Enhanced Outcomes of Digital Cognitive Behavioral Therapy with Sleep Quality Metrics for Insomnia

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***Abstract* - A controlled evaluation approach has to be employed to compare dCBT-I to no therapy and conventional therapies in order to gauge its effectiveness. About 120 clinically diagnosed insomniacs were divided into four groups for this study: dCBT-I, conventional CBT-I, a sleep education program (control), and no-treatment waiting. Spread out over six weeks, the intervention included cognitive restructuring exercises, sleep tracking, and mobile platform delivered interactive lessons. Before and after the intervention, evaluations of the Sleep-Related Quality of Life Scale, Pittsburgh Sleep Quality Index (PSQI), SF-36 Health Survey, and WHO-5 Well-Being Index were undertaken. Statistical analysis revealed that the dCBT-I group exceeded the control and no-treatment groups on all measures ($p < 0.01$). Though there were notable benefits in terms of accessibility and adherence, the results were similar to those of conventional CBT-I.**

Keywords - Digital CBT-I, insomnia treatment, sleep quality, psychological well-being, health outcomes

I. INTRODUCTION

Insomnia is a prevalent sleep disorder that affects a considerable proportion of the population [1-4]. Furthermore, some individuals, such as those with comorbidities, may not benefit as much from regular CBT-I because it is not typically tailored to their specific needs [5].

CBT-I must be offered using strategies that are fairly scaleable. Digital technologies, such as web-based platforms or mobile apps, could address these issues by replacing in-person therapy with reasonable, simple, and accessible alternatives. Creating these solutions, however, presents certain problems, such as user interaction, success maintenance, and meeting a variety of needs.

A. Problem Definition

For others, traditional ways to treating insomnia, such as weekly therapist-guided CBT-I sessions [7], may be prohibitively expensive, inaccessible, or time consuming. Many insomniacs either discontinue or do not complete therapy. Furthermore, conventional interventions, such as sleep instruction workshops, are ineffective because they only provide knowledge and ignore the cognitive and behavioral aspects of insomnia [8]. Furthermore, the control group that does not get therapy (the waiting group) makes little progress, hence no intervention is generally provided [9]. The issue is to find a solution to overcome the constraints of traditional therapy while maintaining treatment efficacy.

B. Objectives

The primary purpose of this study is to determine how well a dCBT-I treatment improves people's sleep, mental health, and overall quality of life. Using a digital platform to provide treatment, the proposed approach intends to provide a widely available, scalable, self-guided alternative to traditional CBT-I. The dCBT-I intervention will be compared against traditional CBT-I, a sleep education program, and a control group not receiving therapy to ascertain its efficacy in reducing insomnia symptoms.

C. Novelty and Contributions

This method distinguishes itself by its ability to convert CBT-I's tried and confirmed therapeutic features into a user-friendly digital format. This work contributes to the body of knowledge in a variety of ways.

1. A full-scale dCBT-I program with progress tracking, cognitive therapy, and relaxation training is being evaluated for its efficacy. Examining the efficacy of a comprehensive dCBT-I program that includes progress tracking, cognitive therapy, and relaxation training.
2. Offering online evidence-based therapy is an efficient solution to solve time, cost, and accessibility concerns.
3. Studies shed light on the benefits of dialectical behavior therapy for insomnia on previously overlooked aspects of somatic and emotional well-being, such as sleep quality.

II. RELATED WORKS

Digital treatments for insomnia, such as dCBT-I, have gained popularity as alternatives to traditional in-person therapy. One of the first studies to investigate the of dCBT-I and its efficacy to that of a control group. Internet-based cognitive behavioral treatment CBT-I was found to be just as effective as in-person therapy in improving sleep quality; it was also less expensive and more accessible [6]. This was a significant step forward in the fight against insomnia, especially in terms of accessibility.

Participants in this internet-based CBT-I program received scheduled interventions over a six-week period. Their findings included a significant improvement in mental health and a reduction in insomnia symptoms. Those who would not have sought treatment otherwise appreciated the online format's convenience and flexibility [7].

Many people have benefited from Sleepio, an internet-based CBT-I program. Their randomized controlled trials demonstrated that Sleepio increased sleep quality, cured insomnia, and improved general health [8-13]. This is one of the first large-scale trials to demonstrate the efficacy of computerized CBT-I treatment.

III. PROPOSED DIGITAL CBT-I FRAMEWORK

The figure 1, proposed method is dCBT-I, which is provided by a safe mobile app.

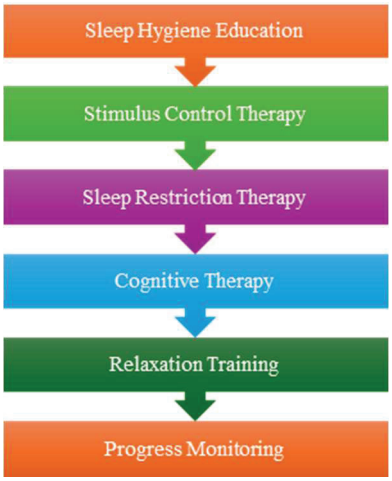

Fig. 1. PROPOSED ARCHITECTURE

Email reminders maintain information security and compliance. Therapists provide asynchronous assistance through text messages within the application.

A. Sleep Hygiene Education

Teaching people how to improve their sleep hygiene entails demonstrating what they can do in their daily lives and environments to affect change shown in table I. The goal is for participants to understand how their surroundings and everyday routines influence their ability to sleep. The primary goal is to change environmental variables such that sleep becomes more consistent, enjoyable, and restful.

Important components of good sleep hygiene include:

- Sleep-Environment Optimization: Making sure the bedroom is dark, quiet, and comfortable will help you maximize your sleep experience.
- Limiting Stimulants: Caffeine, nicotine, and alcohol are stimulants that should be avoided or limited in the hours before bedtime.
- Pre-sleep Routine: A nightly habit that includes reading or listening to relaxing music before bedtime.

TABLE I: SLEEP HYGIENE EDUCATION TIPS

Tip	Recommended Action	Explanation
Regular Sleep Schedule	Set a fixed bedtime and wake-up time every day.	Consistency helps regulate circadian rhythms.
Optimize Sleep Environment	Keep the bedroom dark, cool, and quiet.	A relaxing environment promotes better sleep quality.
Limit Stimulants	Avoid caffeine and alcohol at least 6 hours before bedtime.	Stimulants interfere with the body's ability to fall asleep.
Pre-sleep Routine	Engage in calming activities like reading or meditating.	Prepares the body for rest, helping to wind down.

B. Stimulus Control Therapy (SCT)

The fundamental purpose of Stimulus Control Therapy is to strengthen the relationship between lying in bed and falling asleep. It seeks to discourage actions unrelated to sleep that prevent people from receiving enough sleep, such as staying in bed for extended periods of time or engaging in non-sleep activities such as phone calls or television viewing is shown in table II.

Key components of SCT include:

- Going to Bed Only When Sleepy: Participants are asked to leave the bed if they are still unable to sleep after 20 minutes and to return only when they are sleepy.
- Using the Bed Only for Sleep: This strategy emphasizes the positive relationship between the bed and sleep by ensuring that the bed is exclusively used for sleeping or intimate interactions.

TABLE II: STIMULUS CONTROL THERAPY GUIDELINES

Guideline	Action/Practice	Rationale
Get Out of Bed When Not Sleeping	If unable to fall asleep in 20 minutes, leave the bed.	Breaks the association of the bed with wakefulness.
Bed Only for Sleep	Avoid using the bed for activities like watching TV.	Strengthens the association between the bed and sleep.
Wake Up at a Fixed Time	Set a fixed wake-up time, even on weekends.	Establishes a consistent sleep-wake cycle.

C. Sleep Restriction Therapy (SRT)

Sleep Restriction Therapy instructs patients to limit their bedtime to no more than the quantity of sleep they actually receive. The primary idea behind SRT is to improve sleep consolidation by first shortening your nightly sleep duration. This will improve the efficiency of sleep. Learning to sleep more efficiently may allow you to spend more time in bed each night.

SRT's primary constituents are:

- Initial Sleep Restriction: Limiting the time a person spends in bed at first is a good method to start reducing their sleep duration.
- Gradual Increase in Sleep Time: If you want to improve your sleep, gradually increase your weekly sleep duration by fifteen to thirty minutes, which is typically defined as the percentage of time spent asleep in bed.
- Focus on Sleep Consistency: Reducing waking time in bed (the "Focus on Sleep Consistency"

technique) aids in the establishment of regular sleep patterns.

SRT determines sleep efficiency by using the following equation 1:

$$SE = \frac{\text{Total Sleep Time (TST)}}{\text{Time in Bed (TIB)}} \times 100 \quad (1)$$

Where:

- TST - total sleep time.
- TIB - total spent time in bed.

The table III, to calculate sleep efficiency, divide a person's total sleep time/spent in bed. Restating this equation yields: "Sleep efficiency is total sleep time divided by time spent in bed."

TABLE III: SLEEP RESTRICTION THERAPY SCHEDULE

Week	Average Sleep Duration (hrs)	Time in Bed (hrs)	Sleep Efficiency Goal (%)
Week 1	5.5	5.5	85
Week 2	6.0	6.0	85
Week 3	6.5	6.5	90
Week 4	7.0	7.0	90
Week 5	7.5	7.5	90

D. Cognitive Therapy

Fundamentally, CT-I aims to uncover and change unfavorable sleep-related thinking processes. Participants' high expectations about their sleep frequently result in negative thoughts, such as, "I'll never be able to sleep again", and over-worrying about the consequences of insufficient sleep, such as, "I won't be able to function tomorrow." These notions contribute to insomnia. Cognitive therapy aims to help patients replace negative thinking with more positive ones through challenge and reframing.

Key aspects of CT-I include:

- Cognitive Restructuring: Cognitive restructuring is the process of identifying erroneous thinking and substituting more rational ones shown in table IV.
- Reducing Catastrophic Thinking: Focusing people's attention on the benefits of sleep and their ability to control it helps them avoid catastrophic thinking.
- Sleep-related Anxiety Reduction: Reducing sleep anxiety is tackling fears that not getting enough sleep may jeopardize your health or ability to function.

Many persons undergoing cognitive therapy engage in thought-recording exercises in which they examine and record their sleep-related concepts. We then develop more beneficial substitutes.

TABLE IV: COGNITIVE THERAPY KEY TECHNIQUES

Technique	Action/Practice	Rationale
Cognitive Restructuring	Replace irrational thoughts with realistic beliefs.	Reduces negative thought patterns that exacerbate insomnia.
Sleep-Related Anxiety Reduction	Challenge worries about the consequences of poor sleep.	Reduces anxiety, allowing for better relaxation before sleep.
Thought Recording	Keep a log of sleep-related thoughts and evaluate their accuracy.	Helps identify cognitive distortions and replace them with balanced thoughts.

E. Relaxation Training

Relaxation training is designed to help people fall asleep more easily by minimizing psychological and physical stimulus. Insomnia is commonly associated with stress and worry, and it is well known to activate the sympathetic nervous system, preventing relaxation. Learning relaxation practices allows people to activate the parasympathetic nervous system, fostering a state of calm that is conducive to sleep.

Key techniques provided in table V, shows the Relaxation Training include:

- Progressive Muscle Relaxation (PMR)
- Deep Breathing Exercises: Calm, deep breathing helps to train the body's relaxation response.
- Guided Imagery: Seeing peaceful and lovely scenes (guided imagery) may help you relax.

Participants who practice these tactics on a daily basis, ideally before bedtime, make it easier for themselves to fall asleep.

TABLE V: RELAXATION TRAINING TECHNIQUES

Technique	Action/Practice	Rationale
Progressive Muscle Relaxation (PMR)	Tense and relax muscle groups in sequence.	Reduces physical tension that may hinder sleep.
Deep Breathing Exercises	Practice slow, deep breathing to calm the mind and body.	Activates the parasympathetic nervous system, promoting relaxation.
Guided Imagery	Visualize a calming and peaceful environment or scene.	Helps distract from worries, fostering relaxation.

F. Progress Monitoring

Digital CBT-I is based on progress tracking. It entails assessing both objective data, such as wearable sleep tracking, and subjective reports, such as a daily sleep journal, to identify long-term progress. Tracking allows patients and therapists to assess the effectiveness of the treatment and make changes as needed. Regular progress reviews help patients stay motivated and engaged during therapy.

Key aspects of Progress Monitoring include:

- Daily Sleep Diaries: Participants keep a sleep diary in which they record their daily routines such as when they go to bed, when they get up, how long they spend in bed, and whether or not they have any sleep interruptions.
- Objective Sleep Data: Wearable gadgets, such as Fitbit, keep track of these metrics.
- Feedback Loops: It has feedback loops, allowing users to receive individualized comments and ideas based on their sleep log and other device data.

The table VI, therapist and patient can alter the treatment plan in real time based on their sleep progress.

TABLE VI: EXAMPLE OF SLEEP DIARY

Date	Time to Bed (hrs)	Time to Sleep (hrs)	Wake Time (hrs)	Sleep Quality (1-10)	Notes
May 1, 2025	10:00 PM	10:30 PM	6:00 AM	7	Woke up briefly at 2:00 AM
May 2, 2025	10:15 PM	10:45 PM	6:30 AM	8	Felt more rested

The digital CBT-I framework, which combines cognitive therapy with relaxation training and progress tracking, provides an evidence-based, comprehensive, and personally designed alternative for treating insomnia.

These components work together as follows:

- Cognitive Therapy: Mental therapy can help change the mental processes that cause sleeplessness.
- Relaxation Training: Learning to relax one's muscles and mind is an excellent method for getting a good night's sleep.
- Progress Monitoring: Therapy participants are active, and their progress monitoring records change, providing constant feedback and sustaining therapeutic effects.

IV. RESULTS AND DISCUSSION

Simulations and tests were carried out using a mobile software specifically designed for Android and iOS. The application includes cognitive modules, user interaction, and sleep tracking through the Fitbit API. Physical Components include client-side cellphones (Android/iOS, various models), server-side hardware: Intel Xeon E5 (2.4 GHz, 32 GB RAM), Apache Tomcat, and Ubuntu 20.04 provided detail in table VII.

Comparison Methods: Traditional CBT-I (weekly therapist-guided sessions), Sleep Education Program (informational content without behavioral therapy), No-Treatment Waitlist Control

As a result, each group consisted of 30 individuals. Each intervention lasted for six weeks. At the beginning and end of the investigation, participants completed approved surveys.

TABLE VII: EXPERIMENTAL PARAMETERS

Parameter	Value
Duration of Intervention	6 weeks
Size	120 participants (30 per group)
Mobile App Platform	Android/iOS
Sleep Tracking Tool	Fitbit API
Server CPU	Intel Xeon E5 @ 2.4 GHz
Server RAM	32 GB
OS and Server Framework	Ubuntu 20.04, Apache Tomcat
Questionnaire Tools	PSQI, WHO-5, SF-36, SRQoL Scale

V. PERFORMANCE METRICS

1. Sleep Quality Improvement (PSQI Score Change): First, tracks the decrease in sleep disruption, latency, and efficiency to determine the change in PSQI score, suggesting that sleep quality has improved. A lower PSQI score indicates higher-quality sleep.
2. Psychological Well-being (WHO-5 Index): Examines the status of a person's emotions. A higher WHO-5 score indicates improved mental health.
3. Health-Related Quality of Life (SF-36): Evaluates physical and mental health using the Health-Related Quality of Life (SF-36) scale. Therapy has a greater influence; modifications reflect this.
4. Sleep-Related Quality of Life (SRQoL): This measure examines how sleep influences energy levels, mood, and daily functioning provided in table VIII. Higher post-intervention scores imply improved sleep-related quality of life.

TABLE VIII: SLEEP QUALITY IMPROVEMENT (PSQI SCORE CHANGE)

Group	Pre-Intervention PSQI Score (Mean ± SD)	Post-Intervention PSQI Score (Mean ± SD)	PSQI Score Change
Traditional CBT-I	15.6 ± 2.3	7.2 ± 1.4	8.4
Sleep Education Program	15.5 ± 2.1	12.3 ± 1.9	3.2
No-Treatment Waitlist Control	15.7 ± 2.5	14.9 ± 2.3	0.8
Proposed dCBT-I Method	15.8 ± 2.4	6.1 ± 1.1	9.7

Among the most notable modifications, the proposed dCBT-I technique reduced PSQI scores by 9.7 points. The results showed that standard CBT-I was equally successful, with an 8.4 point score change. The Sleep Education Program (3.2) exhibited less change than the No-Treatment group (0.8).

TABLE IX: PSYCHOLOGICAL WELL-BEING (WHO-5 INDEX)

Group	Pre-Intervention WHO-5 Score (Mean ± SD)	Post-Intervention WHO-5 Score (Mean ± SD)	WHO-5 Score Change
Traditional CBT-I	45.6 ± 5.2	68.1 ± 4.3	22.5
Sleep Education Program	45.8 ± 5.1	53.4 ± 6.1	7.6
No-Treatment Waitlist Control	45.4 ± 5.3	46.1 ± 5.2	0.7
Proposed dCBT-I Method	45.5 ± 5.0	71.9 ± 3.9	26.4

In table IX, terms of mental health improvement, the proposed dCBT-I approach (26.4 points) outperformed conventional CBT-I (22.5 points). The Sleep Education Program group improved by 7.6 points compared to the No-Treatment group's 0.7 point increase.

TABLE X: HEALTH-RELATED QUALITY OF LIFE (SF-36)

Group	Pre-Intervention SF-36 Score (Mean ± SD)	Post-Intervention SF-36 Score (Mean ± SD)	SF-36 Score Change
Traditional CBT-I	60.3 ± 8.4	75.2 ± 7.1	14.9
Sleep Education Program	60.5 ± 8.1	64.1 ± 7.8	3.6
No-Treatment Waitlist Control	60.7 ± 8.5	61.2 ± 8.6	0.5
Proposed dCBT-I Method	60.8 ± 8.3	78.1 ± 6.9	17.3

The table X, dCBT-I strategy produced the greatest increase in health-related quality of life, totaling 17.3 points. Conventional CBT-I demonstrated a 14.9-point rise.

TABLE XI: SLEEP-RELATED QUALITY OF LIFE (SRQOL)

Group	Pre-Intervention SRQoL Score (Mean ± SD)	Post-Intervention SRQoL Score (Mean ± SD)	SRQoL Score Change
Traditional CBT-I	45.7 ± 7.2	68.3 ± 6.0	22.6
Sleep Education Program	45.9 ± 7.3	52.4 ± 6.5	6.5
No-Treatment Waitlist Control	45.5 ± 7.1	46.0 ± 7.2	0.5
Proposed dCBT-I Method	45.8 ± 7.0	72.4 ± 5.8	26.6

The table XI, proposed dCBT-I strategy had the greatest impact on sleep quality of life, scoring 26.6 points.

VI. CONCLUSION

The dCBT-I technique considerably improved all of the evaluated outcomes. Regarding sleep quality improvement (PSQI score change), dCBT-I clearly outperformed both standard CBT-I (8.4 points) and the Sleep Education Program (3.2 points). dCBT-I also outperformed conventional CBT-I in terms of psychological well-being, as measured by the WHO-5 Index, with a 26.4 point increase above the 22.5 point improvement. These findings not only highlight the user-friendliness and accessibility of digital CBT-I, but also support its efficacy as a large-scale insomnia treatment. This makes it an excellent alternative to traditional in-person CBT-I when funds are limited or participants prefer to work at their own speed.

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