A Q-Learning Model for Cognitive Behavioural Therapy of Insomnia Patients

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Abstract— **Cognitive Behavioral Therapy for Insomnia (CBTI), is an approach used to treat insomnia patients and is implemented as internet based Cognitive Behavioral Therapy for Insomnia (iCBTI). However, iCBTI has been implemented in a fixed policy manner, with predetermined generic responses made available for patients at different stages of insomnia treatment. This leads to a less specific treatment plan for the patient as well as longer treatment periods. This in the long run results into insomnia relapse. This research proposes a Q-Learning model that seeks to improve both the CBTI and iCBTI approach as a guided intervention approach in treating insomnia. This study employs a mixed research approach to analyze the existing CBTI and iCBTI processes and recommend a more specific treatment approach as a solution. The findings infer that the use of the proposed model reduces the time taken for the CBTI process by streamlining it into fewer necessary steps. This model also provides a foundation for the ongoing discussions on the effectiveness of using ensembles approach in machine learning solutions. It is recommended that CBTI practitioners and iCBTI applications employ the use of the proposed model to reduce their process time and thus in the long run reduce the chances of insomnia relapse.**

Keywords--Cognitive Behavioural Therapy for Insomnia, Insomnia, Internet Based Cognitive Behavioural Therapy, Ensembles, Q-Learning

I. INTRODUCTION (HEADING 1)

Insomnia is a psychological sleep disorder that is majorly characterized by racing thoughts and constant worry resulting into lack of sleep [1]. It is attributed to serious mental cases such as Schizophrenia and chronic depression; as well as social malpractices such as increase in alcoholism [2]: meriting it as a serious disorder. Cognitive Behavioural Therapy for Insomnia (CBTI) is a non-pharmacological approach used by most clinicians to treat both acute and chronic insomnia and has proven to be effective with a success rate of 70% [2]. As compared to other approaches such as Relaxation Training (RT) and Placebo Training (PT), the CBTI approach was clinically proven to have a deserving and important niche in the clinical management of patients suffering from Insomnia disorder [3].

CBTI aims at questioning the assumption behind the patient's thoughts and breaks the links between these thoughts. This normally involves the CBTI practitioner breaking down the cognitive process of the patient into four facets: fact, thought, emotion and consequence. A report by [1] exemplifies the thoughts of an insomniac patient and normal person as in *TABLE I*. One of the goals of CBTI is thus to get the insomniac patient to follow an almost similar thought process as that of a normal person who has no trouble falling asleep.

The proposed solution will guide the CBTI practitioner as the insomnia patient recursive traverse from one stage of therapy to the next. The aim of the Q-learner model is thus be to achieve an almost close synchronization between the duration of sleep as prescribed by the CBTI practitioner and patient's duration of sleep; hence in the long run reducing patient 's insomnia level.

TABLE I. INSOMNIAC VS. NORMAL THOUGHT PROCESS

Insomniac Patient (Sleep thief thought)	Normal Person (Alternative thought)
Fact: "I'm not feeling very sleepy right now"	***Fact***: "I'm not very sleepy right now"
Thought: "It's already 1:30am, I'm never going to get sleep"	***Thought***: "I'm not sleepy now: but I usually get some sleep during the night. Maybe I will be sleepy soon"
Emotion: "Everybody else is sleeping, I'm no good at sleeping"	***Thought 2***: "It doesn't matter whether or not I fall asleep. I can function well with little sleep. I will relax and not worry about it. I will fall asleep when my body is ready"
Consequence: Continued Lack of Sleep	***Consequence***: "I'm going to get out of bed to go to the toilet and drink some water. I will return to bed in a few minutes when I feel more sleepy"

The remaining sections of this paper is structured as follows: Section II reviews pre-existing works on CBTI. Section III describes the Research Methodology used in this. Section IV discusses the results obtained from tests conducted on a prototype of the build model Finally, Section V presents a discussion on the results obtained and Section VI summarizes the observations and recommendations through this research.

II. LITERATURE REVIEW

A. *Insomnia and Treatment Methods*

Insomnia is the subjective perception of difficulty with sleep initiation, duration, consolidation, or quality that occurs despite adequate opportunity for sleep, and that results in some form of daytime impairment [3]. Most studies classify insomnia only as a secondary symptom that is comorbid with other conditions [2]. However, with further research it has been ascertained that the gravity of the outcomes of chronic insomnia can cause impairment of the immune system, brain functionality, heart variability, impact mood, cause fatigue and even result in a delay of recovery and healing. These outcomes have thus made it possible for insomnia to be classified as a primary symptom warranting special treatment attention [4].

A variety of approaches have been used to treat insomnia. Sleep hygiene and pharmacological are normally the initial response to treating acute insomnia. However, the responses to these approaches have always been short-lived since patients in the long run develop tolerance to these procedure. This is as reported by [1] is because the approaches do not treat insomnia as a psychophysiological disorder thus only focusing on treating the physical aspect of the disorder.

Recent studies have thus proposed the use of both psychological and behavioral techniques to treat chronic and comorbid cases of insomnia. The behavioral intervention incorporates various therapies such as relaxation therapy, stimulus control therapy, sleep restriction therapy; all combined to form cognitive behavioral therapy for insomnia (CBTI) [5]. The behavioral aspect of the CBTI reinforces natural sleep-initiating and maintaining processes, such as sticking to routines, minimizing time in bed spent awake and lowering physical and psychological arousal at bedtime. Cognitive therapy on the other hand emphasizes on the presence of pre-sleep cognitions in patients who find it difficult to get to sleep thus challenging these thoughts to bring about cognitive restructuring [6].

B. *CBTI Process*

The CBTI process as outlined by [7] sets out to achieve the following objectives:

- To train the insomnia patient in re-associating the bed or bedroom with sleep and in re-establishing a consistent sleep-wake schedule.
- To reduce somatic tension or intrusive thoughts at bedtime that interfere with sleep
- To curtail the amount of time spent in bed to the actual amount of time spent asleep, thereby creating a mild sleep deprivation
- To eliminate performance anxiety which may inhibit sleep onset
- To change patients' beliefs and attitudes about insomnia and the behaviours which maintain it

These objectives breaks down the CBTI process into two major sessions. The first session is the Primary Treat Components session which normally lasts between 45 to 60 minutes. This session involves a presentation of treatment rationale to the patient, offering of sleep education, administering of behavioural regimen and instructing the patient on how to make adjustments in individualized Time in Bed (TIB) prescriptions [8]. The primary document that is normally used to aid this session is the sleep log which serves as the baseline data collected over a period of time; as outlined in *TABLE II*.

The second session involves the review of progress with a list of activities which normally spans from 30 to 45 minutes. These activities include the reviewing of sleep logs in order to advise on or alter the TIB prescription, reinforcement of the patient's compliance which is mostly reliant on the CBTI practitioners experience and trouble shooting of the patient's psychological problems [8], which is as exemplified in Table II.

TABLE II. SLEEP LOG TEMPLATE

Date	Mon 1/1/12	…	Fri	Average
What time did you get to bed?	10.30 p.m.			
About what time did you fall asleep?	12 a.m.			
In total about how long were you up in the middle of the night?	1 hours			
What time was you final awakening?	6.30 a.m.			
What time did you get out of bed for the day?	7 a.m.			
Time in Bed (#5 minus #1)	8.5 hours			
Total Time Asleep (#4 minus #2 minus #3)	5.5 hours			
Sleep Efficiency (Time Asleep/Time in Bed)	65%			
How would you rate your quality of sleep?	☐ Very Poor ☐ Fair ☐ Good ☐ Very Good			
In total how long did you nap or doze yesterday?	45 min			
Comments (If applicable)	I have a cold			

C. CBTI for the Internet (iCBTI)

Cognitive Behavioural Therapy for the Internet (iCBTI) consists of a number of methods used to deliver CBT via interactive computer interface hosted on the internet [9]. As further stated by [9], the structured nature of CBTI has made it ideal for it to be adapted as a web program and to be delivered via the internet. iCBTI has been preferred over the traditional CBTI methods due to the fact that it is cost-effective, less intimidating, allows patients to work at their own pace and easily accessible to patients who are in the very remote geographical areas. However to the contrary, the iCBTI approach has been plagued with many shortcomings including concerns over confidentiality, enforcement of legal and ethical codes and inability to respond to crisis situations.

The two major players of internet CBTI according to Gerhard, (2010) are the Randomized Controlled Trials (RCT) by [10] and the Sleep Healthy Using the Internet (SHUTi) program as investigated by [11]. Both of these approaches work interactively by presenting the patients with quizzes in various formats such as text based quizzes, mp3 files, videos and gaming interfaces.

The self-help internet based CBTI suggested by [10] is broken down into three main phases. The first is the registration and basic education phase where the participants sign up with the system and get basic education on sleep and insomnia as well as healthy sleeping habits. The second phase involves daily monitoring of the participants. This involves daily emails that prompts the user on; adherence to the prescribed sleep hygiene, their sleep quality, their total sleep hours in the previous night and their mood that morning on a five point scale. The third module conducts the weekly assessment which generates report based on the daily sleep performance of the participant as well as their sleep e-diaries.

The SHUTi system is made up of 6 cores that employ behavioral, educational and cognitive techniques in treatment of the patient [11]. The first core, just as in the RCT approach, provides the patient with basic rational on using the system [10]. The system generally works by providing the patient with a set of rules to follow so as to regulate their sleep-wake schedule and strengthen the association between the bed or bedroom, bedtime, and sleep among other beliefs associated with sleep. Prior to the commencement of the SHUTi exercise the patients are required to complete the Insomnia Severity Index (ISI) exercise online that then recalibrates the kind of exercise that the patient will perform as they interact with the system [11].

However the therapy procedures, responses and exercises existing in both the systems are fixed responses despite the fact that the route taken to cure a patient is predetermined by their ISI. This is a major limitation since according to [12], despite being classified as a disorder, insomnia often decouples and evolves into an independent, self-sustaining problem, which when comorbid with other disorders such as depression can result into a totally new strain of sleep disorder. This is further precipitated by the different psychological traits of the patients thus the need to make the treatment even further. As such, a model that is self-learning within the CBTI environment is proposed so as guide both the psychiatrist or self-help patient get better CBTI treat.

D. Q-Learning Model

The algorithm chosen to come up with this model is the Q-Learning algorithm. Q-learning [13] is a form of model-free reinforcement learning that provides agents with the capability of learning to act optimally in Markovian domains by experiencing the consequences of actions as they traverse from their one state to the next. Thus for every state there are a number of possible actions that could be taken and for each action taken within each state there is a reward value. The task therefore in Q-learning is to maximize the Q function as in

$$Q(a,i) = Q(a,i) + L(R(i) + Q(a1,i) - Q(a,i)) \qquad 1$$

Where the following is true:

- Q – Table of Q-values
- a – Previous action
- i – Previous state
- j – The new state resulting from the previous action
- a1 – The action that will produce the maximum Q-value
- L – The learning rate (between 0 and 1)
- R – The reward function

This approach was seen as suitable compared to other machine learning models because it works under the assumption that no natural observable phenomena happens the exact same way twice. And as such rather than modelling problems in a probabilistic approach, it chooses a stochastic approach. Stochastic processes are used to model a large number of various phenomena where the quantity of interest varies discretely or continuously through time in a non-predictable fashion [14]. Sleep patterns, though having a uniform pattern, possess a stochastic pattern once insomnia effects kick in. Thus insomnia patterns differ from one patient unto another.

III. RESEARCH METHODOLOGY

This study intends to show how more efficient a Q-Learning Model for CBTI would be as compared to the most automated alternative which is the iCBTI. A closer study at sleep patterns and measures of parameters that surround insomnia such as the Insomnia Severity Index (ISI) qualifies the study to be one that investigates a natural phenomenon. This study thus follows a mixed research approach by virtue of it employing strategies of inquiry that involve collecting data either simultaneously or sequentially to best understand research problem [15]

The data collected consisted of sleep diaries of 50 insomnia patients that captured their sleep data over a period of two weeks each. This data was to be used in training the proposed model. Other secondary data relating to efficiency of the iCBTI process was also collected for purposes of comparative analysis with the efficiency of the proposed model.

With respect to exhibiting a proof of concept for this model, the system prototyping system development methodology was used. System prototyping works by performing the analysis, design, and implementation phases concurrently in order to quickly develop a simplified version of the proposed system and give it to the users for evaluation and feedback. Upon receiving feedback from the intended users of the system, the developers are tasked with the duties to reanalyze, redesign, and re-implement a second prototype that corrects deficiencies and adds more features [16].

IV. RESULTS

A. Who is the Agent?

An agent as defined by [17] as anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators. As earlier mentioned the environment within which the proposed model operates is the CBTI process as conducted by the CBTI expert. It was therefore important to determine who or what the agent would be within this environment so as to establish the various states that would be used in building up the Q-learning model.

B. Ensembles Approach

Q-learning works by learning the action-value function (Q function) that gives the expected utility of performing a given action in a given state. The proposed model is intended for use in real time; that is, as the patient goes through bouts of insomnia. With the CBTI process being the environment, there is need to have more than one entry process into the environment depending on the stage of sleep or ISI levels of the patient. These entry points are not to be chosen arbitrarily by the CBTI practitioner at will or based on their expertise but are to be recommended by the model. The key benefit of having the neural network model stacked to the proposed Q-learning model is to minimize unnecessary redundancy in the CBTI process by eliminating steps that would not further impact the ultimate ISI of the patient.

To arrive at these entry points, a dual layered light artificial neural network model is stacked to the Q-learning model, as a pre-process before the state-action traversals set in. Due to unavailability of data, the Q-learning model was run severally and the data stored as the training data for stacked neural network. The neural network layer was trained using 700 epochs using the data set generated. The Q-learning model was tested for performance without the neural network layer and the cumulative optimal reward was low compared to when the neural network layer was stacked to it.

The inputs to the neural network are captured at the stage of interrupted sleep of the patient. The parameters captured include; the patient's age, the ISI of the patient, number of previously held counselling sessions and morbidity of insomnia condition.

C. Model Architecture

The CBTI model has multiple entry points. With the CBTI process being the environment possessing various stages modelled into states. Movement between each of these states constitute the actions. Movement outside the environment signifies stopping the CBTI process thus no result would be achieved, which implies no improved reduction in the insomnia index.

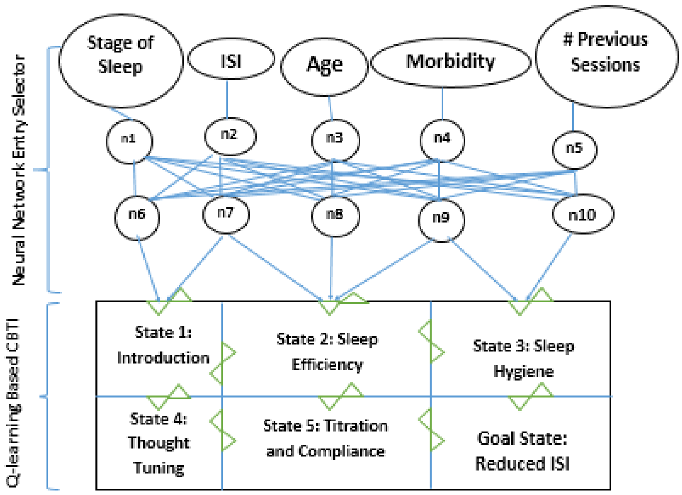


Figure 1. Proposed QCBTI Model

The entry selection process is the first stage of model. This uses the neural network model stacked on the Q-learning model. It works by prompting the CBTI practitioner for the details of the patient in relation to their insomnia metrics which act as inputs into the model. An entry point is then selected by the neural network into the CBTI process environment, within which the agent has an array of finite states and actions to take in order to reach the desired goal state.

Figure 1 shows in generic only five steps of CBTI before reaching the goal state. However, there are micro-states within the states, each with their respective permissible actions as the agent moves from one micro-state to another as illustrated in Figure 2. This thus implies layers upon layers of Q functions as well as Q tables that hold Q values for every state and each state's micro-state as shown in Table III, which interestingly shows that no reward being awarded to a state leading to itself.

TABLE III: Q-C (PARENT STATES)

	State 1	State 2	State 3	State 4	State 5	Goal State
State 1	0.00	0.41	0.22	0.42	0.89	0.83
State 2	0.89	0.00	0.82	0.53	0.11	0.90
State 3	0.59	0.23	0.00	0.98	0.95	0.96
State 4	0.48	0.75	0.54	0.00	0.23	0.85
State 5	0.13	0.45	0.17	0.26	0.00	0.99
Goal State	0.80	0.69	0.82	0.45	0.81	0.93

Figure 2 shows the micro-states for state 3 (Sleep Hygiene). The micro-states all point possess as their possible actions, movement from one micro-state to another with the principal goal remaining as the ultimate goal state.

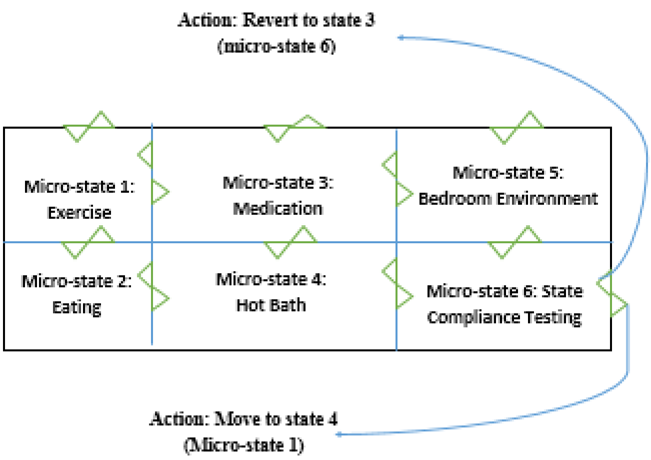


Figure 2: Sleep Hygiene Micro-states

D. *Insomnia Severity Index*

The insomnia severity index was used as a key parameter in informing the model on the criteria for giving rewards to the agent. The initial reward which is arbitrarily assigned to the goal state, is in fact informed with the desired ISI level as calculated by the ISI calculator module of the proposed model. The template used in gathering parameters necessary for arriving at the appropriate ISI is as shown in Table IV

TABLE IV. INSOMNIA SEVERITY INDEX TEMPLATE

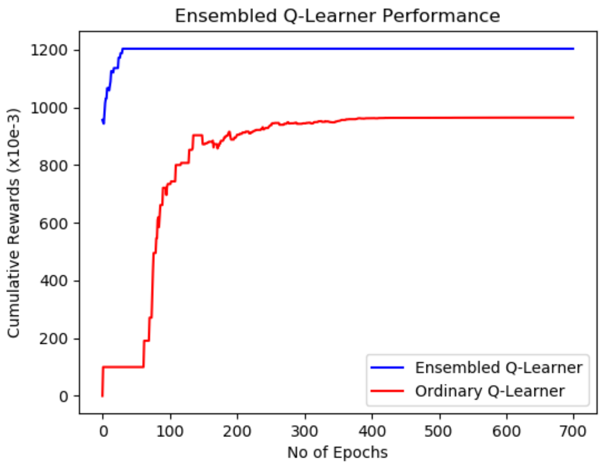
Insomnia Problem	**None**	**Mild**	**Moderate**	**Severe**	**Very Severe**
Difficult Falling Asleep	0	1	2	3	4
Difficulty Staying Asleep	0	1	2	3	4
Problems waking up too early	0	1	2	3	4
Satisfaction with current sleep pattern	Very Satisfied	Satisfied	Satisfied	Dissatisfied	Dissatisfie d
Scores	0	1	2	3	4
Noticeability of Sleep Problem	None	A Little	Somewhat	Much	Very Much Noticeable
Score	0	1	2	3	4
Worry about Sleep Pattern	None	A Little	Somewhat	Much	Very Much Worried
Score	0	1	2	3	4
Interference of Sleep pattern with daily functions	None	A Little	Somewhat	Much	Very Much Interfering
Score	0	1	2	3	4

V. DISCUSSION

A. *Model Perfomance*

The model performed way better when the Artificial Neural Network algorithm was stacked. The ensemble Q-learner had a minimum curve in the very first few iterations, thus little rewards were sacrificed for the algorithm to be stable. Additionally, it recouped its cost of learning faster unlike the ordinary Q-learner whose zero-crossing implies a relatively longer time to learn. Finally, the policy of the ensemble Q-learning CBTI model had a better policy with a higher accumulated reward, accompanied with the asymptotic slope being realized in the much earlier epochs as shown in Figure 3.

The model was trained using sleep-log data of 50 patients accumulated for 2 weeks. The cross-validation process was done randomly with 70% of the data being used for training and 30% being used for validation. The validation was conducted and the number of epochs was arbitrarily set to 700. The model's performance attained initial stability in under 600 tries accumulating the maximum possible reward which is inversely proportion to the ISI rate. This was unlike the case when the neural network layer was introduced; since in under 600 tries, convergence had been reached with a higher cumulative reward level.



B. *Clinical Application*

It is appreciated that performance of the model would not necessarily translate into an obvious successful treatment of insomnia. However, it is anticipated that with a well-designed and interactive application for the model; the CBTI practitioner should find the proposed model quite handy and more personalized approach towards CBTI practice. The performance of the model as shown in Figure 3 implies that it would take a much shorter time for the CBTI practitioner to traverse the CBTI process in course of treating the patient thus finding the best path that leads to a maximum reward (lower ISI) of the patient. The best path also implies a lower risk of relapse following the fact relapse probability is a consideration made in informing the Q-value for every micro-state in the Q-learning CBTI model.

The CBTI approach as dictated by the architecture in Figure 1 has more than one possible start as recommended by the overlying neural network model. This will require the CBTI practitioner to fill at least three of the required parameter by the neural network model, with the ISI level being a mandatory in all the possible permutable entries. Thus any or all the question in Table IV will be asked directly to the patient as the CBTI practitioner fills in the details.

Once the starting point of the procedure is established as recommended by the model, the CBTI practitioner will then be advised on the next micro-state to conduct within their current state. Upon exhaustion of all microstates within a current state, the next state and specific micro-state is recommended to the CBTI practitioner. This process is done recursively until the goal state is achieved.

This entire process is both applicable in scenarios of normal clinical visits where the patient will sit the CBTI practitioner and undergo the therapy session as well as the intensive process where CBTI process is administered for patients as they sleep in real-time or suffer bouts of insomnia in real thus the need for multiple entry points into the model.

VI. CONCLUSION

This work analyzes the internet based CBTI process and identifies the fixed policy approach employed by the process which leads to a longer recovery time of patients, as a result of being subjected to either redundant or unnecessary procedures within both the CBTI and iCBTI process. The study suggests an Ensembled Q-learning CBTI model to be used by the CBTI practitioner in the dispensing of the CBTI process for purposes of streamlining the whole process and minimizing instance of insomnia relapse caused by undue procedures.

Given historical sleep-log of 50 patients, the proposed model in under 600 tries attained the goal state achieving the highest possible reward. The cumulative reward was set to be inversely proportion to the ISI level since the goal of the model is to reduce the ISI level yet the reward level is cumulative in nature thus incremental.

It is recommended that the uptake of the proposed model will improve the both the traditional and internet-based CBTI process by optimizing the most rewarding paths to be taken in conducting therapy for an insomniac patient. The study is however limited to the respect that it used a guided approach, and thus still need to be operated by humans. It is thus further recommended that future improvements on the model interact with the patient directly rather than having a guided approach. This pre-supposes the soliciting of sensorial technology.

In conclusion, this study has demonstrated that the use of an ensembles approach highly boosts the performance of any machine learning model, if applied in a refined and calculative manner. This is a pointer in machine learning development towards the building of more efficient models.

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