The Mobile Application Implementation of Active Intervention Methods for the Improvement of Sleep for z^3

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***Abstract*— This report investigates current research into cognitive behavioural therapy and gamification to justify and outline the design for active intervention features in a mobile application to improve sleep quality. It then sets out an evaluation and work plan.**

I. INTRODUCTION

z^3 is a system that is designed to improve the user's sleep quality through the monitoring of the bedroom environment, tracking of daily activities and guidance in practicing proper sleep hygiene techniques. The app brings cognitive behavioural therapy (CBT) techniques to the wider population who may benefit from the methods but would not qualify for or seek treatment from the National Health Service or other health service providers.

This report will describe how research into CBT-I (CBT for Insomnia) and gamification will be incorporated into its features, and discuss how their success will be evaluated upon completion of the app. Front-end design of these features is important because it is one of the main points of interface with the user and due to the sensitive nature of creating an app claiming to help a health problem, it is important that the features will not cause greater harm than good to the user.

II. RESEARCH

Sleep is vital for good health, and it has been shown to be linked to many aspects of our health besides energy levels: supporting the immune system [1] [2], regulating mood [3] and weight [4] to name a few. Thus poor sleep quality results in more than a mere inconvenience for an individual. It can create extra burden on health services to treat these people and others affected by their fatigue after the damage has been done, for example in car accidents involving driver fatigue.

As a result, there are numerous guides written by governmental organisations [5][6][7] and reputable news sources [8] with the intention to educate the public on good sleep hygiene practices and motivate them to follow this advice. This is a decent starting point for intervention, since it is free and widely available. On the other hand, brochures and web pages are passive tools and cannot engage with their recipients to reinforce the advice at a more important time, such as before bed. In addition, generic advice may not work for everyone [9], therefore personalisation is important in making recommendations.

With the proliferation of smartphones and the internet, there have been many attempts to harness these technologies to make intervention more effective. There are many existing mobile applications aimed at improving sleep in various ways. As of the 23rd of February, the top 10 sleep applications in the iTunes UK store consist of 3 apps dedicated to playing soothing noises [10] [11][12]; 1 focused on providing insights into your quality of sleep without attempting to inform the user of factors affecting their sleep [13]; 2 use meditation and mindfulness techniques as intervention methods [14][15]; and the last 4 claim to deliver some amount of analysis to how external factors affect the user's sleep quality [16][17][18][19], although require the user to pay for these services. These are all popular in general in the category of health and fitness, so clearly there is a demand from users for various different types of smart alarm clocks.

A. Cognitive Behavioural Therapy

1) Mobile Application Implementations: There have been several studies in the effectiveness of CBT delivered through web and mobile applications. One showed that CBT delivered through web and mobile applications resulted in similar, statistically significant, long-term improvement in participants with depression [20]. This study did create some contact between participant and a clinical psychologist on top of using automated mechanisms such as lessons and assignments, therefore there may be less improvement without this human contact. On the other hand, our target audience are those who are not affected enough to seek out professional help, therefore we hope automated methods are sufficient in guiding our users to better sleep. Additionally, even the researchers conducting the study believed it to be unnecessary to continue contact with the participant beyond the two sessions, citing their previous research, thus, in participants with less severe problems, the necessity for this is outweighed by the cost to the user. The 6 lessons were delivered in a comic book style which concluded with giving the user assignments to put into practice the lessons learned. The paper mentions that other resources were available, including information on sleep hygiene, however does not describe these in detail. This study did not have a control group so was not able to compare the results of using these two methods over traditional, or no, treatment. This format would be less suitable for our application, since we would

like to encourage long-term use as opposed to the short-term nature of a set number of lessons.

Another group studied the effects of a similar system developed solely through a web-based application aimed at those suffering with chronic insomnia [21]. They found that CBT delivered in such a way does improve sleep "and associated daytime functioning" in comparison to a placebo and usual treatment. The system, which is a commercially available application called Sleepio® (www.sleepio.com), delivers traditional CBT through a virtual therapist. Their system appears to be a comprehensive migration of CBT to a digital platform, however does not incorporate personalisation through machine learning techniques as our system will. This same group found that using digital CBT targeting insomnia can also alleviate symptoms of depression and anxiety [22], further underlining the additional benefits to improving sleep through a mobile application. The approach of using a virtual therapist, however, may not appeal to a wider population who do not qualify as having a serious issue because this style of app was not seen in the most popular apps on iTunes. This would likely be due to a lack in motivation to spend time on lessons when they feel like they will not bring a significant improvement on the user's life. As a result, I would like the interventions in z^3 to be smaller and quicker to carry out.

2) Techniques: Reviewing the techniques that make up CBT, especially CBT-I, helps to design the features that should be included in z^3. As seen in the discussion of existing technologies that implement CBT, some are more suitable to the wider population than others. I will a number of techniques and discuss their suitability to this mobile app.

Sleep restriction therapy involves reducing the amount of time spent in bed to the time spent sleeping, attempting to go to bed later when they are more tired and avoiding naps during the day. This form of therapy, however should not be used for those with sleep apnea [23], so it's use is less suited to a general user base, since the app should not risk harming undiagnosed individuals.

Stimulus control is similar, and is rooted in the idea that repeatedly performing behaviours together can create associations between the two behaviours. In terms of sleep, this can be about creating a strong association between the bed and sleeping, a link that can be broken down by frequently performing other activities such as watching television, using a phone or worrying in bed. People engaging in these behaviours can have difficulty falling asleep as a result. The first study into the effectiveness of stimulus control outlined the instructions they gave participants, and showed how following these instructions lead to an improvement in all subjects with regards to the time taken to fall asleep, stay asleep and the reported levels of fatigue during the day [24].

Stimulus control and sleep restriction therapy provide the inspiration for an interesting idea for utilising the strengths of a sleep app. The TI SensorTag [25] that our system uses to measure factors of the bedroom environment is capable of detecting light levels. As a result I intend to create a feature which, if there is low light levels and phone activity is detected, will send the user a notification to remind them to put away their phone as it will make it more difficult to go to sleep. Additionally, if it does appear from the sensor data that the user regularly starts the sensor long before they are asleep, which would indicate the unsuccessful attempt at going to sleep, then the application can advise the user to wait until they are more tired before going to bed and encourage the user not to stay in bed for more than 20 minutes if they are not falling asleep.

Another aspect of CBT is using relaxation techniques to help relax the mind and body before sleep. This could consist of meditation exercises or, more frequently in CBT-I, requires the patient to tense and relax one muscle at a time [26]. There are, however, many resources online and available as mobile applications, as mentioned, which focus on implementing these relaxation techniques, therefore I did not think it would be as fruitful to attempt to replicate these features when other, novel features are ready to be explored.

Sleep Hygiene Education is also an important part of treatment, since it educates users on good sleep practices, and has been shown to be effective in improving sleep quality on it's own [27]. This, however, is more centered around more passive intervention through education, and will be implemented through the recommendation engine part of z^3, thus is not suitable to be discussed in this report.

Writing thoughts down is a common technique used in therapy, for example to help the therapist and patient to identify thought patterns [28], as well as being cited as a helpful action to take if you experience racing thoughts [5]. As a result, I believe it would be beneficial to build a feature into z^3 that allows the user to write down their thoughts should it be necessary. A password feature would be helpful as well to make the users feel comfortable in writing personal thoughts down. If we choose to create a version of the system which is backed up remotely, allowing these diary entries to be backed up remotely as well would be strictly an opt-in feature because of the privacy issues associated to sending and storing data on a remote server. This feature would also be helpful to individuals who decide to seek professional help in the future, as they would be able to show their previous entries to the therapist. It may seem contradictory to ask the user to spend more time looking at a screen since the glare from screens is associated with poorer sleep, however the aim would be to replace their current phone activity with this, more productive one. In order to do so, the user will only be explicitly prompted to record their thoughts at night if the system detects that the user is using their phone when low light is detected, suggesting that they intended to get to sleep but are now distracted by their phone.

B. Sleep Schedule Training

There are a few mobile applications that help the user build a physical workout program to suit their schedule, some which increase workout difficulty as the program progresses. The same has not been applied to any popular sleep app, the closest being an app that lets you set the amount of sleep you want to get and tells you if you are accumulating a

sleep debt [19] or Apple's native alarm clock which allows to to visualise the clock to more easily find out what time you have to go to sleep to get the desired amount of sleep according to when you have to wake up. These two designs, however, do not free the user from regular decision-making, which z^3 will with the sleep schedule training feature.

It is easy, particularly during holidays, to let your sleep schedule shift to later in the evening, making it difficult to adjust to a normal work schedule. Sleep schedule regularity, however, has been shown to result in greater reported alertness [29]. Common advice to those who want to shift their sleep schedule to wake at a different time is to wake up gradually earlier by 15 minute increments [30], so I would like to make this task easier through the automation of the calculation of new sleep/wake times.

The way it would work is that firstly, the user can opt into this feature, at which point they will be asked to input a goal wake up time. The app will suggest an optimal sleep time based on their personal patterns, which will be sourced from the recommendation engine of the system, or, if they are a new user, use 8 hours as a default; both will have the option for the user to override this timeframe. The user will also input a goal date that they desire to be waking up at that time for, this could also be recommended by the app based on their current bedtime and ideal sleep shifting rate. The app will then show the user when they should go to sleep every night to gradually shift their schedule to the desired time. This will be supported by notifications at intervals of 1 hour before and 30 minutes before their new bedtime. The system's hardware components can then monitor whether they are adhering to this schedule, and if not make the user aware that they are not helping themselves through additional notifications and offers to change the rate of the adjustment if it seems to be too fast.

Secondly, if the user turns off the alarm for a night, the application can ask whether they are planning on getting a late night and remind them that it is better to adhere to the same wake up time but go to bed earlier the next night, or only sleep in for marginally longer. This would encourage the adherence to the schedule and would help the user maintain regularity. This feature can be supported by gamification techniques which would give in-app rewards for following a sleeping plan.

C. Gamification Techniques

Gamification is the act of applying "game design elements in non-game contexts" [31], and has been adopted by many applications. There are varying opinions on the ethics and effectiveness of this design methodology, but a comprehensive review of gamification research concludes that it can be utilised effectively for motivating users but must not act as a replacement for good design in underlying aspects such as having clear rules, paths for progression and creation of a sense of belonging [32]. The same author argues for the importance of the inclusion of goal-setting, reinforcement of self-efficacy, rewards and social features to encourage motivation in an application.

In my opinion, the most suitable aspect of gamification for this application is the use of badges. Badges are rewards given to users for the completion of particular goals, and are different from points, which are given to or taken from the user much more regularly and are not persistent. Points, therefore, could induce stress in the patient, especially if combined with leaderboards, since the user will have the added worry of not gaining or even losing points for sleeping poorly or falling out of routine when they may not have even been in control of the situation in the first place. Badges, on the other hand, cannot be so directly comparable, and the user would not know when to expect them, therefore there will be a more general sense of desire to do well to earn more badges but not the constant management of points. Additionally, seeing past achievements may reinforce an individual's sense of self-efficacy, or their ability to achieve goals.

The creation of a social community is another technique commonly employed in gamification. In this case, I believe that it could be useful to act as a support network for individuals, but I would avoid implementing leaderboards for the reasons described above. A sense of competition likely would not help with sleep latency since worrying about getting to sleep is often cited as a reason one was not able to fall asleep. In addition, the technological challenge of setting up a social network may prevent progress in the development of other features, so it is of a lower priority to this application.

III. EVALUATION

In order to evaluate the effectiveness of these features it would be important to test them independently to the core functionality of z^3, which will give personalised advice and display trends in factors such as mood over time. To do so, the experimental group should be split into two, one which simply receives the core features, and one which receives the features outlined in this report. Then, measures such as mood, energy levels, sleep quality and engagement would be monitored to determine if there is a statistically significant improvement in the latter group to investigate whether these features should be developed further or added to. Ideally the latter group would be further split to measure how each feature affects sleep quality and related factors, however this would require a large group of people which may be infeasible to acquire.

IV. WORK PLAN

So far I have begun to develop the core feature of the application, which is the alarm clock functionality. This process has been aided by an open-source GitHub repository which contains some basic functions with the intention for other developers to take the code and build upon it for their own use [33].

The first feature to start implementing would be the sleep scheduler, as this most naturally leads from the development of an alarm clock which the user is able to customise. The initial code for this as well could be independent from the development of data acquisition since it can start by

simply giving the user notifications and creating a schedule without suggesting ideal sleep times based on their data. The ability to create a separation is helpful to make it more straightforward to develop the system concurrently.

The next feature would be implementing the ability for the user to input diary entries. Since this is a functionality helpful to many apps, there are some open-source bases that can be developed upon, such as the "Standard Notes for iOS" project available on GitHub [34]. Once data acquisition is created, the act of writing notes before bed can be recorded as another factor that may influence sleep, so the recommendation would be able to incorporate this in the advice given to the user. Furthermore, this can be combined with the stimulus control feature, for example in the notification reminding the user to avoid using their phone for other things before going to sleep, it can suggest the user writes down what may be bothering them and causing them to seek a distraction. The GitHub project claims to have a password protect feature, however I would like to further investigate this to ensure the user's password will be securely stored.

Once the data acquisition part of the system has been built, I can work on the final two features, badge rewarding and stimulus control. These features could be developed earlier with dummy data, but since there are other tasks to complete this will likely be unnecessary, and the finalisation of the correct formatting of the data will make developing these features smoother.

V. CONCLUSION

This report has proposed a novel method for improving sleep quality with a mobile application and has outlined the system that will need to be created to implement it. In summary, the intervention methods, beyond personalised advice provided by the recommendation engine are:

- Stimulus control through notifications on phone;
- Ability to input diary entries;
- A sleep scheduler;
- Badges to reward users for prolonged healthy habits.

These features have been backed up by research, however will ideally be tested to determine their effectiveness in improving sleep beyond the core elements of the z^3.

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