit development may play an important role in supporting PA maintenance over time. Key active components of the LifelongU intervention included (a) the use of a running application for self-monitoring, (b) achievable goal-setting, and (c) habit formation behaviour change techniques. Future studies using randomized designs, larger samples, and objective physical activity measures are needed to confirm and extend the present results.

Keywords: physical inactivity; habit; physical activity; behaviour change intervention; university students

1. Introduction

Physical inactivity is responsible for raising the risk of non-communicable diseases[1] and mental disorders[2,3]. While the World Health Organisation recommends that healthy adults engage in at least 150-300 minutes of moderate-intensity physical activity (PA) or 75-150 minutes of vigorous-intensity PA[4], few adults meet current PA guidelines[5]. Existing behaviour change interventions primarily focus on cognitive and self-regulatory mechanisms, such as motivation, action planning, and self-monitoring, to facilitate PA behaviour change[6]. While these approaches can effectively initiate PA, maintaining PA over the long term remains a significant challenge[7]. Habit is a key determinant of the long-term maintenance of a behaviour[6].

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Habits are formed through context-dependent repetition, in which consistent pairing of PA with stable cues (e.g., time of day, location) leads to automatic initiation with minimal cognitive effort[8]. As habit strength increases, PA becomes less reliant on motivation and self-regulation, reducing barriers to long-term engagement[9].

The LifelongU intervention is a physical education curriculum designed for physically inactive university students, grounded in an integrated theoretical framework (**Figure 1**). The proposed framework systematically integrates Habit Theory (HT)[10] and the Affective-Reflective Theory (ART) of physical inactivity and exercise[11] into the Physical Activity-related Health Competence (PAHCO) model[12], creating a novel dual-process approach to address physical inactivity. HT contributes its foundational principles of behavioural automaticity, particularly through cue-action-reward loops that transform intentional exercise into habitual routines. Concurrently, ART complements this by elucidating the dual-process system where (a) the affective system generates immediate hedonic responses to exercise stimuli and (b) the reflective system evaluates long-term consequences, together determining volitional engagement. Within the PAHCO architecture, this synthesis manifests across three competency domains: movement competence, self-regulation competence, and integrated health literacy. This theoretical framework bridges neurobehavioral habit formation (HT) with the emotional-decisional processes (ART) that collectively govern exercise adoption and maintenance[13], particularly relevant for intervention-resistant university populations. Therefore, this study develops and tests the LifelongU intervention to reduce physical inactivity among university students.

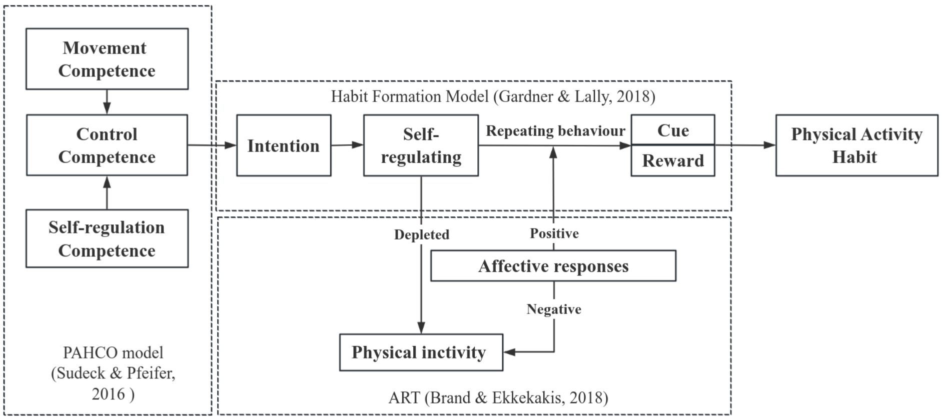

Figure 1. The theoretical framework of the LifelongU intervention.

2. Materials and methods

2.1. Study design

This study used a quasi-experimental design with two parallel groups and non-random allocation. The study has been approved by the ethics committee of the Chongqing University Cancer Hospital (No.: CZLS2023275-A). The trial has been registered on ClinicalTrials.gov (ID NCT06140680).

2.2. Participants

Participants were recruited face-to-face in the compulsory physical education class of Chongqing University. Participants from different majors were free to choose physical education courses in the Spring semester of 2023-2024. The teacher presented detailed information about the LifelongU intervention during the first week. These participants were informed that there was a 50% chance they would be assigned to the control group. Participants were free to withdraw from the study at any time without providing a reason or affecting their care.

The inclusion criteria were (1) university students aged 18-29 years, (2) failure to meet the recommended PA guidelines (< 150 minutes of MVPA or < 70 minutes of VIPA in total a week) at the time of recruitment, and (3) a score of habit in PA lower than 4[14]. The exclusion criteria were (1) students already meeting recommended PA levels or having higher PA levels, (2) students already attending another similar PA intervention, and (3) the presence of health conditions that prevented safe engagement in PA.

Previous studies on behaviour change interventions have found an expected effect size (Cohen's *d*) of 0.31 for habit[15], 0.39 for physical activity, and 0.54 for affective variables[16]. The total sample size was 28, as determined using G*Power 3.1.9.4. It was assumed that participants would exhibit a dropout rate of 17% and a follow-up attrition rate of 9%[17]; the minimally required sample size was 36 participants.

2.3. Procedure

2.3.1. The experimental group

The LifelongU intervention, which lasted for 12 weeks, included four modules: 1) Education, 2) Physical Development, 3) Skills Development, and 4) Maintenance.

Education Module provided through the Small Private Online Course (SPOC) platform of Chongqing University (https://courses.cqu.edu.cn). The learning content consists of 40 required videos, 137 optional videos, 15 units of homework, and 4 graphic materials, totalling at least 9 hours of study time. Participants were required to complete all mandatory videos, at least one optional video, and the exams within 12 weeks from the start of the first week.

Physical and Skills Development Modules were integrated into a 90-minute standard physical education (PE) course for 12 weeks. At the beginning of 1-2 weeks, sessions primarily focused on health-related physical fitness measurement. Following 3-4 weeks, the exercise methodologies for each health-related physical fitness component were emphasised. The curriculum then shifted focus during weeks 5–8 to the technical learning of tennis skills, covering fundamental techniques such as the forehand, backhand, and serve. In the final 9-12 weeks, students engaged in modified games to suit different skill levels. The overall teaching arrangement followed a structured format: 10-minute warm-up, 20-minute review of the previous session, 30-minute new learning, 20-minute physical fitness exercise, and 10-minute cooldown.

Maintenance Module utilises long-distance running exercises via Budaolepao® (Wuhan, China) application combined with habit formation strategies. This application is specifically designed to track and record various metrics associated with an intelligent anti-cheating system for extracurricular running activities. Participants are required to complete a minimum of 3 km per run at a pace of 3 to 9 min/km, 24 sessions over 12 weeks.

2.3.2. Control group

The control group only includes Physical and Skills Development Modules. Students participated in 90 minutes of traditional PE courses as prescribed by the university's regular curriculum for 12 weeks without any relevant behaviour change techniques. The lesson contents and total exercise dose per session were the same as those of the experimental group.

2.4. Instrument

Demographic variables include age and sex, while covariate variables include baseline physical fitness levels encompassing four essential components: body composition, flexibility, cardiorespiratory endurance, and muscular strength.

Body composition: Body mass index (BMI) is automatically calculated from height and weight measured by the weighing machine® HK6800-ST (Hengkangjiaye®, Inc., Shenzhen, GD, China).

Flexibility: Sit-and-reach was measured using Hengkangjiaye® HK6800-TQ. Participants sat with their legs straight and feet positioned 10–15 cm apart. While keeping their arms extended forward, they leaned forward and pushed horizontally against the test board. They gradually extended their fingertips to push the test bar as far as possible, until they could not move it any farther. Each participant was allowed two attempts, and the greatest distance recorded in centimetres was used.

Cardiorespiratory endurance: (1) 800 m run was measured using a stopwatch. Participants stood behind the starting line for the 800 m run. The test began when the instructor gave the "ready-and-go" command. Timekeepers started recording as participants began running and stopped when they crossed the finish line. The completion time was recorded in minutes and seconds, accurate to one decimal place. (2) The vital capacity of the lung was measured using Hengkangjiaye® HK6800-FH with a dry and sterilised plastic mouthpiece. Participants took a deep breath and exhaled slowly into the mouthpiece until they could no longer exhale. The spirometer automatically measured and displayed the maximum lung capacity (in millilitres) after the exhalation was completed. Each participant performed the test twice with a 15-second interval, and the higher score was recorded.

Muscular strength: (1) The standing long jump was measured using Hengkangjiaye® HK6800-LT. Participants stood behind the starting line with their feet apart in a natural stance and were instructed to jump forward. They were required to jump with both feet simultaneously from a standing position without any additional movements. The horizontal distance was measured from the back edge of the starting point to the nearest back edge of the landing point. Each participant was allowed three attempts, with the longest jump recorded in centimetres. (2) 50 m run was measured using Hengkangjiaye® HK6800-PB. Participants stood at the starting line of the 50 m straight track. The test began when the instructor gave the "ready-and-go" command. The timekeeper started recording at the moment of the command and stopped when the participant's chest crossed the finish line. The time was recorded in seconds, accurate to one decimal place.

Habit was measured using the Physical Activity Self-Report Habit Index (PA-SRHI), a modified version of the Self-Report Habit Index[18]. The SRHI is a 12-item questionnaire answered on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree), with higher scores indicating stronger habit strength. The SRHI has a stem 'X is something...' followed by items such as 'I do without thinking'. Within the questions, we replaced the symbol "X" with "physical activity". In the pilot study, the PA-SRHI-Chinese version in university students confirmed good reliability (α = .96) and reasonable test-retest reliability (r = .64-.90).

PA was assessed using the Global Physical Activity Questionnaire (GPAQ; WHO, 2021), a brief self-report measure suitable for large student samples and aligned with WHO PA guidelines. The GPAQ assesses the frequency, duration, and intensity of PA, with PA expressed as MET-minutes per week. PA was measured at four time points (baseline, week 6, week 12, and week 16) to examine longitudinal trajectories and self-reported PA maintenance. The GPAQ has demonstrated acceptable reliability and validity in global samples and among Chinese college students[19,20].

2.5. Data collection and analysis

Data were collected at baseline (week 1) and at weeks 6, 12, and 16. All statistical analyses were conducted using SPSS version 26. All analyses were conducted using a per-protocol approach, including only participants who completed all four assessment time points. Descriptive statistics were computed for participant characteristics based on questionnaire data. Baseline equivalence between the experimental and control groups was examined using independent *t-tests* for continuous variables and chi-square tests for categorical variables. The normality of outcome variables was assessed using the Shapiro–Wilk test.

To examine longitudinal changes and intervention effects, linear mixed-effects models (LMMs) with random participant intercepts were employed. Time (four measurement occasions), group (experimental vs. control), and their interaction were specified as fixed effects, and models were estimated using maximum likelihood, allowing the inclusion of all available observations without replacing missing values. This approach accounts for within-subject correlations and unbalanced data across time points. All LMMs were adjusted for sex, BMI, and baseline fitness.

3. Results

The participant flow is illustrated in **Figure 2**. A total of 126 individuals were assessed for eligibility, of whom 54 were enrolled, yielding a recruitment rate of 42.86%. Following allocation, attrition occurred primarily due to non-completion of training sessions and assessments, resulting in attrition rates of 46.15% in the experimental group and 48.28% in the control group. The baseline characteristics, anthropometry and physical fitness of the experimental and control groups were compared to assess their equivalence before the intervention (**Table 2**). The experimental group had a mean age of 18.60 years, while the control group had a mean age of 18.36 years, indicating similar age distributions between the groups. The independent-samples t-test showed a non-significant difference in habit between males and females (t = .70, p = .49) and between the experimental and control groups (t = -.03, p = .97).

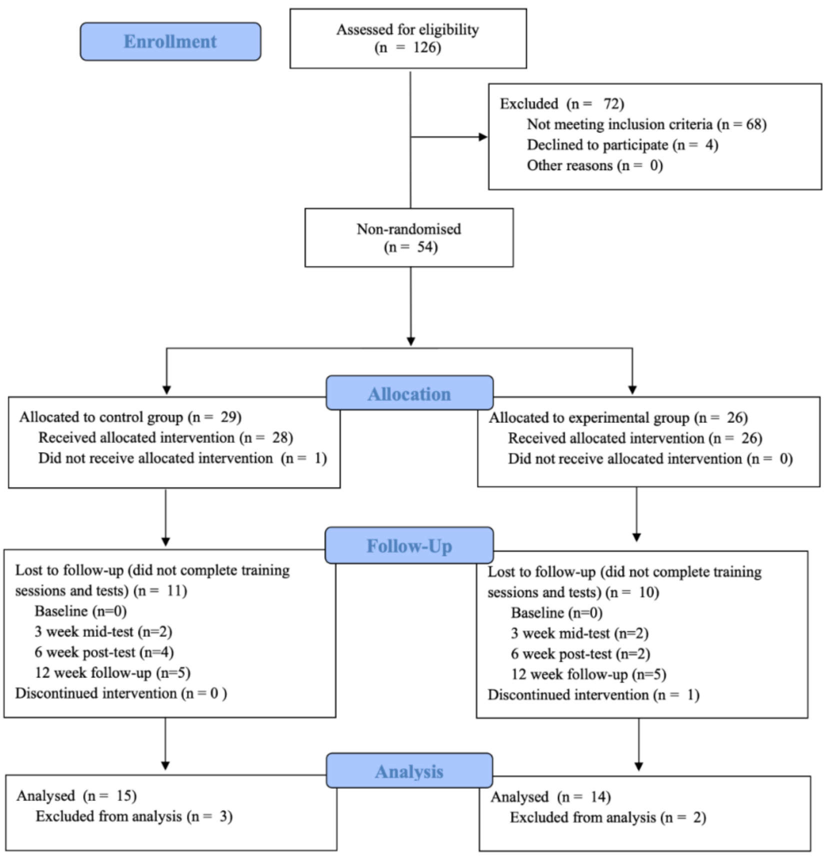

Figure 2. Flow diagram of participants in the LifelongU intervention from baseline to week 12.

Table 2. Participant characteristics and demographics

Characteristics	Experimental group N=15		Control group N=14	
	Mean	**SD**	**Mean**	**SD**
Age (years)	18.60	.82	18.36	.63
Gender N (%)				
Female	2	13%	6	43%
Male	13	87%	8	57%
Anthropometry				
Height (cm)	170.19	7.34	165.67	9.53
Weight (kg)	73.99	24.26	61.47	16.69
BMI (kg/m²)	25.20	6.59	22.22	4.85
Physical fitness				
VC (ml)	3264.27	815.27	2765.50	696.71
50 meters (sec.)	8.42	.99	8.49	1.12
800 meters (min)	4.08	.61	4.02	.57
SAR (cm)	12.36	7.84	16.01	8.19
SLJ (cm)	206.79	30.14	196.78	30.89

SD = standard deviation; N = number; BMI = body mass index; VC = vital capacity; SAR = sit-and-reach; SLJ = standing long jump; cm = centimetre; kg = kilogram; m = meter; ml = milliliter; sec. = second; min = minute.

As shown in **Table 3**, habit was analysed using a linear mixed-effects model with random participant intercepts and maximum likelihood estimation to account for within-subject correlations across the four measurement occasions (baseline, week 6, week 12, and week 16). The model revealed a significant main effect of time, F(3,87)=14.74, *p*<.001, indicating that habit changed significantly over the experimental group. The main effect of group was not statistically significant, F(1,29)=3.81, *p*=.061, suggesting no overall difference in habit between the experimental and control groups when averaged across time points. Importantly, a significant group × time interaction was observed, F(3, 87)=4.66, *p*=.005, indicating that habit trajectories differed between groups over time.

Table 3. Fixed Effects for Habit (LMM).

Effect	*F*	df_1	df_2	*p*
Time	14.74	3	87	<.001
Group	3.81	1	29	.061
Group × Time	4.66	3	87	.005

Inspection of estimated marginal means suggested that habit increased more steeply in the experimental group across the intervention period, whereas changes in the control group were comparatively modest. These longitudinal patterns are illustrated in **Figure 3A**. Random-effects estimates further indicated significant between-individual variability in baseline habit strength (variance = 0.67, *p = .003*), supporting the inclusion of participant-level random intercepts in the model (see **Table 4**).

Table 4. Random effects for habit (LMM).

Random Effect	Variance	SE	*p*	95% CI
Intercept (Participant)	0.67	0.23	.003	[0.35, 1.30]
Residual	0.73	0.11	<.001	[0.54, 0.98]

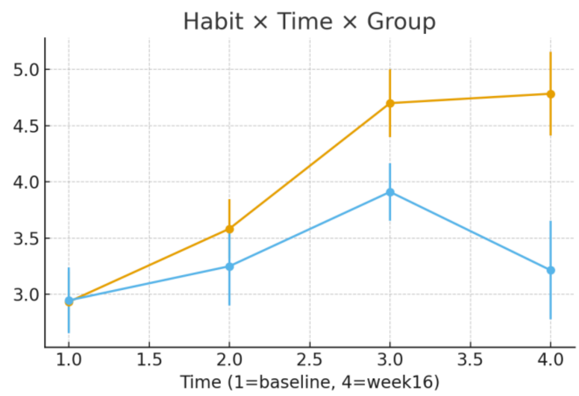

Figure 3A. Trajectories of habit across the 16-week intervention period.

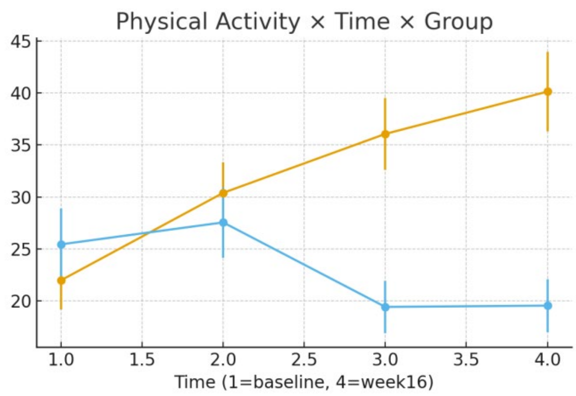

Figure 3B. Trajectories of physical activity across the 16-week intervention period.

As shown in **Table 5**, Physical activity was analysed using a linear mixed-effects model with random participant intercepts and maximum likelihood estimation to account for repeated measurements at baseline, week 6, week 12, and week 16. The analysis revealed a significant main effect of time, $F(3,87)=7.49$, $p<.001$, indicating that physical activity levels changed significantly over the course of the study. A significant main effect of group was also observed, $F(1,29)=5.33$, $p=.028$, suggesting overall differences in physical activity between the experimental and control groups when averaged across time points. Crucially, a highly significant group × time interaction emerged, $F(3, 87) = 32.78$, $p < .001$, demonstrating that the two groups exhibited markedly different physical activity trajectories over time.

Table 5. Fixed effects for physical activity (LMM).

Effect	F	df_1	df_2	*p*
Time	7.49	3	87	< .001
Group	5.33	1	29	.028
Group × Time	32.78	3	87	< .001

Examination of estimated marginal means indicated that participants in the experimental group showed a sustained and progressive increase in physical activity from baseline to week 16. In contrast, the control group displayed comparatively smaller changes over the same period. These divergent trajectories are illustrated in Figure 3B. Random-effects estimates further revealed substantial between-individual variability in baseline physical activity (variance = 106.89, $p < .001$), supporting the appropriateness of the mixed-effects modelling approach (see **Table 6**).

Table 6. Random effects for physical activity (LMM).

Random Effect	Variance	SE	*p*	95% CI
Intercept (Participant)	106.89	29.96	< .001	[61.71, 185.14]
Residual	28.45	4.31	< .001	[21.13, 38.29]

4. Discussion

The present findings suggest that changes in habit may be associated with PA maintenance over time. Participants in the LifelongU intervention group not only demonstrated steeper trajectories of habit development but also exhibited sustained and progressively higher PA across the 16 weeks. In contrast, changes in both habit and PA were comparatively limited in the control group. This parallel pattern suggests that the LifelongU intervention may have facilitated the internalisation of repeated PA behaviours into more automatic, habit-like responses, thereby supporting PA maintenance beyond initial adoption. From a theoretical perspective, these findings are consistent with habit-based accounts of PA maintenance, which propose that repeated enactment of behaviour in stable contexts strengthens cue–response associations and reduces reliance on conscious, effortful regulation[21].

One possible explanation for the observed increase in habit in both the experimental and control groups relates to the shared environmental conditions under which the study was conducted. Participants in both groups were exposed to a highly consistent PA context, including a fixed weekly schedule, the same location, guidance from the same instructor, and participation alongside the same group of peers. Such environmental stability may have facilitated habit development by repeatedly pairing stable contextual cues with PA behaviour, even in the absence of the LifelongU intervention.

Prior research suggests that stable environments can reinforce habit formation by strengthening cue–behaviour associations, thereby promoting automaticity through repeated exposure to consistent contextual signals[22]. From this perspective, the similar increases in habit observed across groups may partly reflect the influence of shared contextual regularities, alongside any intervention-specific effects. This interpretation highlights the role of environmental consistency as a foundational condition for habit development and provides a complementary explanation for the longitudinal habit trajectories observed in the present study.

The result also revealed that the LifelongU intervention had a delayed effect, with its impact on the experimental group becoming more pronounced over time. Although both groups exhibited similar habit trends during the intervention period, a significant difference emerged only at follow-up. Within-group analysis of the experimental group revealed significant improvements in habit formation at each measurement point throughout the 12-week intervention period. Notably, habits remained stable from the end of the intervention to the 16-week follow-up, indicating sustained improvement. Conversely, the control group showed a decline in habits after the intervention period, reverting to levels observed in week 6.

The habit change curve in the control group resembles an inverted triangle, with habit strength peaking at the end of the intervention period and gradually declining over the following four weeks to near baseline levels. This trajectory aligns with the triangular relapse pattern, in which an initial spike in healthful behaviours during the intervention is followed by a post-intervention decline back toward baseline[23]. Such relapse patterns are considered a critical factor contributing to the inability to sustain physical activity behaviours over time.

However, in the experimental group, the habit change follows an asymptotic curve, with habit strength increasing steadily at first and then gradually levelling off as it approaches a plateau. From previous longitudinal studies, habit formation typically does not follow a linear progression but instead adheres to an asymptotic model. For example, people reached peak automaticity for healthy nutrition habits within 59 days[14], whereas it took approximately 84 days for exercise habits to reach a similar level[24]. Moreover, exercise in the morning takes 106 days to reach the plateau, whereas it takes 154 days in the evening[25]. Lally[22] also found that the exercise group took 1.5 times longer to reach their asymptote than the eating or drinking groups, suggesting that the development of exercise habits may require a longer period of consistent engagement.

In the LifelongU intervention, using a running app played a pivotal role in promoting habit. By allowing students to track their PA progress, set personalised goals, and view their achievements, the app facilitated greater self-awareness and accountability. This is supported by Fukuoka[26], which demonstrated that the combination of a mobile phone app and brief in-person counselling significantly improved adherence to physical activity among physically inactive women.

Moreover, higher self-efficacy facilitated the transition from planned PA to habitual PA. During the LifelongU intervention, students were provided with a personalised, manageable running pace (4-8 min/km), enabling them to complete the required physical activity. In particular, the required running pace of approximately 3 minutes and 12 seconds per 400m lap is comparable to a brisk walking speed rather than a typical running pace for most individuals. Research indicates that running as little as 5 to 10 minutes per day at a brisk walk or very slow jog is associated with markedly reduced risks of death from all causes and cardiovascular disease[27]. This evidence challenges the common misconception that higher running speeds always yield greater health benefits.

Additionally, the core strategy contributing to the effectiveness of the LifelongU intervention was habit formation BCTs, which included three core components: repetition, context cues, and rewards. The LifelongU leveraged this mechanism by encouraging students to consciously link their chosen exercise routines with specific times, places, and preceding events. Furthermore, the LifelongU intervention allowed students to select their preferred exercise intensity, thereby facilitating the formation of robust exercise habits by optimising the interplay among repetition, contextual cues, and rewards. The theory of Effort Minimisation in Physical Activity holds that appropriate exercise intensity minimises perceived effort and promotes positive affective responses, which serve as intrinsic rewards that further reinforce the cycle of automatic repetition [28].

Overall, the present findings suggest that habit development may play an important role in supporting PA maintenance over time, as evidenced by the parallel longitudinal trajectories observed in the LifelongU intervention. However, several limitations should be acknowledged. First, PA was assessed using self-reported measures, and objective or app-based behavioural data were not available; therefore, conclusions regarding PA maintenance should be interpreted as reflecting self-reported trajectories rather than objectively verified behaviour. Second, the quasi-experimental design, relatively small analytic sample, and attrition following allocation may limit statistical power and external validity. Although linear mixed-effects models adjusted for key baseline covariates were employed to mitigate confounding, the findings should be interpreted with caution. Future studies using randomized designs, larger samples, lower attrition, and objective physical activity measures are needed to confirm and extend the present results.

Author contributions

Conceptualization, D.H.; methodology, XG.Y.; software, D.H.; validation, D.H., H.Z. and N.D.; formal analysis, D.H.; investigation, D.H.; resources, D.H.; data curation, D.H.; writing—original draft preparation, D.H.; writing—review and editing, NN.D.; supervision, SBH. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflicts of interest.

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