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A Real-Time Brain-Computer Interface (BCI) Framework for Sleep State Stimulation Using a Deep-Learning Technique: Proposal

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Abstract— Sleep disturbance can cause mental illnesses such as depression, hypertension, metabolic syndrome, and cognitive impairment. To date, various methods have been proposed as intervention measures for sleep disturbance, including taking a short mid-day nap. Falling asleep depends on several external factors, such as the ambience, temperature, sound, and lighting. On top of that, the factors that affect the quality and period of falling asleep can be subjective. The attempt to provide feedback based on the configuration of those external factors is time-consuming. Additionally, if those external factors are incorrectly configured, the intended short nap as a solution may have the opposite effects. As such, research on real-time sleep analysis plays an important role. However, the current study on deep-learning techniques regarding the sleep analysis that can give real-time results is still scarce compared to the offline sleep analysis. Therefore, this study aims to design and develop a real-time BCI framework for sleep state stimulation.

Keywords: *BCI, Sleep, Sleep Stimulation, Deep Learning.*

1. INTRODUCTION

Sleep quality and duration play an essential role in human health. Sleep is crucial for maintaining and regulating various biological functions at a molecular level [1], which helps humans restore physical and mental well-being and proper brain function during the day [2]. Stranges et al. [3] highlighted that sleep-related problems are a looming global health issue. In their study, datasets from the World Health Organization (WHO) and the International Network for the Demographic Evaluation of Populations and Their Health (INDEPTH) were used to investigate the prevalence of sleep problems in low-income countries. It was reported that 16.6% of the adult population, which amounts to approximately 150 million, have sleep problems and current trends indicate that this figure will increase to 260 million by 2030.

It has been reported that taking a brief nap in the middle of the day can help in improving the cognitive wellness of the sleeper [4]. The mid-day nap has been widely practised in different cultures with various names such as power-nap, inemuri, siesta, taaseela, and qai'lullah [5]–[7]. In China, the mid-day nap right has been enshrined in the Chinese Constitution since 1949 [8]. While napping is ideologically accepted in Japan in work, some companies even highly recommend it. It is called "inemuri", which means "to be asleep while present" [9]. Taking a nap in the afternoon is called "siesta" in Spanish and "taaseela" in Egypt.

Similarly, in Islamic literature, the term describing napping activity during midday is called qai'lullah [10]. Qai'lullah is accepted by Islam to be done before or after lunch and after Friday prayer as practised by the Prophet Muhammad (PBUH) [5]. Moreover, scientifically qai'lullah provides excellent benefits, and scientists worldwide have acknowledged it. Practising qai'lullah in our daily schedule will act as a high sleep-quality booster, supported to a study by Ji and Wilson [11].

Qailulllah is an Arabic word originated from the root word قَالَ-يَقِيلُ-قَيلا-قَيلُولَة. Ibnu Manzur stated that *Qailullah* is sleep in the middle of the day [12]. Imam al-San'ani said that the meaning of *Qailullah* is resting in the middle of the day even if one is not sleeping [13].

The meaning of *Qailullah* can be understood from the hadith of the Prophet PBUH from Ibnu Mas'ud RA, where the Prophet PBUH said:

مالي وللدُّنيا إنَّما مَثَلي ومَثَلُ الدُّنيا كمثل راكبٍ قالَ في ظلِّ شجرةٍ ثم راحَ وتركها

"What have I to do with the world? I am like a rider who had sat under a tree for its shade, then went away and left it." Sunan al-Tirmizi (2377) and Sunan Ibnu Majah (4109)

The scholars agreed that *Qailullah* is sunnah. This is in accordance with the hadith of the Prophet PBUH from Ibnu Abbas from the Prophet PBUH:

قِيلُوا فَإِنَّ الشَّيَاطِينَ لَا تَقِيلُ

"Perform *Qailullah* for the shaytan never rests." Narrated by al-Tabarani in Al-Mu'jam Al-Awsat.

Simply put, *Qailullah* is a short rest even if one is not sleeping. Fiqh scholars have differing opinions regarding the time for *Qailullah*. We include their opinions as the following:

Al-Khatib al-Syarbini said that the time for *Qailullah* is before the sun passes the zenith which is before zohor. It is sunnah for those who always pray tahajjud to take a nap before zohor. It is a preparation for qiamullail. *Qailullah*'s time before zohor is the same as the time of sahur for fasting [14]. He presented this opinion in his book Al-Mughni Al-Muhtaj [15].

اسْتَعِينُوا بِطَعَامِ السَّحَرِ عَلَى صِيَامِ النَّهَارِ ، وَبِالْقَيْلُولَةِ عَلَى قِيَامِ اللَّيْلِ

"Seek help by eating Suhur for fasting that day, and by taking a brief rest (at midday) for praying at night." Sunan Ibn Majah (1693)

Al-Munawi stated that *Qailullah* is a nap at noon when the sun passes the zenith or the approximate time before or after the sun passes the zenith [16]. Al-Bujairimi said that *Qailullah* is a break time before the sun passes the zenith. And the famous opinion is *Qailullah* is a nap before or after the sun passes the zenith (which is after zohor) [17]. Imam al-Nawawi said that *Qailullah* is a nap at noon. Syeikh Syamsul Haq al-'Azim al-Abadi cited the words of Ibnu Qutaibah. Ibnu Qutaibah said: It is not named as Ghada' (noon) and *Qailullah* is after the sun passes the zenith [18]. Syeikh Dr Wahbah al-Zuhaili said that *Qailullah* is rest at noon even when one is not sleeping, whether it is in a cold or hot weather [19]. There is an opinion that states the time for *Qailullah* is after the sun passes the zenith. This is according to the statement of Sahl, where he said:

مَا كُنَّا نَقِيلُ وَلَا نَتَغَدَّى إِلَّا بَعْدَ الْجُمُعَةِ

"We did not take a Qailulah nor eat Ghada' until after Friday (prayer)."Sahih al-Bukhari (839) and Sahih Muslim (2028)

From the above statement, this means that the time of *Qailullah* is after the Friday prayer which is equivalent of after zohor..

2. LITERATURE REVIEW

The effectiveness of a nap can be measured through brain activation signals, including an electroencephalogram (EEG). Sousa et al. developed a system based on knowledge of subjects′ and variability of some indicators that characterize sleep stages and follow the American Academy of Sleep Medicine (AASM) rules. Six EEG and two electrooculographic (EOG) channels were used to classify wake, non-rapid eye movement (NREM) sleep – N1, N2 and N3, and rapid eye movement (REM) sleep [20]. Some other studies only utilize a single-EEG channel to identify sleep stages [21]–[23].

A new single-channel EEG based sleep-stages identification system using a novel set of wavelet-based features extracted from a large EEG dataset was developed by Sharma et al. [21]. While Hasan and Bhuiyan presented the application of the newly proposed tunable-Q factor wavelet transform (TQWT) to devise a single-channel EEG based computerized sleep staging algorithm. The computerized sleep scoring scheme propounded herein can expedite sleep disorder diagnosis, contribute to the device implementation of a sleep monitoring system, and benefit sleep research [22]. Finally, Hsu et al. presented a recurrent neural classifier for automatically classifying sleep stages based on energy features from the EEG signal of the Fpz−Cz channel. The result demonstrates that the proposed recurrent neural classifier using the energy features extracted from characteristic waves of EEG signals can classify sleep stages more efficiently and accurately using only a single EEG channel [23].

In general, the mid-day nap is taken in a very brief period. It is set during the middle of the day to stimulate creativity, strengthen our memory [6] and improve the performance of complex tasks (executive function) [24]. Many Research has demonstrated that a short mid-day nap can benefit cognitive performance the most [25], including episodic memory [26], emotion regulation [27], and attention [26]. Napping has also been endorsed as a way to boost creativity [28], help people cope with fatigue related to shifting work [29], and the value of a nap is also dependent on when the nap is taken within the day [30]. Its effectiveness depends on several factors such as the ambience, temperature, sound and lighting. Xinbo xu et al. found out that the external factors that improve sleep are temperature and sound. Specifically, the temperature had a more significant impact on the sleep quality of males, while noise level had a more significant impact on the sleep quality of females [31]. Not only for adults, but those external factors also impact children's sleep quality. A previous study by Ahmad Fadzil found that noisy and not well-darkened rooms are predictive factors that impact children's sleep quality [32].

Nurses have a crucial role in hospitalized patients controlling the external factor that impacts sleep quality. For example, a study done by Shailesh Bihari et al. proves that noise and lightning are essential factors that can improve the Sleep Quality of Patients in the Intensive Care Unit [33]. On the other hand, da costa and Ceolim find out that lighting is the highest factor that impacts sleep quality. The study was conducted on 117 patients hospitalized for at least 72 hours in stable clinical conditions.

Therefore, this study explores the framework of managing the external factors that affect sleep using a brain-computer interface that may give a more accurate impact through the brain signals.

3. METHODOLOGY

To address the research questions and objectives, the methodology of this study consists of 4 major phases:

1. **A meta-analysis of research on EEG features for sleep state classification.**
   A meta-analysis of research on EEG features for sleep state classification will be conducted. This phase is important to provide the groundwork for the study and enable the researchers to develop a sleep state classification using BCI.
2. **Identification of existing external factors stimulates and affects the quality and period of falling asleep.**
   It is essential to identify the existing external factors that can stimulate and affect the quality and period of falling asleep. On top of that, the factors that affect the quality and period of falling asleep can be subjective. The effect of each external factor can be identified through BCI.
3. **Design and develop a real-time BCI framework for sleep state stimulation using a deep-learning technique.**
   Design and development of a real-time BCI framework for sleep state stimulation using a deep-learning technique, including:
   i. Signal acquisition: Brain signals will be acquired from participants who will be asked to perform sleep for around 20 minutes with the external factor stimulation.
   ii. Signal Processing and External factors analysis: There are five brain waves in those frequency ranges called delta, Theta, Alpha, Beta and Gamma with their respective frequency. This research will focus on the lowest frequency range (0.5Hz to 3Hz), namely Delta, which correlates with sleep patterns. Many approaches have been proposed to stimulate the sleep state, and the pattern will be analysed based on the external factor's stimulation in the previous stage.
   iii. Sleep state analysis: At this stage, several deep-learning techniques will be explored and evaluated for a real-time sleep state analysis.
   iv. Design and development of a real-time BCI framework for sleep state stimulation: In this stage, a real-time BCI framework will be designed and developed to give real-time feedback in response to the sleep analysis.

4. **Evaluate a real-time BCI framework for sleep state stimulation to improve sleep quality.** In the final stage, a real-time BCI framework will be evaluated.

4. CONCLUSION

To conclude, we are inclined towards the opinion that *Qailullah* is a rest time or a nap before the sun passes the zenith which is after zohor. We advised those who are working to use the rest time allocated for *Qailullah* to motivate oneself to continue on working. However, do not exceed the set time for we are all bound to our work responsibility. Do not betray the trust we are given to do our work. This research aims to design and develop a real-time BCI framework for sleep state stimulation. Despite advancements in neuroimaging technology, BCI allows the communication between the human-brain computer is still in the experimental phase across academia. This allows academia to produce significant research findings. This will undoubtedly help improve individual cognitive performance and indirectly their quality of life, benefiting society. Our research is also aligned with the Ministry of Higher Education's thrust in IR4.0. Through this research, the academia-industry linkage between university and industrial partners can serve as a platform for greater collaboration to transfer technology and potentially transform the academic output into commercial output. Lastly, this research also supports the Malaysia Mental Health Policy, emphasizing treatment and rehabilitation, and aims to improve mental health by improving sleep quality. This research supports the sustainable environment by using green materials for the EEG machine components.

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