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The Effects of Behavioral Sleep Extension on Cognitive-Affective Functions in Habitual Short-Sleeping Young Adults: Study Protocol for a Randomized Controlled Trial

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Study protocol

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Title {1a}

The Effects of Behavioral Sleep Extension on Cognitive-Affective Functions in Habitual Short-Sleeping Young Adults: Study Protocol for a Randomized Controlled Trial

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Abstract

- **Background**: Chronic short sleep worsens cognitive performance and emotional wellbeing, so sleeping more is likely to help. However, many existing interventions are largely educational or advice-based and are not explicitly grounded in behavioural theory or tailored to individual needs. Our personalized intervention for short sleepers -- grounded in the Health Action Process Approach and behavior change techniques, delivered using motivational interviewing -- aims to boost their sleep and cognitive-affective functioning.
- **Methods**: This single-blind, two-arm randomized controlled trial has a one-week baseline, three-week intervention and a one-month follow-up. We will recruit 210 adults in Hong Kong and randomly assign them to an active control group (n=70; sleep hygiene only) or an intervention group (n=150; sleep hygiene plus sleep extension). After baseline monitoring, all participants will receive a week of personalized sleep

hygiene guidance. All participants will be asked to maintain sleep hygiene. The intervention group will be asked to sleep for 90 minutes more per night for two weeks, followed by a one-month maintenance period for both groups. Outcome measures include: (a) daily actigraphy and ecological momentary assessment of sleep and cognitive-affective functions; (b) pre- and post-intervention laboratory assessment of sleep architecture and cognitive-affective functions, including vigilance, working memory, planning, and electroencephalography-recorded emotional regulation, and (c) pre- and post-survey responses about sleep, emotional wellbeing, and psychological characteristics (e.g., self-efficacy, motivation). We will analyze these data with multilevel structural equation modeling under both intention-to-treat and as-treated principles.

- **Discussion**: This study determines whether adding a structured sleep extension component to sleep education further boosts sleep duration and cognitive-affective functions. By combining ecological assessment with laboratory measures, this theory-driven, personalized intervention aims to build a multi-level evidence chain linking behavioral interventions to sleep and cognitive-affective outcomes, hence informing the development of more personalized and scalable sleep health programs.
- **Trial registration**: Chinese Clinical Trial Registry, ChiCTR2600116669. Retrospectively registered on January 13, 2026.

Keywords

sleep extension; sleep hygiene; emotional wellbeing; cognitive-affective functions; short sleepers

Structured summary {1b}

Item	Description
Primary Registry and Trial Identifying Number {4}	Chinese Clinical Trial Registry (ChiCTR), ChiCTR2600116669. Registered on January 13, 2026. [URL:https://www.chictr.org.cn/showprojEN.html?proj=292221]
Secondary Identifying Numbers	N/A

Source(s) of Monetary or Material Support	General Research Fund (GRF) of the Research Grants Council (RGC), HKSAR, China (Grant Number: EdUHK #18609423).
Primary Sponsor and contact information {3b}	The Education University of Hong Kong (EdUHK). Contact: 10 Lo Ping Road, Tai Po, New Territories, Hong Kong.
Role of sponsor and funder {3c}	The funder (RGC) and sponsor (EdUHK) had no role in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication.
Contact for Public Queries	sleeplab@eduhk.hk
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Public Title	Behavioral Sleep Extension and Wellbeing in Young Adults
Scientific title	The Effects of Behavioral Sleep Extension on Cognitive-Affective Functions in Habitual Short-Sleeping Young Adults: Study Protocol for a Randomized Controlled Trial
Countries of Recruitment	Hong Kong, China
Health Condition(s) or Problem(s) Studied	Non-clinical habitual short sleepers
Intervention(s)	Experimental: Personalized Sleep Hygiene (SH) + 90-minute Sleep Extension (SE). Control: Personalized Sleep Hygiene (SH) only.
Key Inclusion and Exclusion Criteria	Inclusion: 18-29 years, sleep < seven hours/night. Exclusion: Diagnosed sleep/psychiatric disorders, shift work, bed-sharing, sleep efficiency <85% (via actigraphy).
Study Type	A two-arm, single-blind, randomized, parallel-group, explanatory superiority trial. Allocation ratio 1:2.
Date of First Enrollment (planned)	November 27, 2024
Sample Size	Target N = 210 (Intervention n=140; Control n=70).
Primary outcome(s)	Daily Total Sleep Time measured by actigraphy

Key Secondary outcome(s)	Sleep health parameters (e.g., sleep fragmentation, satisfaction and architecture), cognitive-affective functions (e.g., vigilance, affective experiences, and emotional wellbeing), and psychological mediators (e.g., self-efficacy, motivation).
Ethics Review	Approved by the Human Research Ethics Committee of The Education University of Hong Kong (Reference no. A2022-2023-0141-02).
Individual Trial Participant Data sharing statement	De-identified individual participant data (IPD), statistical code, and the full protocol will be available from the corresponding author upon reasonable request following the publication of primary results.

Protocol version {2}

protocol version 2.0; October 8, 2025. Ethics Ref: A2022-2023-0141-02

Introduction

Background and rationale {9a}

As many young adults sleep less than seven hours (chronic short sleep), they risk impaired mental and physical health [1-2]. Early intervention can prevent diseases, slow their progression, and boost lifelong health. Simple strategies, like spending more time in bed increases sleep duration in the short term [3]. However, sleep is complex. While some individuals may biologically function well on shorter sleep due to genetic mutations [4], many others face chronic insufficiency influenced by lifestyle [5], attitudes towards sleep, norms [6], self-efficacy [7-8] and the environment [9]. Thus, a monolithic sleep extension (SE) plan is insufficient for many people. For them, lasting change requires understanding and addressing individual drivers. Indeed, reviews urge more studies on personalized approaches and long-term effects [3,10-11]. Accordingly, we developed a Personalized Health Action (PHA) intervention based on the Health Action Process Approach (HAPA) framework [12], using evidence-based behavior change techniques (BCTs) [13], to address the individual drivers of non-clinical chronic short sleepers.

The HAPA framework conceptualizes behavior change as three sets of key facilitators across phases: motivation (e.g., intention, outcome expectancies), volitional skills (e.g., planning, self-monitoring), and self-efficacy [12]. To operationalize these processes, we use BCTs, especially Motivational Interviewing (MI), which helps overcome ambivalence and strengthens intrinsic motivation and self-efficacy for changing sleep behavior [14]. Our PHA targets HAPA elements via MI processes: engage, focus, evoke, plan [15]. Initial engagement builds rapport and collaboratively identifies participant's habitual sleep patterns to design personal sleep hygiene (SH) targets (*focusing*; e.g., identifying a sustainable bedtime from irregular sleep patterns), which fosters early action self-efficacy. *Evocation* identifies personal barriers and explores their values and reasons for change, which strengthens intrinsic motivation. Finally, collaborative *planning* translates this motivation into concrete strategies via evidence-based techniques like shaping knowledge, goal setting, and action planning [10].

From a mechanistic perspective, sleep loss disrupts the prefrontal cortex (PFC), thereby destabilizing key neurobehavioral functions such as vigilant attention and executive control [16]. This disruption also increases amygdala reactivity, which impairs the prefrontal-limbic balance essential for emotion regulation (ER) [17]. SE might reverse these neural disruptions by normalizing brain networks that subserve attention [18], and strengthening the inhibitory connectivity between the PFC and amygdala to support top-down control of affect [19]. Evidence from intervention studies supports the mechanistic benefits of SE but highlights key limitations. While extending sleep can improve cognitive-affective functions, evidence is often confined to narrow outcome domains and specific populations. For instance, findings show reduced negative affect (NA) in depressed women [20], and improved attention in sleep-satiated healthy males [18]. Furthermore, while benefits like increased positive affect (PA) have been noted in habitual short sleepers, the robustness of these effects is often obscured by social desirability bias and a reliance on subjective measures [21]. Consequently, more ecologically valid research that employs objective metrics to track functional recovery in habitual short sleepers are needed. Our trial combines longitudinal survey data and ecological momentary assessments, objective home sleep tracking with laboratory measures of sleep architecture, neurophysiology, and cognitive-affective functions. These include daily diaries with actigraphy and computerized pre- and post-experimental tasks.

Explanation for the choice of comparator {9b}

Personalized SH education serves as the active control. Using SH rather than a waitlist control matches the groups on non-specific factors, including researcher contact, participant expectancy, and self-monitoring, thereby strengthening internal validity while ensuring all participants receive sleep support. Adding a prescribed SE goal to SH education can boost effectiveness [3], so our intervention includes both phases. All participants start with personalized SH for early success and self-efficacy [8], on top of sleep stabilization. Then, we randomize participants to either (a) continue SH or (b) add a personalized 90-minute SE goal for two weeks, followed by one-month maintenance. This design allows us to isolate and evaluate the specific additive efficacy of the 90-minute SE goal and its subsequent impact on cognitive-affective functions.

Objectives {10}

The study aims to evaluate the efficacy and psychological mechanisms of PHA intervention. Specific objectives include:

- To assess the efficacy of SH and SE (vs. SH only) for increasing sleep duration (primary objective).
- To examine the secondary effects of the intervention on cognitive-affective functions (e.g., attention, ER) and other sleep parameters (e.g., sleep fragmentation, architecture).
- To evaluate the maintenance of intervention effects on sleep and functional outcomes at the one-month follow-up.
- To investigate the psychological mediators of the intervention effect, specifically whether changes in self-efficacy and motivation mediate the relationship between the intervention and changes in sleep duration.

Methods: Patient and public involvement, and trial design

Patient and public involvement {11}

During the initial conceptualization phase, four students with chronic short sleep shared their insights in weekly team meetings and helped shape our study design. They tested our sleep monitoring equipment and ensured that our materials were easy to use. Also, they refined recruitment ads and shared them with their friends. Their insights made our protocol more practical and focused on participants, so we honored their contributions with formal recommendation letters.

Trial design {12}

This is a single-blind, two-arm, parallel-group, randomized controlled trial with a 1:2 allocation ratio (Active Control vs. Intervention). The study is designed as a superiority trial to evaluate the efficacy of a personalized SE intervention compared to SH education alone.

Methods: Participants, interventions and outcomes

Trial setting {13}

Recruitment will be conducted primarily on university campuses and in the broader community in Hong Kong SAR, China, through mass emails, social media, and on-campus posters. All pre- and post-intervention laboratory assessments, including computerized cognitive-affective tasks with electroencephalogram (EEG) recording, and sleep monitoring via polysomnography (PSG) and the Belun Ring (Belun Technology Company), will be performed in the sleep laboratories located at the University Research Facility of Human Behavioral Neuroscience at The Education University of Hong Kong. Daily monitoring of sleep and cognitive-affective functions (via actigraphy and ecological momentary assessment) will take place in participants' own home environments to ensure ecological validity.

Characteristics of the people who are needed for the trial

Table 1 outlines the expected demographic characteristics.

Characteristic	The people we would expect to see included
Age	Young adults aged 18–29 years. We expect a mean age of approximately 21.0 years (SD ± 2.5).
Sex	Male and Female. We aim for an approximate 1:1 ratio. Intersex individuals are eligible but their inclusion depends on spontaneous recruitment.
Gender	Women, men, and other gender identities (e.g., non-binary).

Race, ethnicity and ancestry	Predominantly Han Chinese (expected >95%), reflecting the local demographic of Hong Kong university students and staff. Other ethnic minorities will be reported as identified by participants.
Socioeconomic status	Diverse socioeconomic backgrounds, ranging from low to high household income levels, categorized by the study authors based on self-reported housing type and family income.
Geographic location	Participants are recruited from urban areas in Hong Kong SAR. The study coordination site is located at The Education University of Hong Kong, New Territories (urban).
Other characteristics relevant to the trial	Academic/Occupational Status: Predominantly full-time university students or young workers. Residency: Includes both permanent residents and non-permanent residents (e.g., mainland) residing in urban Hong Kong

Eligibility criteria for participants {14a}

Inclusion criteria:

a) Aged 18–29 years.
b) Habitual short sleep, defined as sleeping less than seven hours per night on average.
c) Perceived need for at least 30 minutes more sleep than current duration.
d) Proficient in Chinese (i.e., Cantonese or Mandarin).
e) Right-handed (required for standardized EEG assessment).
f) Normal or corrected-to-normal vision.

Exclusion criteria:

a) Current or history of diagnosed sleep, psychiatric, or significant neurological conditions.
b) Chronic illnesses or use of medication affecting sleep or cognition
c) Recent shift work (in the past 2 weeks)
d) Bed-sharing (i.e., with partner; pets)
e) Habitual napping (> 90 minutes and > 3 times/week)
f) Low sleep efficiency (< 85%).

We assess eligibility with the registration survey, incorporating validated instruments such

as the Sleep Condition Indicator short-form [22] and the Obstructive Sleep Apnea (OSA) screening questionnaire [23], alongside items addressing habitual sleep duration, lifestyle, and medical history. Additionally, objective PSG is conducted at T2 to screen for occult sleep disorders (e.g., Apnea-Hypopnea Index, AHI > 5).

Eligibility criteria for sites and those delivering interventions {14b}

Two doctoral students in psychology, trained in MI, will conduct individual interviews. For effective communication, interviewers are matched to participants based on language proficiency (Cantonese or Mandarin). Other two trained research assistants (RAs) and several student helpers will assistant with laboratory data collection.

Who will take informed consent? {32a}

Potential participants will first be screened by RA via an online registration survey. Those meeting the criteria will be contacted by phone to brief the study's procedures. All phone communications and in-person briefings follow standardized scripts. During the first laboratory visit (Timepoint 1, T1), the trained RA conducts a detailed briefing to explain the specific experimental protocols, task requirements at each time point, instructions for wearing the actigraphy watch, and compliance for daily questionnaires. All participants provide written informed consent on first visit, before any formal assessments begin. The research team retain the original physical copies of the signed consent forms, and participants are encouraged to take a digital photograph of their signed form for their personal records.

Additional consent provisions for collection and use of participant data and biological specimens {32b}

Not applicable. This study does not involve the collection of biological specimens, and there are no ancillary studies planned that require additional consent for the use of participant data.

Intervention and comparator

Intervention and comparator description {15a}

The study consists of a one-week baseline period followed by a two-week intervention phase and a one-month maintenance period. Participants are randomized into two arms: SH-only group (active control) or SH plus SE group (SH+SE; Intervention). The active

control group intervention focuses solely on improving SH, while the intervention group adds a 90-minute SE goal. Each component is tailored to fit individual sleep patterns and circadian preferences to help overcome individual barriers.

The intervention comprises two MI-based interviews at T2 and T3 and daily text nudges. These strengthen autonomous motivation and self-efficacy; aiding the initiation of behavior change and its maintenance [24]. Guided by MI principles (Partnership, Acceptance, Compassion, Evocation) and core skills (open questions, affirmations, reflective listening, summaries) [25], our protocol integrates BCTs from Coventry, Aberdeen, and London-Refined taxonomy [13]. These BCTs are collaboratively elicited and embedded within the four MI processes (engaging, focusing, evoking, and planning) to align with each participant's autonomy, readiness, and values. See interview details in Table 2.

[Table 2. Motivational Interviewing Protocol for T2 and T3 Sessions]

During the engaging and focusing phases, the interviewer uses collaborative data review (BCT 16: Self-monitoring) to identify personalized SH targets. Targets are reviewed in the second interview, during which the interviewer provides feedback on their performance (BCT 19) and evaluates their behavioral goals (BCT 10). To evoke intrinsic motivation and bolster self-efficacy, interviewers explore participants' motivations and values, reflect on past successes (BCT 18), and stimulate anticipation of future rewards (BCT 40). During collaborative problem-solving (BCT 8), the interviewer and participant discuss the participant's ambivalence toward barriers (e.g., phone use, workload).

In the planning phase, participants set specific goals (BCT 5) and action plans (BCT 7) tailored to their actual schedules and living environments. First, they consider potential challenges and design suitable coping plans (BCT 35: Relapse prevention). The SH+SE group also identifies realistic opportunities to extend sleep by 90 minutes. In our flexible, person-centered protocol, interviewers may adapt techniques to meet individual needs. For example, those seeking relatable peer models can use social comparison (BCT 28). To highlight and facilitate target sleep changes, we send daily text nudges (training to use prompts, BCT 23; follow-up prompts, BCT 27; environmental restructuring, BCT 24) [26]. See nudge examples in Table 3.

[Table 3 Daily nudge text messages sent to participants]

Criteria for discontinuing or modifying allocated intervention/comparator {15b}
Participants may withdraw for any reason at any time. Participation will be terminated if a participant is newly diagnosed with a medical or psychiatric condition that conflicts with the inclusion criteria. If a participant's eligibility status changes temporarily (e.g., temporary shift in work schedule affecting sleep), the intervention will be paused. Participants may be reassessed for a return to the study once they regain their eligibility.

Strategies to improve adherence to intervention/comparator {15c}
We track adherence to intervention goals via daily sleep diaries and actigraphy. If participants meet predefined adherence targets (≥50% of nights) for T2-T3 and T3-T4, they proceed as usual. If they do not meet the target at either time, they have one chance to repeat the intervention that week with a revised plan. If they refuse to repeat or still do not meet the target without extenuating circumstances, their intervention stops.

Concomitant care permitted or prohibited during the trial {15d}
Permitted: Participants may continue their usual medical care and any stable medications disclosed during screening. New prescriptions must be reported immediately to the research team to evaluate their potential impact on sleep outcomes.

Prohibited: Participants must not initiate new treatments for sleep or mental health during the study, including melatonin, prescription sedatives, antidepressants, or other structured behavioral sleep programs.

Ancillary and post-trial care {34}
There are no formal provisions for ancillary care or compensation for harm, as this is a low-risk behavioral study. To ensure all participants benefit from the research, those in the active control group will receive the SE instructional videos and guidance materials after they complete their final assessment. Access to campus counselling and health services remains available to all participants should any distress arise.

Outcomes {16}

The study evaluates outcomes across three levels: (a) daily home-based outcomes, (b) multi-wave trait outcomes, and (c) laboratory-based experimental outcomes.

The primary outcome is Total Sleep Time (TST), defined as the total duration of daily sleep measured in minutes through the whole protocol. The analysis metric is the between-group difference in the daily mean TST during the intervention phase relative to the baseline phase, assessed via the Time × Group interaction in the multilevel (ML) model. Data are aggregated as daily observations (Level 1) nested within participants (Level 2), nested within recruitment cohorts (Level 3), and summarized as means (Standard Deviation, SD) across the assessment period for descriptive reporting.

Secondary outcomes include:

- a comprehensive set of daily sleep and cognitive-affective variables collected through the whole protocol. Sleep variables include sleep onset latency, sleep efficiency, the number of minutes past midnight, sleep fragmentation index, sleep variability, sleep satisfaction, morning vitality, and sleepiness. Cognitive-affective variables include PA, NA, ER strategy use, emotional well-being, overall functioning, memory, and concentration. Consistent with the primary outcome, the specific measurement variables are the daily ratings or actigraphy-derived values. The analysis metric is the between-group difference in daily mean levels or daily slopes (time trends) relative to baseline.

- trait-level survey outcomes assess changes in participant's characteristics across three waves (pre-, post-intervention, and follow-up). Trait sleep variables include sleep quality, bedtime procrastination, chronic sleep reduction, chronotype, sleepiness, sleep hygiene practice, and sleep knowledge. Trait cognitive-affective functions include symptoms of depression, anxiety, stress, emotion reactivity, and difficulties in ER. For these measures, the analysis metric is the between-group difference in change scores from baseline to post-intervention and follow-up, aggregated as mean scores (SD) for each validated scale.

- laboratory-based outcomes, assessing at pre-test and post-test to evaluate objective changes in functional performance and sleep physiology. Cognitive-affective performance is measured via computerized tasks, with specific measurement variables including vigilance (mean reaction time and lapses), working memory (accuracy and

reaction time), planning (total correct/move scores and initiation/execution times), implicit ER (conflict adaptation effect via reaction time differences), and explicit ER (valence and arousal ratings for images). Sleep physiology outcomes include sleep architecture (duration and percentage for NREM and REM stages) and nocturnal autonomic activity (percentage of parasympathetic and sympathetic) derived from PSG and Belun Ring recordings. The analysis metric is the between-group difference in the change from T2 to T4, aggregated as means (SD) or percentages per task condition.

- exploratory outcomes, focusing on theory-based psychological characteristics for behavior change to investigate intervention mechanisms across multiple waves. The main variables are sleep self-efficacy and motivation, and other exploratory variables include perceived threat/benefits, subjective norms, attitudes, intention, and action/coping planning. The analysis metric examines the between-group difference in the longitudinal trajectories of these constructs, aggregated as repeated measures across available waves to explore their mediating effects on sleep outcomes.

Harms {17}

The risk of direct harm is low. Potential risks include temporary sleep disruption during initial adjustment (e.g., more sleep fragmentation or daytime sleepiness as sleep homeostasis adapts) [27], psychological discomfort due to negative images in the ER task, and physical discomfort from wearing overnight PSG equipment. We will mitigate these risks as follows. First, we inform participants of their right to withdraw from the study at any time without penalty. Second, if participants report distress, we will offer campus student counselling services. Third, we track sleep-related complaints via a question in the daily diaries. If needed, study personnel will offer guidance. Fourth, after giving informed consent at T1, participants will view sample negative images for early detection of potential discomfort. Fourth, we will explain possible PSG-related mild discomfort before setting up. Also, we urge participants to report any issues for prompt adjustment. Our research team will record and review all unexpected events.

Participant timeline {18}

Both groups follow a multi-phase protocol over two months: one-week baseline (T1-T2), one-week SH intervention (T2-T3), two-week continuation phase (T3-T4), and 1-month maintenance period (T4-T5; see Figure 1).

Our longitudinal mixed-methods study gathers data across levels (daily and person) and time (T1: Baseline, T2: Pre-intervention, T3: Mid-intervention, T4: Post-intervention, T5: one-month Follow-up). See our schedule of enrollment, interventions, and assessments in SPIRIT Figure 2.

[Figure 1. Intervention Procedure]
[SPIRIT Figure 2. Participant timeline: Schedule of enrollment, interventions, and assessments]

Baseline: At T1, after giving informed consent, participants wear the PRO-Diary actigraphy (CamNtech) and complete morning and evening diaries throughout T1 to T4. Participants complete a baseline survey, and maintain their habitual sleep pattern during the one-week baseline.

Pre-intervention: At T2, participants complete computerized cognitive-affective tasks, including vigilance, working memory, planning, and EEG-recorded emotional inhibitory control and regulation tasks, followed by an overnight sleep monitoring session with PSG and the Belun Ring. Then, the participant and interviewer co-create a personalized SH plan in the first MI-based interview session. Participants follow their SH plan for a week. If their average baseline sleep exceeds seven hours or if the AHI as calculated by the PSG exceeds five, they do not qualify as a non-clinical chronic short sleeper and will be excluded from the study.

Randomization & Mid-intervention: At T3, participants are randomly assigned to SH or SH+SE. A second interview reviews progress and the sleep goal for the next two weeks: SH for the SH-only group and a 90-minute SE goal in addition to SH goal for the SH+SE group. Interviewers briefly check-in with participants at the middle of the two-week period, checking their daily diary for adherence and provided additional support to resolve barriers or refine sleep goals as needed.

Post-intervention: At T4, participants complete the cognitive-affective tasks and overnight sleep with PSG and Belun Ring (refer to pre-intervention at T2). The next morning, participants complete the post-intervention survey.

One-month Follow-up: We encourage participants to maintain healthy sleep patterns with daily diaries for the next month. Then, they complete the final survey. Participants receive compensation proportionate to participation and protocol adherence: $200 for completing T3 interview with >70% adherence; an additional $400 (total $600) for completing T4 assessments with >70% adherence from T3 to T4; and a final $200 (total $800) for completing T5 survey with >70% adherence from T4 to T5.

Sample size {19}

Based on Parsons & Young's (2022) variance parameters for sleep duration (n = 72, ICC range: 0.42 – 0.52) [21], *powerlmm* yields a minimum sample size of 210 participants provides 80% power at α = 0.05 to detect a medium effect size (Cohen's d = 0.50) for SE effect, accounting for 20% attrition. This sample also suffices for secondary outcomes, as it exceeds the n = 72 required to detect small to medium effects on emotion observed in multilevel designs [21]. Furthermore, our structure of 30 cohorts and approximate 5,880 daily observations is robustly powered for exploratory three-level mediation analyses, satisfying the requirements for 1-sided tests (i.e., > 20 highest-level units and > 600 observations) [28].

Recruitment {20}

Primary recruitment involves mass emails sent to the student and staff of the university, supplemented by social media advertisements (e.g., Rednote). Physical posters with QR codes for the screening survey will also be displayed across the campus. The research team regularly monitors the recruitment rate and, if necessary, will extend recruitment to other community centers to ensure an adequate and diverse sample.

We use a staggered cohort strategy to manage our laboratory resources, which include 15 actigraphy devices and two beds equipped with PSG in the sleep laboratory. Participants are recruited in 30 cohorts of approximately seven individuals each. Each cohort follows a six-to-eight-week cycle that covers screening, the four-week intervention, and a buffer period for equipment maintenance or holiday-related rescheduling. This approach allows us to maintain high data quality while accounting for real-world disruptions. To ensure we reach the target sample size within the planned 24-30 months, we continuously promote the study through mass emails, campus posters, and social media advertisements.

Assignment of interventions: randomisation

Sequence generation: who will generate the sequence {21a}

The random allocation sequence was generated by an independent RA who is not involved in the direct recruitment or assessment of participants. This RA used a computer-based random number generator to create a pre-determined list for 210 potential participants.

Sequence generation: type of randomisation {21b}

We employed simple randomization with a 1:2 allocation ratio (SH-only group and SH+SE group). This unequal split boost statistical power for robust exploratory analyses of SE-specific mechanistic pathways.

Allocation concealment mechanism {22}

The randomization sequence is stored in an excel file. Participants are assigned their ID and corresponding group after they have passed the initial screening. Crucially, as all participants receive identical baseline assessments and SH intervention before T3, the specific intervention group remains irrelevant to the study procedures until the T3 differential intervention session, at which point the interviewer accesses the allocation to deliver the corresponding protocol.

Implementation {23}

The RA responsible for recruitment and screening assigns participant IDs according to the pre-filled randomization list once eligibility is confirmed. To minimize bias, the interviewers who deliver the personalized interventions at T3 do not participate in the initial recruitment or baseline data collection.

Assignment of interventions: blinding

Who will be blinded {24a}

Participants are blinded to their group assignment; while they are informed that the study investigates sleep improvement, they are not told whether they are in the intervention or

the control group. RAs are not blinded, and the interviewers only become aware of the group assignment at the T3 session to deliver the specific protocol.

How will be blinding be achieved {24b}

Participant blinding is maintained by providing both groups with a similar initial experience, including baseline assessments and SH materials.

Procedure for unblinding if needed {24c}

There are no anticipated circumstances that require unblinding during the trial.

Data collection and management

Plans for assessment and collection of outcomes {25a}

All personnel will adhere to the NIH Behavioral Change Consortium's standardized training and monitoring protocol for treatment fidelity and data quality [29], see fidelity plan in Table 4.

[Table 4 Treatment Fidelity Strategies for Monitoring and Improving Provider Training and Treatment Delivery]

The trial instruments include ambulatory assessments, validated surveys, and laboratory assessments. For daily home-based measures and trait-level surveys, Table 5 details the specific variables, validated instruments, scoring methods, and assessment timelines. Full items for daily assessments and scales are provided in the Appendix file 1.

[Table 5]

Pre- and post-intervention laboratory sessions include cognitive-affective tasks and overnight sleep monitoring.

Computerized Tasks:

- Vigilance: Sustained attention is measured via the 10-minute Psychomotor Vigilance Task [55]. Participants respond to a visual counter using a high-precision and low latency gaming mouse.

- Working Memory (N-back): A spatial N-back task consisting of two 0-back blocks (control) and three 2-back blocks (experimental). Participants indicate if a symbol's location matches the one presented two items ago.
- Planning (Tower of London): Planning is assessed by the Tower of London-Drexel University version [56]. Participants must rearrange three colored beads on three pegs to match a target configuration using the fewest moves possible (4–7 moves), adhering to physical capacity constraints and moving one bead at a time.
- Implicit ER (Emotion conflict adaptation): Adapted task assesses the resolution of emotional conflict [57]. Participants identify facial expressions (happy/fearful) while ignoring overlaid incongruent emotion words. The paradigm comprises 244 trials across four blocks, balanced by emotion and trial sequence (e.g., congruent-to-incongruent). Each trial consists of a 500-ms fixation, a 400–600 ms random blank interval, a 1000-ms stimulus presentation, and a 1000-ms post-stimulus blank.
- Explicit ER: Adapted task includes 168 trials [58], consisting of four conditions: negative-distraction, negative-reappraisal, negative-maintenance, and neutral-maintenance. Trials follow a sequence of fixation (1,000 ms), regulation cue (2,000 ms), image presentation (5,000 ms), and subjective ratings of valence and arousal (1–9).

Physiological Monitoring:

- EEG Acquisition: Implicit and explicit ER tasks are recorded using a 64-channel actiCAP (Curry Neuroimaging Suite) arranged according to the international 10-20 system (ground: AFz; reference: linked mastoids). The sampling rate is 1000 Hz, with impedances maintained below 10 kΩ.

- Overnight sleep: In-lab sleep at T2 and T4 is recorded via the Grael 4K PSG system (Compumedics Neuroscan) and the medical-grade Belun Ring. The montage includes EEG (E1-M2, E2-M2, F3-M2, F4-M1, C3-M2, C4-M1, O1-M2, O2-M1), EOG, EMG, ECG, and respiratory sensors, with impedances maintained below 20 kΩ. To maximize ecological validity, participants follow their habitual (pre-test) and personalized extended (post-test) sleep patterns.

Feasibility is assessed via study logs tracking recruitment rates, retention/dropout rates, and adherence to intervention targets. Acceptability is evaluated via a post-intervention

satisfaction survey

Plans to promote participant retention and complete follow-up {25b}

To maximize retention, we employ high-touch monitoring and digital communications. Participants receive pre-intervention Belun Ring sleep reports to understand their sleep characteristics and identify issues and post-test reports to visualize progress. Each participant has one WhatsApp group including a support helper (daily nudge sending), a RA (weekly sleep diary checks and missing data follow-up), and the Interviewer (sleep-related support and T3-T4 check-ins).

For participants who discontinue the study, we document the reason for dropout but do not collect further outcome data. For participants who deviate from the protocol but remain in the study (e.g., SH-only participants who naturally extend sleep, or SH+SE participants with suboptimal adherence who have not met discontinuation criteria), we continue to collect all scheduled outcome data.

Data management {26}

Multiple digital platforms are used for data entry and storage. Participant-reported daily diaries and trait-level surveys are collected via personal Qualtrics links, which are automatically integrated into a password-protected Google Sheet for real-time monitoring. Daily cognitive-affective assessments are recorded through PRO-Diary software via actigraphy, while objective daily sleep metrics are extracted using MotionWare software. Experimenters verify data integrity at each timepoint. Laboratory cognitive-affective performance is recorded via task-specific software (e.g., E-Prime). PSG data are recorded via the Grael 4K system and scored by certified technicians blinded to group allocation according to American Academy of Sleep Medicine standards, while Belun Ring data are uploaded directly to its secure cloud platform.

Upon completion of assessment phases, trained RAs download and consolidate all digital records into a centralized master database. Data quality is promoted through electronic checks (e.g., mandatory field constraints in Qualtrics) and manual review. RAs perform weekly data cleaning to screen for logical inconsistencies and missing values. All corrections are documented in a version-controlled file to maintain a comprehensive audit

trail.

Confidentiality {33}

All data are de-identified with a unique participant ID immediately upon collection. The master key linking these IDs to personally identifiable information is stored in a separate, password-protected file accessible only to the Principal Investigator (PI). Electronic data are backed up weekly onto an encrypted hard disk. Physical records, including signed informed consent forms, are secured in a locked cabinet within a dedicated laboratory. All research records will be retained for two years following the first publication, after which identifying keys and physical documents will be destroyed. The PI maintains participant data confidentiality before, during, and after the study and reserves the authority to pause or terminate the study based on ethical considerations or unforeseen risks.

Statistical methods

Statistical methods for primary and secondary outcomes {27a}

Primary and Daily Outcomes: To assess intervention effects across all daily outcomes (including primary TST and secondary outcomes), we will employ a three-level ML-structural equation model (SEM) [59]. The model for the outcome y for day i of participant j in cohort k is:

$$OUTCOME_{yijk} = \beta_{0y} + \beta_{1y}(SH_{yijk}) + \beta_{2y}(INT_{yijk}) + \beta_{3y}(FUP_{yijk}) + \beta_{4y}(Group_{yjk}) + \beta_{5y}(INT_{yijk} \times Group_{yjk}) + \beta_{6y}(Dose_{yijk}) + \beta_{7y}(Day_{yijk}) + u_{0yjk} + u_{1yjk}\,INT_{yijk} + u_{2yjk}\,Dose_{yijk} + u_{3yjk}\,Day_{yijk} + v_{0yk} + e_{yijk}$$

SH_{ijk}: Indicator of the T2-T3 phase for day i of participant j in cohort k (1 = T2-T3, 0 = otherwise)

INT_{ijk}: Indicator of the differential intervention phase (1 = T3-T4, 0 = otherwise)

FUP_{ijk}: Indicator of the maintenance phase (1 = T4-T5, 0 = otherwise)

$Dose_{ijk}$: Daily as-treated extension dose, defined as the deviation of that day's sleep duration from the participant's baseline mean.

Day_{ijk}: Time-in-study variable indexing linear trend across days (e.g., days since first baseline day).

$Group_{jk}$: Randomized treatment condition for participant j in cohort k (0 = SH-only, 1 = SH+SE), constant across days.

Random Effects:

u_{0jky}: Participant-level random intercept for outcome, capturing person-specific deviations from the average baseline level within cohort k.

u_{1jky}: Participant-level random slope for INTijk, capturing individual differences in change from baseline to the differential intervention phase (T3-T4) for outcome.

u_{2jky}: Participant-level random slope for $Dose_{ijk}$, capturing individual differences in the within-person association between daily extension dose and outcome (i.e., who benefits more or less from actually sleeping longer)

u_{3jky}: Participant-level random slope for Day_{ijk}, capturing individual differences in linear time trends in outcome across the study.

v_{0ky}: Cohort-level random intercept for outcome, capturing differences between recruitment cohorts.

e_{ijky}: Day-level residual error for outcome.

Fixed-effect coefficients

β_{0y}: Overall intercept for outcome: expected value at baseline, in the SH-only group, on the reference day (Day = 0), with zero extension dose (Dose = 0), averaged across cohorts.

β_{1y}: Effect of being in the SH phase (T2-T3 vs. baseline) on outcome in the SH-only group.

β_{2y}: Effect of being in the differential intervention phase (T3–T4 vs. baseline) on outcome in the SH-only group.

β_{3y}: Effect of being in the follow-up phase (T4–T5 vs. baseline) on outcome in the SH-only group.

β_{4y}: Baseline group difference in outcome between SH+SE and SH-only (SH+SE minus SH-only) when $INT_{ijk} = 0$, $Dose_{ijk} = 0$, and $Day_{ijk} = 0$.

β_{5y}: Intervention-by-group interaction for outcome, representing the additional change from baseline to the intervention phase in the SH+SE group relative to the SH-only group (intention-to-treat, ITT effect).

β_{6y}: Average as-treated (dose–response) effect of daily extension on outcome, expected change in y associated with a one-hour increase in sleep, above and beyond phase and group effects.

β_{7y}: Average linear time trend in outcome per day increase.

Within this three-level multivariate ML model, we examine mechanisms with a 2-2-1 ML-SEM. To test for interaction effects, we use residual centering, in which the intervention condition and mediator changes are Level-2 variables, and individual differences in intervention-related changes in each outcome are the participant-level random INT slopes u_{1yjk}.

In-lab and Biological Outcomes: PSG sleep architecture and nocturnal autonomic activity will be compared pre- and post-intervention using paired-sample t-tests or non-parametric equivalents. For computerized tasks, we will analyze behavioral metrics (e.g. reaction time, accuracy, lapses). EEG data will be preprocessed in EEGLAB/ERPLAB; Raw signals will be band-pass filtered (e.g., 0.1–30 Hz) and re-referenced to the average of the linked mastoids. Independent Component Analysis will be employed to identify and remove ocular (blinks, movements) and muscular artifacts. Continuous data will be segmented into epochs relative to stimulus onset (e.g., -200 to 1000 ms), with baseline correction applied using the pre-stimulus interval. Epochs containing residual artifacts exceeding ±75 μV will be excluded. To assess the neural resolution of emotional conflict, we will calculate the P300 peak amplitude at CPz within a 300–600 ms post-stimulus window. For ER task, the Late Positive Potential (LPP) will be averaged across electrodes CPz, Pz, and Oz. We will analyze mean amplitudes across three distinct time windows: early (300–600 ms), middle (600–1000 ms), and late (1000–1500 ms).

Qualitative Data: We analyze the interview data with reflexive thematic analysis [60]. After translation and data cleaning, two researchers independently review the interviewer notes and iteratively assign categories, before reconvening to examine interrater reliability. We assess code saturation via Code Frequency Counts [61]. This study will analyze participants' barriers to sufficient sleep, sleep change motivation, and the perceived efficacy of strategies.

Who will be included in each analysis {27b}

Following the ITT principle, we include all randomized participants in their originally assigned groups. To assess SE effects, we will also conduct as-treated analyses based on treatment response. To determine whether dose–response associations are related to outcome, we compute the mean increase in TST during T3–T4 relative to baseline. For sensitivity analysis, we will compare baseline characteristics of completers and dropouts, and conduct per-protocol analyses with only participants who adequately adhered to the two-month protocol without intervention repetition/rescheduling.

How missing data will be handled in the analysis {27c}

For missing data, we will use multiple imputation by chained equations ('mice' package), with results pooled per Rubin's rules [62]. By imputing missing values at the daily level rather than relying on listwise deletion, we minimize attrition bias and maximize statistical power, particularly for days with partial data (e.g., missing subjective ratings but valid actigraphy).

Methods for additional analyses (e.g. subgroup analyses) {27d}

Descriptive statistics (means, SDs, and percentages) will summarize feasibility and acceptability metrics, including recruitment, retention, and adherence rates. Figure 3 details the expected attrition throughout the protocol. Subgroup analyses may be explored based on baseline sleep quality or chronotype if significant heterogeneity in treatment response is observed.

Interim analyses {28b}

No formal interim analyses are planned for this trial. However, the PI will review safety data (adverse event reports) on a monthly basis. The final decision to terminate the trial based on unforeseen safety risks rests with the PI.

Protocol and statistical analysis plan {5}

The full protocol and statistical analysis plan are contained within this published document. No separate statistical analysis plan has been submitted. Any future amendments to the protocol or analysis plan will be documented in updates to the trial registry and reported in the final publication.

Oversight and monitoring

Composition of the coordinating centre and trial steering committee {3d}

The trial is coordinated at a single site by a core team led by the PI, who ensures scientific integrity and ethical conduct. Graduate students and RAs manage recruitment, screening, and data collection, supported by student helpers who assist with daily nudges and laboratory setups (EEG/PSG). The team meets weekly during the initial and pilot phases to review progress and ensure protocol adherence, transitioning to monthly meetings once operations stabilize.

Composition of the data monitoring committee, its role and reporting structure {28a}

Due to the study's limited scale and low-risk behavioral intervention, no independent Data Monitoring Committee or Trial Steering Committee has been established; all trial oversight, including safety monitoring and data review, will be conducted by the core study team led by the PI.

Frequency and plans for auditing trial conduct {29}

There are no plans for independent external auditing of trial conduct. However, the study team performs internal monitoring during their scheduled meetings to ensure data quality and adherence to the randomization and intervention protocols. If necessary, external audits or inspections may be conducted by relevant regulatory bodies, but this is not currently planned.

Protocol amendments {31}

Any significant modifications to the protocol (e.g., changes to study design, eligibility, or outcomes) will be submitted to the Institutional Review Board for approval prior to implementation. Approved amendments will be updated in the trial registry and clearly documented in the final study report.

Dissemination policy {8}

Study findings will be disseminated through peer-reviewed publications in high-impact journals and presented at international conferences. Upon completion of the study, the trial registry will be updated with a summary of the results. To maximize public engagement, the findings will also be shared via the PI's dedicated website [63], which provides plain language summaries translating sleep and wellbeing research for the general public.

Discussion

Our theory-driven and personalized PHA intervention determines the effect of adding SE to personalized SH education for non-clinical chronic short sleepers. We work with participants to understand their motivations and contexts to co-create suitable strategies to help them obtain longer sleep. This approach is likely to boost autonomy, self-efficacy, acceptability, adherence, and long-term efficacy. By offering a transparent and barrier-free framework, this approach serves as a scalable model for public health education and might be adaptable to other health behavior domains.

Furthermore, we employ several ecological and laboratory measures to assess intervention effectiveness. We collect objective actigraphy and subjective daily mood in natural settings, complemented by lab-based sleep architecture and EEG-derived event-related potential metrics. The integrated approach addresses the need for more real-world evidence and is expected to yield robust, multi-level evidence linking behavioral changes to psychophysiological outcomes.

Moreover, the significance of this protocol is especially important in Hong Kong, where short sleep (averaging 6.65 hours in adults) is linked to diminished happiness [64]. While certain genetic mutations enable functional short sleep [4], we focus on the broader population whose sleep needs exceed their actual rest. By including a one-month

maintenance period to evaluate sustainability, this study provides a practical tool for improving individual well-being while raising public awareness of the preventive value of SE.

This study has a few limitations. First, our recruitment from university campuses may introduce self-selection bias; individuals who volunteer for a sleep-focused study may already possess higher-than-average motivation for behavior change, which could lead to overestimation of the intervention's efficacy. Also, compared to the general workforce, our sample from university may have more flexible schedules that facilitate SE, potentially limiting the generalizability of our findings to populations with rigid professional or familial commitments. Future studies should include more diverse age groups and occupations to validate intervention effects across different lifestyle constraints.

Furthermore, we utilized an active control condition (SH-only) rather than a waitlist control (i.e., a passive observation group receiving no intervention) to isolate the unique, incremental effect of SE beyond personalized SH support. However, this design complicates proving PHA's efficacy; both groups might show benefits and differ only slightly. Also, this design demands a larger and costlier sample to detect differences than a comparison with a placebo or waitlist. Without a true placebo, proving clear superiority or non-inferiority is harder, especially if the active comparator does not perform as expected.

Additionally, the personalized nature of our intervention, involving MI and tailored behavioral strategies, is notably resource-intensive in terms of both time and specialized labor. While this high-intensity approach may limit immediate large-scale implementation, it serves as a critical exploratory step to identify which behavioral components appear most effective for. By documenting our detailed protocol and exploring behavior change mechanisms, we hope to provide the empirical foundation for developing cost-effective intervention, such as creating automated digital health platforms using algorithms to deliver precision interventions, mimicking the personalized support of MI to tailor motivational strategies to an individual's psychological profile, thereby significantly reducing costs while maintaining efficacy.

Trial status

This study is currently adhering to protocol version 2.0 (dated October 8, 2025). Recruitment began on November 27, 2024, and is expected to conclude by December 2026. As of January 2026, 94 participants have been enrolled across eight cohorts. Following baseline actigraphy verification, 24 individuals were excluded (e.g., non-short sleepers) and 4 withdrew during the intervention. To date, 66 participants have completed the intervention, with 54 having finished all follow-up assessments and 12 currently remaining in the follow-up phase. Formal statistical analysis has not yet been initiated.

Abbreviations

- AHI: Apnea-Hypopnea Index
- BCTs: Behavior Change Techniques
- EEG: Electroencephalogram
- ER: Emotion Regulation
- HAPA: Health Action Process Approach
- ITT: Intention-To-Treat
- MI: Motivational Interviewing
- ML-SEM: Multilevel Structural Equation Model
- NA: Negative Affect
- OSA: Obstructive Sleep Apnea
- PA: Positive Affect
- PFC: Prefrontal Cortex
- PHA: Personalized Health Action
- PSG: Polysomnogram
- PI: Principal Investigator
- RAs: Research Assistances
- SE: Sleep Extension
- SH: Sleep Hygiene
- T: Timepoint
- TST: Total Sleep Time

Declarations

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Authors' contributions {3a}

L.E.Y.Y. is the Principal Investigator who conceived the study and secured funding.
W.W. led the protocol development, contributed to the study design, and drafted the manuscript.
M.H.Y.D. contributed to the protocol development, manuscript drafting.
C.M.M. contributed to the statistical analysis plan, funding acquisition and revised the manuscript.
Z.J.X., W.M.L., C.S.H., H.J.H., and L.Y.C. contributed to the study design and funding acquisition.
All authors have read, edited, and approved the final manuscript.
Artificial intelligence technology was used during the preparation of this manuscript to assist with language polishing and structural refinement.

Sources of funding and other support {7a}

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Availability of data and materials {6}

De-identified data, statistical code, and the full protocol will be made available upon reasonable request after publication of peer-reviewed articles. Access to the final trial dataset will be restricted to the Principal Investigator and authorized members of the study team to ensure participant confidentiality. There are no contractual agreements that limit such access for investigators.

Ethics approval and consent to participate {30}

This study was approved by the Human Research Ethics Committee of The Education University of Hong Kong (Reference no. A2022-2023-0141-02). Written, informed consent to participate will be obtained from all participants. A copy of the original ethical approval

document and consent form are provided as additional files in this submission.

Consent for publication

Not applicable. This study protocol does not contain any individual person's data, images, or videos. The authors are willing to provide a model consent form on request.

Competing interests {7b}

The authors declare that they have no competing interests

References

1. Pankowska MM. Prevalence and geographic patterns of self-reported short sleep duration among US adults, 2020. Prev Chronic Dis. 2023;20. Available from: https://www.cdc.gov/pcd/issues/2023/22_0400.htm
2. Wang W, Cheung SH, Cheung SF, Sun RW, Hui CH, Ma HYD, et al. A systematic review and meta-analysis of group-based trajectory modeling of sleep duration across age groups and in relation to health outcomes. Sleep. Apr 2025;48(4):zsaf021. https://doi.org/10.1093/sleep/zsaf145
3. Gadam S, Pattinson CL, Rossa KR, Soleimanloo SS, Moore J, Begum T, et al. Interventions to increase sleep duration in young people: A systematic review. Sleep Med Rev. Aug 2023;70:101807.
4. Shi G, Xing L, Wu D, Bhattacharyya BJ, Jones CR, McMahon T, et al. A rare mutation of β1-adrenergic receptor affects sleep/wake behaviors. Neuron. 2019;103(6):1044-55.
5. Zheng, Y. B., Huang, Y. T., Gong, Y. M., Li, M. Z., Zeng, N., Wu, S. L., ... & Bao, Y. P. (2024). Association of lifestyle with sleep health in general population in China: a cross-sectional study. Translational Psychiatry, 14(1), 320.
6. Hamilton K, Ng HTH, Zhang CQ, Phipps DJ, Zhang R. Social psychological predictors of sleep hygiene behaviors in Australian and Hong Kong university students. Int J Behav Med. Apr 2021;28(2):214-226.
7. Tagler MJ. Allowing time for 8+ hours of sleep: identification and validation of important beliefs using the reasoned action approach. Front Psychol. Aug 2024;15:1402322. Available from: https://www.frontiersin.org/articles/10.3389/fpsyg.2024.1402322/full
8. Ghose SM, Dzierzewski JM, Dautovich ND. Sleep and self-efficacy: The role of domain specificity in predicting sleep health. Sleep Health. Apr 2023;9(2):190-195.
9. Caddick ZA, Gregory K, Arsintescu L, Flynn-Evans EE. A review of the environmental parameters necessary for an optimal sleep environment. Build Environ. Mar 2018;132:11-20.
10. Baron KG, Duffecy J, Reutrakul S, Levenson JC, McFarland MM, Lee S, et al. Behavioral

interventions to extend sleep duration: a systematic review and meta-analysis. Sleep Med Rev. Dec 2021;60:101532.

11. Niu X, Zhou S, Casement MD. The feasibility of at-home sleep extension in adolescents and young adults: a meta-analysis and systematic review. Sleep Med Rev. Aug 2021;58:101443.
12. Schwarzer R. Health Action Process Approach (HAPA) as a theoretical framework to understand behavior change. Actual Psicol. 2016;30(121):119-130.
13. Hagger MS, Keatley DA, Chan DKC. CALO-RE taxonomy of behavior change techniques. In: Eklund RC, Tenenbaum G, editors. Encyclopedia of Sport and Exercise Psychology. Thousand Oaks (CA): SAGE; 2014. p. 100-105.
14. Vrabec A, Milligan MA, Antshel KM, Kidwell KM. A meta-analytic review of cognitive behavior therapy and motivational interviewing for adolescent and young adult sleep concerns. Clin Child Psychol Psychiatry. Apr 2025;30(2):386-401.
15. Cole SA, Sannidhi D, Jadotte YT, Rozanski A. Using motivational interviewing and brief action planning for adopting and maintaining positive health behaviors. Prog Cardiovasc Dis. Mar 2023;77:86-94.
16. Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. Semin Neurol. 2005;25(01):117-29.
17. Yoo SS, Gujar N, Hu P, Jolesz FA, Walker MP. The human emotional brain without sleep: a prefrontal amygdala disconnect. Curr Biol. Oct 2007;17(20):R877-R878.
18. Arnal PJ, Sauvet F, Leger D, Van Beers P, Bayon V, Bougard C, et al. Benefits of sleep extension on sustained attention and sleep pressure before and during total sleep deprivation and recovery. Sleep. 2015;38(12):1935-43.
19. Motomura Y, Kitamura S, Nakazaki K, Oba K, Katsunuma R, Terasawa Y, et al. Recovery from unrecognized sleep loss accumulated in daily life improved mood regulation via prefrontal suppression of amygdala activity. Front Neurol. Jun 2017;8:306. Available from: https://www.frontiersin.org/articles/10.3389/fneur.2017.00306/full
20. Casement MD, Livingston NR, Allen NB, Forbes EE. Feasibility, acceptability and affective consequences of at-home sleep extension in young women with depressive symptoms: a pilot study. J Sleep Res. 2021;30(2):e13045.
21. Parsons CE, Young KS. Beneficial effects of sleep extension on daily emotion in short-sleeping young adults: an experience sampling study. Sleep Health. 2022;8(5):485-493.
22. Wong ML, Lau KNT, Espie CA, Luik AI, Kyle SD, Lau EYY. Psychometric properties of the Sleep Condition Indicator and Insomnia Severity Index in the evaluation of insomnia disorder. Sleep Med. 2017;33:76-81.
23. Chung F, Y. STOP questionnaire: a tool to screen patients for obstructive sleep apnea. Anesthesiology. 2008;108(5):812-21.

24. Flannery M. Self-determination theory: intrinsic motivation and behavioral change. Oncol Nurs Forum. Mar 2017;44(2):155-156.

25. Haque SF, D'Souza A. Motivational interviewing: the RULES, PACE, and OARS. Unpublished teaching material; year unknown.

26. Murayama H, Takagi Y, Tsuda H, Kato Y. Applying nudge to public health policy: practical examples and tips for designing nudge interventions. Int J Environ Res Public Health. 2023;20(5):3962.

27. Reynold AM, Bowles ER, Saxena A, Fayad R, Youngstedt SD. Negative effects of time in bed extension: a pilot study. J Sleep Med Disord. Aug 2014;1(1):1002.

28. Williams NJ, Preacher KJ, Allison PD, Mandell DS, Marcus SC. Required sample size to detect mediation in 3-level implementation studies. Implement Sci. 2022;17(1):66.

29. Dennis CL, Marini F, Prioreschi A, Dol J, Birken C, Bell RC. The Canadian Healthy Life Trajectories Initiative (HeLTI) trial: a study protocol for monitoring fidelity of a preconception-lifestyle behaviour intervention. Trials. Apr 2023;24(1):262.

30. Carney CE, Buysse DJ, Ancoli-Israel S, Edinger JD, Krystal AD, Lichstein KL, et al. The consensus sleep diary: standardizing prospective sleep self-monitoring. Sleep. 2012;35(2):287-302.

31. Hoddes E, Zarcone V, Smythe H, Phillips R, Dement WC. Quantification of sleepiness: a new approach. Psychophysiology. 1973;10(4):431-36.

32. Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. Journal of personality and social psychology. 1988 Jun;54(6):1063.

33. McMahon TP, Naragon-Gainey K. The multilevel structure of daily emotion-regulation-strategy use: An examination of within-and between-person associations in naturalistic settings. Clinical Psychological Science. 2019 Mar;7(2):321-39.

34. Fung SF, Kong CY, Liu YM, Huang Q, Xiong Z, Jiang Z, Zhu F, Chen Z, Sun K, Zhao H, Yu P. Validity and psychometric evaluation of the Chinese version of the 5-item WHO well-being index. Frontiers in Public Health. 2022 Mar 30;10:872436.

35. Tsai PS, Wang SY, Wang MY, Su CT, Yang TT, Huang CJ, Fang SC. Psychometric evaluation of the Chinese version of the Pittsburgh Sleep Quality Index (CPSQI) in primary insomnia and control subjects. Quality of Life Research. 2005 Oct;14(8):1943-52.

36. Fang Y, Cai X, Gao Y. Validity and reliability of the Chinese bedtime procrastination scale among college students. Int J Progressive Sci Technol. 2022;34(1):353-61.

37. Meijer AM. The Chronic Sleep Reduction Questionnaire (CSRQ): A cross-cultural comparison and validation in Dutch and Australian adolescents. Journal of Sleep Research. doi:10.1111/J.1365-2869.2012.00999.X

38. Smith CS, Reilly C, Midkiff K. Evaluation of three circadian rhythm questionnaires with suggestions

for an improved measure of morningness. Journal of Applied psychology. 1989 Oct;74(5):728.

39. Pornpitakpan C, Yue W, Fu SF. Chinese composite scale of morningness: Psychometric properties of the full and the reduced versions and their relevance to business. Global Empirical Marketing Studies. 2025;1(1).
40. Chen NH, Johns MW, Li HY, Chu CC, Liang SC, Shu YH, Chuang ML, Wang PC. Validation of a Chinese version of the Epworth sleepiness scale. Quality of Life Research. 2002 Dec;11(8):817-21.
41. Lin SC, Cheng CP, Yang CM, Hsu SC. Sleep Hygiene Practice Scale. Journal of Health Psychology. 2007
42. Gallasch J, Gradisar M. Relationships between sleep knowledge, sleep practice and sleep quality. Sleep and Biological Rhythms. 2007 Jul;5(1):63-73.
43. Wang K, Shi HS, Geng FL, Zou LQ, Tan SP, Wang Y, Neumann DL, Shum DH, Chan RC. Cross-cultural validation of the depression anxiety stress scale–21 in China. Psychological assessment. 2016 May;28(5):e88.
44. Preece D, Becerra R, Campitelli G. Assessing emotional reactivity: Psychometric properties of the Perth Emotional Reactivity Scale and the development of a short form. Journal of Personality Assessment. 2019 Nov 2;101(6):589-97.
45. Zhao Y, Wu K, Wang Y, Zhao G, Zhang E. Construct validity of brief difficulties in emotion regulation scale and its revised version: Evidence for a general factor. Current Psychology. 2022 Feb;41(2):1085-96.
46. Grandner MA, Jackson N, Gooneratne NS, Patel NP. The development of a questionnaire to assess sleep-related practices, beliefs, and attitudes. Behavioral sleep medicine. 2014 Mar 4;12(2):123-42.
47. Grandner MA. Sleep, health, and society. Sleep medicine clinics. 2022 Jun 1;17(2):117-39.
48. Knowlden AP, Sharma M. Health belief structural equation model predicting sleep behavior of employed college students. Family & Community Health. 2014 Oct 1;37(4):271-8.
49. Johnson R. Predictors of sleep quality: Depression, anxiety, and sleep self-efficacy. 2018
50. Knowlden AP, Sharma M. Health belief structural equation model predicting sleep behavior of employed college students. Family & Community Health. 2014 Oct 1;37(4):271-8.
51. Lao HC, Tao VY, Wu AM. Theory of planned behaviour and healthy sleep of college students. Australian Journal of Psychology. 2016 Mar 1;68(1):20-8.
52. Branscum P, Fay KQ, Senkowski V. Do different factors predict the adoption and maintenance of healthy sleep behaviors? A reasoned action approach. Translational Behavioral Medicine. 2020 Feb;10(1):78-86.
53. Hessler DM, Fisher L, Polonsky WH, Bowyer V, Potter M. Motivation and attitudes toward changing health (MATCH): a new patient-reported measure to inform clinical conversations. Journal of Diabetes and its Complications. 2018 Jul 1;32(7):665-9.

54. Rajabi Majd N, Broström A, Ulander M, Lin CY, Griffiths MD, Imani V, Ahorsu DK, Ohayon MM, Pakpour AH. Efficacy of a theory-based cognitive behavioral technique app-based intervention for patients with insomnia: randomized controlled trial. Journal of Medical Internet Research. 2020 Apr 1;22(4):e15841.

55. Reifman J, Kumar K, Khitrov MY, Liu J, Ramakrishnan S. PC-PVT 2.0: An updated platform for psychomotor vigilance task testing, analysis, prediction, and visualization. J Neurosci Methods. 2018;304:39-45.

56. Culbertson WC, Zillmer EA. The Tower of LondonDX: A standardized approach to assessing executive functioning in children. Arch Clin Neuropsychol. 1998;13(3):285-301.

57. Lam YC, Li C, Hsiao JHW, Lau EYY. A sleepless night disrupts the resolution of emotional conflicts: Behavioural and neural evidence. J Sleep Res. 2024;33(5):e14176.

58. Zhang JX, Lau EYY, Hsiao JH. Using emotion regulation strategies after sleep deprivation: ERP and behavioral findings. Cogn Affect Behav Neurosci. Apr 2019;19(2):283-295.

59. Jöreskog KG, Sörbom D. LISREL 12. Skokie (IL): Scientific Software International; 2022.

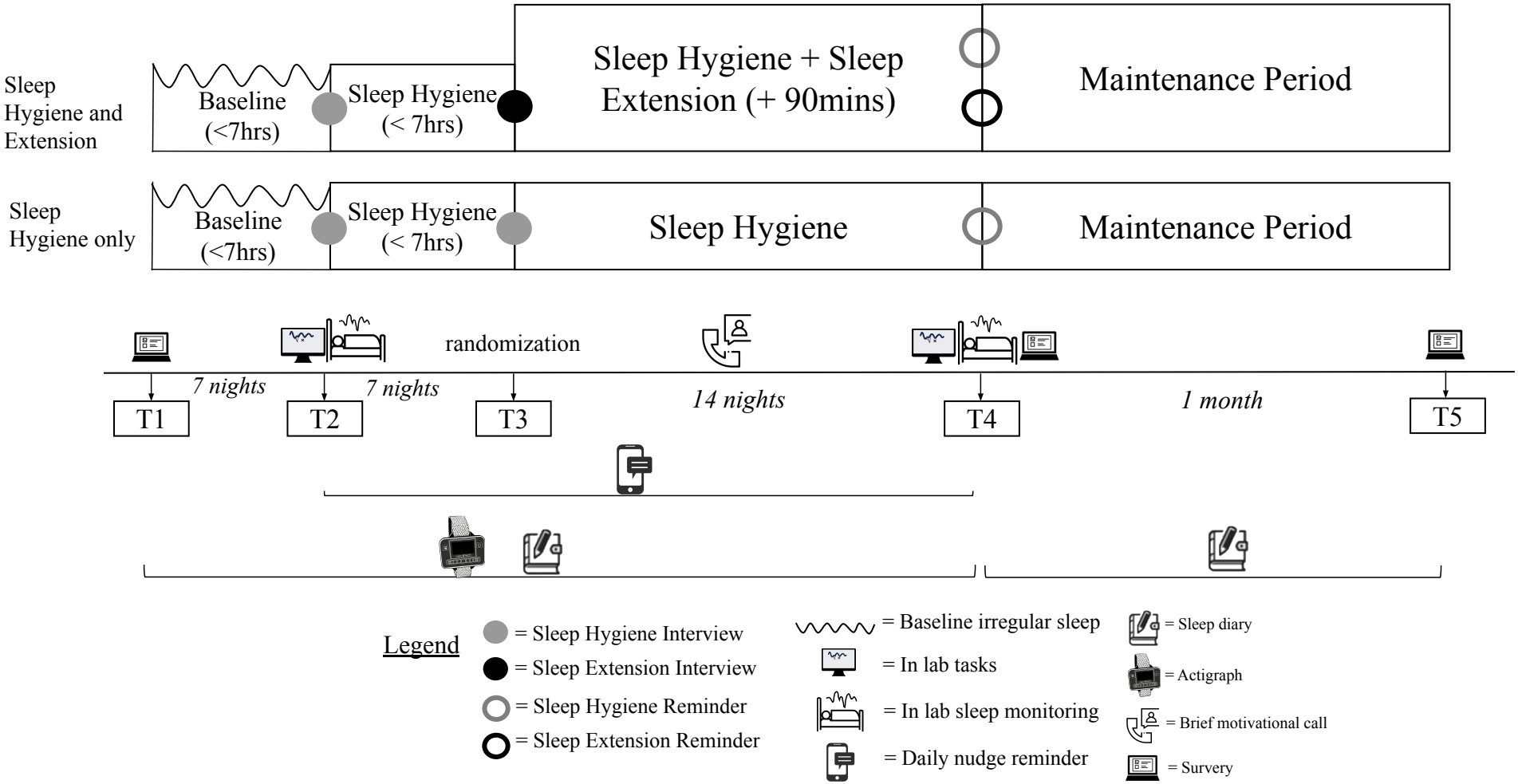
60. Braun V, Clarke V. Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches. Couns Psychother Res. 2021;21(1):37-47.

61. Hennink M, Kaiser BN. Sample sizes for saturation in qualitative research: a systematic review of empirical tests. Soc Sci Med. 2022;292:114523.

62. van Buuren S, Groothuis-Oudshoorn K. mice: multivariate imputation by chained equations in R. J Stat Softw. 2011;45:1-67.

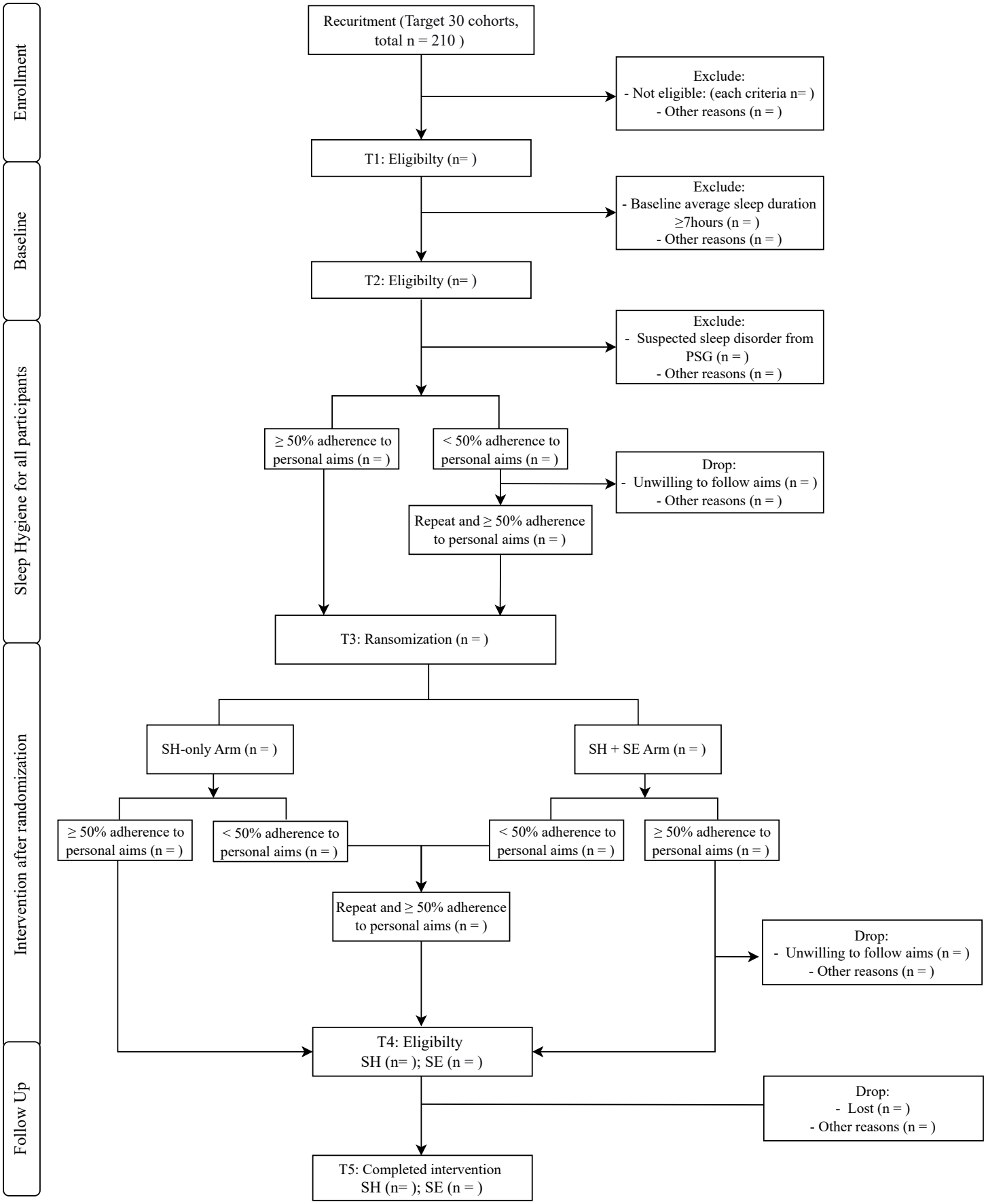
63. The Sleep, Spirituality and Human Flourishing Website https://ftbc-psych.wixsite.com/sshf.

64. Zhao SZ, Wang MP, Viswanath K, Lai A, Fong DYT, Lin CC, et al. Short sleep duration and insomnia symptoms were associated with lower happiness levels in Chinese adults in Hong Kong. Int J Environ Res Public Health. 2019;16(12):2079.


Sleep Hygiene and Extension
Baseline (<7hrs)
Sleep Hygiene (< 7hrs)
Sleep Hygiene + Sleep Extension (+ 90mins)
Maintenance Period
Sleep Hygiene only
Baseline (<7hrs)
Sleep Hygiene (< 7hrs)
Sleep Hygiene
Maintenance Period
randomization
7 nights
7 nights
14 nights
1 month
T1
T2
T3
T4
T5
Legend
= Sleep Hygiene Interview
= Sleep Extension Interview
= Sleep Hygiene Reminder
= Sleep Extension Reminder
= Baseline irregular sleep
= In lab tasks
= In lab sleep monitoring
= Daily nudge reminder
= Sleep diary
= Actigraph
= Brief motivational call
= Survery

Participant timeline: Schedule of enrollment, interventions, and assessments.

	STUDY PERIOD				
	Enrollment	**Pre intervention**	**Post-randomization**		
TIMEPOINT	**T1**	***T2***	***T3***	***T4***	***T5***
ENROLLMENT:					
Eligibility screen	X	X			
Informed consent	X				
Randomization			X		
INTERVENTIONS:					
Sleep Hygiene and Extension group		—	—	—	
Sleep Hygiene only group		—	—	—	
ASSESSMENTS:					
Demographics	X				
Trait-level Sleep and Cognitive-Affective Questionnaires	X			X	X
In-lab Cognitive-Affective Tasks and Overnight Sleep monitoring		X		X	
Daily Sleep and Cognitive-Affective functions	—	—	—	—	
Behavior Change Psychological characteristics	X	X	X	X	X



Note: Other reasons will be detailed.
Abbreviation: PSG = polysomnography; T = Timepoint; SH = sleep hygiene; SE = sleep extension

Table 2. Motivational Interviewing Protocol for T2 and T3 Sessions

Interview Phase	Key Activities & MI Techniques	Example Interviewer Prompts / Actions	Purpose & MI Alignment
T2 Interview: Sleep Hygiene Engagement & Planning (40-minute for all)			
Reviewing Baseline Patterns	• Collaborative Review: Jointly review actigraphy data and sleep diary. • Neutral Information Sharing: Explain sleep parameters without labeling. • Eliciting Self-perception: Use open-ended questions and reflections.	• "Let's look at your sleep data together. I see your sleep onset time varied between 1 a.m. and 3 a.m. last week. What's your own sense of how that went?" • (After participant responds) "So, it feels quite unpredictable and sometimes frustrating." (Reflection)	MI Process: Engaging, Focusing. MI Principle: Express Empathy, Elicit (vs. Prescribe). Purpose: To understand the participant's perspective, build rapport, and establish a collaborative focus.
Evoking Motivation	• Focusing on Values: Explore perception towards better sleep and what it would enable. • Evoking Change Talk: Use open-ended questions to draw out participant's own reasons, desires, and needs for change (e.g., perceived benefit).	• "What aspect of your sleep are you most hoping to change through this program?" • "If your sleep were a bit more on track, what would be different for you during the day?" • "What makes improving this aspect of sleep important to you personally?"	MI Process: Focusing, Evoking. MI Principle: Develop Discrepancy (indirectly). Purpose: To strengthen the participant's intrinsic motivation by connecting sleep change to their personal values and goals.
Exploring Ambivalence & Barriers	• Assessing Barriers: Participant completes a series of likert scale questions on their sleep barriers; interviewer explores key items qualitatively. • Reflective Listening: Discuss the subjective experience towards the barrier. • Double-Sided Reflection: Acknowledge the ambivalence of change and to develop discrepancy.	• (Regarding nighttime phone use) "On one hand, staying up on your phone is the one time you truly relax and feel connected to yourself. On the other hand, it leaves you feeling exhausted the next morning, which is the opposite of taking care of yourself."	MI Process: Evoking. MI Principle: Roll with Resistance, Exploring Ambivalence. Purpose: To normalize ambivalence, reduce defensiveness, and help the participant articulate the cost of current behaviors versus their values.
Planning for Change	• Collaborative Goal Setting: Set a specific, personalized, and actionable sleep hygiene goal for the upcoming week, utilizing participant's own words (reflective listening). • Building Self-Efficacy: Affirm strengths, explore past successes.	• "What's one small, specific step you'd be willing to try this coming week?" • "You mentioned successfully managing your schedule during exams before. What skill from that could you apply here?" (Affirmation & Evoking)	MI Process: Planning. MI Principle: Support Self-Efficacy, eliciting change talk. Purpose: To translate motivation into a concrete, personalized, and confidence-building action plan.

	• Problem-Solving: Brainstorm "if-then" plans for anticipated challenges.	• "If the urge to scroll social media at bedtime comes up, what's your backup plan in addressing it?"	
Nudge Personalization & Education	• Tailoring Support: Participant selects nudge categories and timing. • Providing Resource: Participant watches the 2-min sleep hygiene education video.	• "To support our plan, you can choose reminders about XX. What time of day would be most helpful for you to receive them?" • "Here's a short video summarizing key sleep tips. Let's watch it, and you can tell me if anything stands out."	Purpose: To operationalize support and provide standardized education that reinforces and informs the personalized plan.
T3 Interview: Progress Review & Plan Adjustment (30-minute for sleep hygiene only group, 40-minute for sleep hygiene and sleep extension group)			
Reviewing Progress (all groups)	• Eliciting Self-Evaluation: Ask for self-assessment of the past week, and review sleep data together • Exploring Successes & Challenges: Use reflections to deepen understanding of personal strengths and difficulties faced.	• "Looking back at the past week and the goal we set, what do you feel went well?" • "You tried going to bed earlier, but it was tough on nights with social events. What did you learn from that? How do you feel about it?"	MI Process: Engaging, Evoking. Purpose: To assess adherence, reinforce successes, and understand persistent barriers in an MI-consistent manner.
Sleep Extension Planning (sleep hygiene and extension group only)	• Providing Resource: Participant watches the 5-min educational video on the benefits of adequate sleep duration. • Collaborative Scheduling: Map out a realistic 90-minute extension plan based on participants' schedule and circadian rhythm; Should participants be unable to think of any goals, suggestions are provided and adopted should the participant agree.	• "Based on your schedule, if we aimed to find an extra 90 minutes for sleep, where might the most realistic opportunities be? Could it be going to bed earlier, waking later, or a mix of the both? Would breaking down the 90-minute extension into smaller, manageable increments be more realistic?"	MI Process: Planning. Purpose: To collaboratively develop a personalized sleep extension strategy based on the T3 review.

Note: MI = Motivation interviewing.

Table 3. Daily nudge text messages sent to participants.

Category	Sub-category	Objective	EAST Framework	Example nudges	Example nudges (translated)
Daylight exposure	-	To increase participants' visual exposure to natural light. Addressing daytime sleepiness, nighttime wakefulness, and circadian rhythm	Easy	🌞将手機/電腦背景換成自然風光🏞️，提醒自己出去走走。	Change your phone/computer wallpaper to a nature scene, to remind yourself to go outside more.
			Attractive	🌞安排在戶外吃午飯🍽️，在享受美食的同時也享受陽光。	Plan to have lunch outdoors. Enjoy your meal and the sunshine at the same time.
Physical activity	-	To increase participants' physical activity level. Addressing low daytime activity (i.e., facilitating nighttime sleepiness)	Social	🤸邀請或者加入朋友一起做運動吧！互相監督和鼓勵，共同進步👫。	Invite or join a friend for some exercise! Motivate and encourage each other to make progress together.
			Easy	🤸行樓梯替代坐電梯🪜也是一種很好的運動。	Take the stairs instead of the elevator. It's a simple, great way to get moving.
Eating habits	Alcohol use	To address problematic (in terms of use timing and/or amount) alcohol use	Timely	把囤積在家裏的酒精飲品送給別人或藏起來，減少飲酒的誘惑。	Give away or hide the alcoholic drinks you have at home to reduce temptation.
			Easy	將水杯放在酒杯前面，每次倒酒時先倒水，提醒自己適量飲酒。	Place your water glass in front of your wine glass. Pour water first each time as a reminder to drink in moderation.
	Caffeine use	To address problematic (in terms of use timing and/or amount) caffeine use	Timely	☕🚫在咖啡製作區貼上標簽🤌提醒適量飲用咖啡。	Put a label on your coffee station to remind yourself to drink coffee in moderation.
			Easy	☕🚫提前為下午的工作/學習準備一杯果汁🍹作爲咖啡的替代吧。	Prepare a cup of juice in advance for your afternoon work/study session as an alternative to coffee.
	Timing, portions, and food types	To address problematic (in terms of use timing and/or amount) eating behaviors	Easy	🥣保持每日規律的飲食，定時定量的🍳早餐🍝午餐🍲晚餐，有助於維持生理節律和睡眠質量。	Maintain a regular daily diet with timed, balanced meals (breakfast, lunch, dinner). It helps regulate your body's rhythm and improve sleep.
			Timely		

				🥣晚餐後避免過量進食，如果睡前很餓，選擇輕食🍌如水果或堅果，有助於消化和睡眠。	Avoid heavy eating after dinner. If you're hungry before bed, choose a light snack like fruit or nuts to aid digestion and sleep.
Nighttime sleep habits	Sleep timing and regularity	To address irregular sleep/ circadian patterns (e.g., weekday-weekend differences)	Social	💤⏱️告知自己的家人自己在改善睡眠，将社交时间调整在白天而不是晚上。	Tell your family you're improving your sleep, and schedule social time during the day instead of late at night.
			Timely	💤⏱️建立穩定的睡前程序，如洗澡、刷牙、閱讀等，幫助你的大腦和身體知道該準備入睡了。	Create a consistent bedtime routine—like showering, brushing your teeth, or reading—to let your brain and body know it's time to wind down.
	Room environment	To improve sleep environment (e.g., distractions; light)	Easy	💤🛏️維持良好的睡眠環境，將臥室裡與休息無關的東西盡量移走，確保床鋪舒適、房間安靜。	Keep your bedroom for rest. Remove items unrelated to sleep, make sure your bed is comfortable, and keep the room quiet.
			Attractive	💤🛏️保持床上用品的清潔度，每周清潔床上用品，將床上用品在陽光下晾曬，有助於減少細菌和增添清新的太陽香味。	Keep your bedding fresh. Wash sheets weekly and air them in the sun to reduce germs and add a fresh, clean scent.
Digital and social media use	Use timing	To reduce excessive late-night media use and to increase awareness of one’s digital use	Timely	📵⏱️社交媒體永遠在線，而你的大腦現在需要下線！	Social media is always online—but your brain needs to be offline now!
			Timely	📵⏱️關閉不必要的通知🔕 避免在夜間被打擾，影響睡眠質量。	Turn off unnecessary notifications at night to avoid disruptions and protect your sleep quality.
	Use type	To shift intensive digital use habits (e.g., social media) to more sleep-compatible digital behaviors (e.g., music; diary writing)	Timely	📵📝睡前兩小時，如果需要使用手機，請選擇放鬆的內容，如輕音樂或冥想應用，而不是刺激或情感激烈的社交媒體內容	If you use your phone two hours before bed, choose relaxing content like light music or a meditation app—not stimulating or intense social media.
			Easy	📵📝將社交媒體、遊戲、短視頻相關應用圖	

			標隱藏，或設置到手機屏幕的第二頁，減少在屏幕上的視覺提示，降低使用衝動。	Hide social, gaming, or short-video app icons, or move them to your phone's second screen. Reduce visual cues to lower the urge to use them.
Other digital usage (watching videos/ streams; gaming)	To address other forms of digital use (e.g., watching videos; livestreams; gaming)	Timely	📺 🎮 在床上就好好休息吧，把床鋪與睡眠聯繫起來，而不是與娛樂活動聯繫。	Let your bed be for rest. Connect it with sleep, not entertainment.
		Attractive	📺 🎮 晚間選擇舒緩的背景輕音樂或白噪音，代替數碼娛樂，幫助大腦進入放鬆狀態。	In the evening, choose calming background music or white noise instead of digital entertainment to help your brain relax.

Note. Each domain contains 10–20 distinct nudges. Nudges are sent as-is or are individualized should participants request it or find other reminders more useful (e.g., some find a reminder 30 minutes prior to bedtime useful to nudge them to prepare for bed). Each participant chooses up to three categories of nudges and selects the time for each nudge to be sent each day from T2-T4. At T3, participants provide feedback on the nudges and suggest changes to the content and/or time of sending if necessary.

Table 4. Treatment Fidelity Strategies for Monitoring and Improving Provider Training and Treatment Delivery

NIH BCC Component	MI Strategies	Strategies for Helpers
Standardized Training & Reduce Differences Within Treatment	• Standardized MI Training: Both interviewers learn MI skills from MI Network of Trainers (MINT). To ensure uniform skill application, they conduct a recorded 20-minute role-play session with an MI expert. • Structured Protocols & Materials: All intervention sessions are guided by a standardized interview protocol (outlining key themes/steps and MI-consistent prompts) and supported by uniform participant-facing slides. A shared note-taking template is used for interviewers to document interview contents, promoting consistency.	• Uniform Technical Training: All helpers received hands-on training sessions from equipment suppliers and the project lead, ensuring identical foundational knowledge for Actigraphy, Belun Ring, PSG, and EEG setup. • Detailed Operational Manuals & Scripts: For each timepoint (T1 briefing, T2/T4 lab assessments), helpers follow both a quick-reference checklist and a comprehensive, step-by-step manual with verbatim scripts for participant interaction. • Nudge sending: Sending pre-written nudges based on the participant's individualized plan provided by interviewers.
Ensure Provider Skill Acquisition	• Performance-Based Certification: Prior to the study, each interviewer conducted a full pilot interview with a consenting participant. The audio recording was reviewed by a clinical psychologist and MINT-certified trainer against predefined MI competency criteria to certify interviewers' readiness. • Continuous Learning: Subscribe to Everyday MI to maintain learning and improvement.	• Demonstrated Competency: Before independent operating of technical procedures, each helper was required to demonstrate proficiency in all technical procedures (e.g., PSG/EEG setup) under observation of the project lead. • Nudge sending: Nudges will be sent in the participants' group, with monitoring by the interviewer.
Minimize Provider Skill "Drift"	• Regular Peer Supervision: The two interviewers hold structured debriefing meetings. They cross-review each other's notes and reflections, discuss challenging cases, and align their strategies to prevent drift and maintain intervention integrity. • Access to Expert Supervision: For complex cases or disagreements, the interviewers schedule a meeting with the supervising clinical psychologist for consultation and problem-solving.	• Scheduled Fidelity Checks: The project lead conducts direct observational checks on each helper's performance frequently to ensure continued adherence to the technical protocols. • Support & Resources: A project helper WhatsApp group provides a platform for helpers to instantly seek clarification and report issues. Additionally, instructional videos of all procedures are available for helpers to review as a booster between infrequent lab sessions.

Accommodate Provider Differences	Both interviewers are PhD candidates in sleep science under the same supervisor, ensuring a shared theoretical foundation. The intensive, standardized training and ongoing peer supervision are designed to homogenize their delivery style, minimizing the impact of individual differences.	All helpers are undergraduate or graduate psychology students. The project lead provides continuous, centralized oversight of all procedures. The combination of detailed manuals, the supportive WhatsApp group, and the provider-centered training ensures that helpers of varying experience levels can perform their duties effectively.
Control for Provider Differences	While not a formal primary measure, each participant will be assigned to one interviewer for the entire intervention, and the extensive standardization efforts aim to minimize inter-interviewer variability.	Not Applicable. The role of helpers is primarily technical and standardized, with minimal therapeutic interaction that could be perceived differently by participants.
Ensure Treatment Adherence	• Interview Guidance: The interview protocol template helps providers maintain focus on the intervention content. • Post-Interview Documentation: After each interview, the interviewer sends the agreed-upon sleep plan and goals to the participants' WhatsApp group, with the project lead monitoring for any omissions or deviations.	• Participant Tracking Sheets: A comprehensive checklist is used at every timepoint to ensure all tasks (survey, in-lab tasks, PSG setup, etc.) are completed accurately and in sequence. Also, any deviations or technical issues (e.g., poor signal quality, participant compliance) are documented on tracking sheets, allowing for proactive management and ensuring protocol adherence. The project lead regularly audits these sheets.
Minimize Contamination Between Conditions	The study uses an active control design. Interviewers are trained on the specific protocols for each group, with a clear emphasis on withholding SE instructions from the SH-only group during the T3-T4 phase. The ethical principle of maximizing participant benefit is upheld; any natural sleep improvement in the control group is noted but not actively discouraged.	Helpers are blinded to the participant's group assignment where possible (e.g., during T2 assessments before randomization). Their scripts and tasks are identical for all participants at T1, T2, and T4, minimizing the risk of inadvertently delivering intervention content.

Note. MI = Motivational interviewing; SH = Sleep hygiene; SE = Sleep extension; PSG = Polysomnography; EEG = Electroencephalography; BCC = Behaviour Change Consortium

Table 5. Variables, Instruments, and Assessment Schedule for (a) Daily Home-Based Assessments and (b) Five-Time Surveys

Domain	Sub-domain / Variable (no. items of each sub-domain)	Specific Measure / Instrument with Reliability in Chinese sample if available (Cronbach's Alpha)	Unit/Scoring (higher scores indicate…)	Assess at
Primary Outcome				
At-home sleep	Total sleep time (1)	*Actigraphy and Consensus Sleep Diary [30] The lights off time and wake up time are calibrated with sleep diary, and sleep variables are extracted from Actigraphy via MotionWare software Version 1.4.25, CamNtech Ltd	minute	Daily (T1-T5)
Secondary Outcomes				
At-home sleep	Sleep onset latency	Actigraphy	minute	Daily (T1-T5)
	Sleep efficiency		%	
	***Central phase measure		minute	
	Sleep fragmentation		wake frequency	
	Sleep variability		hh/mm	
	Sleep satisfaction (1)	**Morning questionnaire - Consensus Sleep Diary	1-5 (Higher satisfaction)	
	Morning vitality (1)		1-5 (Higher vitality)	
	Sleepiness (1)	Actigraphy - please select the number that best describes your current state of sleepiness [31]	1-8 (Higher sleepiness)	Daily (T1-T4)
At-home cognitive-affective functions	Positive affect (4)	Actigraphy - modified Positive and Negative Affective Schedule [32]	1-5 (Higher positive affect)	Daily (T1-T4), five random actigraphy prompts (built-in questionnaires), filled in at least 3 times per day
	Negative affect (5)		1-5 (Higher negative affect)	
	Emotion regulation strategy: Acceptance; Distraction; Avoidance; Suppression; Reappraisal; Rumination	Actigraphy - modified Emotion Regulation strategy [33]	1-5 (Higher use of each strategy)	
	Emotional well-being (5)	**Evening questionnaire - WHO-5 Well-Being Index (0.85 in Chinese university students) [34]	1-5 (Better wellbeing)	Daily (T1-T5)

	overall function (1)	**Evening questionnaire - In what ways did the quality and quantity of your sleep affect your work, studies, or social interactions today?	1-5 (Greater impact)	
	Memory (1)	**Evening questionnaire - How would you rate your memory today?	1-5 (Better memory)	
	Concentration (1)	Actigraphy - Is your mind wandering away from your current task?	1-5 (1: My mind is blanking; 2: I'm thinking about the future; 3: I'm thinking about the past; 4: I'm distracted by things around me; 5: I'm focused on the task)	Daily (T1-T4)
Trait sleep	Sleep quality - Subjective sleep quality (1); Sleep latency (2); Sleep duration (1); Habitual sleep efficiency (3); Sleep disturbances (9); Daytime dysfunction (2)	#Chinese-Pittsburgh Sleep Quality Index; (0.82-0.83 in Chinese adults with primary insomnia and healthy controls) [35]	0-3 (Worse sleep quality)	T1; T4; T5
	Bedtime procrastination (9)	Bedtime Procrastination Scale (0.89 in Chinese undergraduates) [36]	1-5 (More instances of bedtime procrastination)	
	Chronic sleep reduction - Shortness of sleep (6); Irritation (5); Loss of energy (5); Sleepiness (4)	Chronic Sleep Reduction Questionnaire [37]	1-3 (More chronic sleep reduction)	
	Chronotype (13)	Composite Scale of Morningness [38] (0.84 in Chinese university students [39]	1-5 (Stronger morningness preference)	
	Sleepiness (8)	Chinese-Epworth Sleepiness Scale (0.81 in Chinese English bilinguals) [40]	0-3 (Higher chance of dozing)	
	Sleep hygiene practice (19)	Sleep Hygiene Practice Scale [41]	0-5 (Higher agreement with each sleep practice statement)	
	Sleep knowledge (15)	Sleep Knowledge Questionnaire [42]	0-1 (true, false, or "don't know")	
Trait cognitive-	Depression (7), anxiety (7), and stress (7) symptoms	Depression Anxiety Stress Scale (0.8-0.83 in Chinese college students) [43]	0-3 (More experience of symptoms)	T1; T4; T5

affective functions	Positive and negative emotion reactivity - Activation (6); Intensity (6); Duration (6)	Perth Emotional Reactivity Scale-Short Form [44]	1-5 (Higher agreement with emotion reactivity items)	
	Difficulty in emotion regulation - Strategies (3); Non-acceptance (3); Impulse (3); Goals (3); Awareness (3); Clarity (3)	Difficulties in Emotional Regulation Scale-Short Form (0.88 in Chinese university students) [45]	1-5 (More difficulties in emotion regulation)	
Trait psychological characteristics for behavior change	Perceived threat of short sleep - Perceived susceptibility/ likelihood and severity/ impact (17)	Adapted 10-item short and 7-item long term effect examining the specific potential outcomes of short sleep [46-47]	1-5 (Higher perceived threat)	T1; T4; T5
	Perceived benefit of sufficient sleep (4)	Health Belief items on perceived benefits [48]	1-5 (More perceived benefit)	T1; T4; T5
	Perceived sleep self-efficacy (9)	Sleep Self-Efficacy Scale [49]	1-5 (Higher self-efficacy)	T1; T2; T3; T4; T5
	Internal cues to sleep (5)	Internal cues to sleep [48]	1-5 (Higher likelihood of achieving continuous sleep)	T1; T4; T5
	Subjective norms - Injunctive norms (4); Descriptive norms (4)	Adapted items for injunctive and descriptive norms [51-52]	1-7 (Higher agreement to normative statements)	
	Attitude of changing sleep behavior (6)	Adapted items for Attitudes [52]	1-5 (More positive attitudes toward changing sleep behavior)	
	Motivation toward changing sleep behavior (9)	Motivation and attitudes toward changing health [53]	1-5 (Higher confidence with changing sleep)	T1; T2; T3; T4; T5
	Sleep behavior change intention (1)	“I intend to implement healthy sleep practices/extend my sleep everyday"	1-5 (Later stages of change according to change theory)	
	Action (4) and coping (5) plan	Action planning and coping planning scales [54]	1-5 (Higher agreement to readiness to act and cope with behavior change challenges)	T2; T3

* Consensus Sleep Diary administered across T1-T5, actigraphy across T1-T4
** Morning diary is completed within 30 minutes of waking up, evening diary is completed within 1 hour before bedtime
*** Sleep midpoint between “Fell asleep” and “Wake up”, expressed as the number of minutes past midnight
# All Pittsburg Sleep Quality Index subscales except the sleep medication item were used
Note. Cronbach's alpha for each scale and subscale will be computed after completion of data collection.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementaryitems.pdf