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Submitted to: JMIR Research Protocols
on: February 26, 2025

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Abstract

Background: The traditional monitoring of sleep disorders usually uses polysomnography. However, with the development of medical sensors and deep learning technology in recent years, more and more research has begun to explore the combination of artificial intelligence technology and medical sensors to achieve automatic monitoring, analysis and early warning of sleep, so as to more accurately assess, treat and care for this population.

Objective: In this paper, a deep learning combined with medical sensor is designed to collect patient sleep and physiological data in order to solve the difficulty of patient sleep acquisition and assessment.

Methods: A sleep monitoring system for type 2 diabetes in the elderly based on a deep learning model was designed. Sleep data (sleep time, sleep duration, sleep depth, etc.) and physiological parameters (blood glucose level, blood oxygen saturation, heart rate variability, breathing rate, blood pressure) were collected for elderly patients with type 2 diabetes through medical sensors. Deep learning was used to train and analyze the data to identify the type of sleep disorder and predict its severity.

Results: The research situation is expected to be released in the first quarter of 2026.

Conclusions: The sleep monitoring system of deep learning combined with medical sensor data can effectively evaluate sleep disorders in elderly patients with type 2 diabetes.This approach provides an effective and innovative solution for the management of sleep disorders in elderly patients with diabetes.

(JMIR Preprints 26/02/2025:73176)
DOI: https://doi.org/10.2196/preprints.73176

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Monitoring of sleep disorders: a protocol based on deep learning combined with medical sensors

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Monitoring of sleep disorders: a protocol based on deep learning combined with medical sensors

Abstract

Background: With the acceleration of the aging process, the number of elderly patients with type 2 diabetes mellitus has increased significantly, and some patients have sleep disorders, which may lead to blood sugar fluctuations, increase cardiovascular risks, and even aggravate the complications of diabetes. Therefore, there is an urgent need for more precise monitoring and personalized treatment means to improve the quality of life of elderly patients with T2DM.
Aim: In this paper, a deep learning combined with medical sensor is designed to collect patient sleep and physiological data in order to solve the difficulty of patient sleep acquisition and assessment.
Methods:A sleep monitoring system for type 2 diabetes in the elderly based on a deep learning model was designed. Sleep data (sleep time, sleep duration, sleep depth, etc.) and physiological parameters (blood glucose level, blood oxygen saturation, heart rate variability, breathing rate, blood pressure) were collected for elderly patients with type 2 diabetes through medical sensors. Deep learning was used to train and analyze the data to identify the type of sleep disorder and predict its severity.
Results: The results of this study are expected in the first quarter of 2026
Conclusion: The sleep monitoring system of deep learning combined with medical sensor data can effectively evaluate sleep disorders in elderly patients with type 2 diabetes mellitus.This approach provides an effective and innovative solution for the management of sleep disorders in elderly patients with diabetes.
Keywords:type 2 diabetes□sleep disorder□deep learning□medical sensor□personalized treatment

1 | Introduction

With the deepening of China's aging population, the number of people aged 60 and above is 264.02 million, accounting for 18.70% of the total population, which increased by 5.44 percentage points compared with 2010 **[1]**.The elderly population is huge, the corresponding demand for medical and health services is also increasing, and the health problem of the elderly has become a hot topic in recent years. The prevalence of diabetes in the elderly in China is as high as 30% **[2]**.According to this estimate, about 78.13 million elderly people in China have diabetes (more than 95% of which are type 2 diabetes) **[3]**.The elderly population has become the main disease group of diabetes in China. Diabetes and its complications are one of the main causes of harm to the health of the elderly, and also bring a heavy economic burden to the public health care budget.

According to the International Classification of Sleep Disorders, Third Edition (ICSD-3) **[4]**,Sleep disorders can be divided into six categories: insomnia, sleep-related breathing

disorders, central narcolepsy disorders, circadian sleep-wake disorders, parasomnia, and sleep-related movement disorders.Sleep disorders often lead to disturbances in the quality, quantity, and timing of sleep, which can interfere with normal daytime life. Sleep disorders are particularly common in people with type 2 diabetes, with about 37% to 50% of patients having sleep problems **[5]**.Sleep disorders have an adverse impact on the health of people with diabetes and may lead to elevated blood sugar **[6]**, increase the risk of cardiovascular events **[7]**, and even aggravate the condition.

The traditional monitoring of sleep disorders usually uses polysomnography (PSG). However, with the development of medical sensors and deep learning technology in recent years, more and more research has begun to explore the combination of artificial intelligence technology and medical sensors to achieve automatic monitoring, analysis and early warning of sleep, so as to more accurately assess, treat and care for this population.

1.1 | Purpose and Aim

In this study, we aimed to use deep learning algorithms to analyze data from medical sensors to assess the severity and type of sleep disturbances associated with older patients with type 2 diabetes.By collecting patients' sleep data, including rest time, sleep duration, sleep duration, sleep depth and sleep cycle, combined with other physiological parameters such as blood sugar level, blood oxygen saturation, heart rate variability, respiratory rate and blood pressure, a comprehensive data model was built.This data is then trained and learned using neural network-based deep learning algorithms to identify and predict patients' sleep disorders, such as insomnia and sleep apnea syndrome.This will achieve accurate assessment, early warning and personalized treatment and care for elderly type 2 diabetes patients with sleep disorders, improve the treatment effect, improve the health status of patients, and thus improve the quality of life.

1.2 | Deep learning

Deep Learning (DL) is a machine learning technique that utilizes multilayer nonlinear information processing for supervised or unsupervised feature extraction, transformation, and pattern analysis and classification **[8]**.DL is mainly implemented using artificial neural networks (ANN), a mathematical model inspired by the way biological nervous systems work. Common Deep Neural networks (DNN) include Multi-Layer Perceptron (MLP),

Convolutional Neural Network (Convolutional Neural Network), and multi-layer Perceptron (MLP). CNN), Recurrent Neural Network (RNN), Deep Autoencoder (DAE) [9].Due to its excellent performance in automatically extracting task-relevant features, deep learning has been widely used in many fields such as network security [10], computer vision [11], medicine [12], and so on.

1.3 | Medical sensors

With the development of science and technology, sensor technology has been widely used in the medical field. The medical sensor can be regarded as an information transformation device, which converts the physiological information of the human body into electrical information with a definite functional relationship, through which the changes of the body can be intuitively understood or pathological analysis can be carried out.As an important connection between medical instruments and human body, medical sensors play an important role in medical diagnosis, medical instrument development, medical research and so on. The application of medical sensors significantly reduces the labor cost, effectively reduces the error rate, and improves the reliability and accuracy of disease diagnosis.In clinical medicine, medical sensors are mainly used in the following aspects: (1) to provide diagnostic biological information: such as heart sound, blood pressure, pulse, blood flow, breathing, body temperature, etc., for clinical diagnosis and medical research.(2) Clinical monitoring: Monitor the changes of the patient's physiological parameters before and after surgery, such as body temperature, pulse, blood pressure, respiration, ECG, etc., monitor whether these parameters are in the normal range, understand the patient's recovery process, and timely alarm when abnormal.(3) Control of human physiological process: use the monitored physiological parameters to control the physiological process of the human body. For example, the action of the automatic respirator is controlled by the detected physiological parameters, so that the breathing is synchronized with the normal state.(4) Clinical test: Obtain diagnostic information from samples of various body fluids (blood, urine, saliva, etc.).

2 | Methods

Medical studies have shown that sleep disorders in older people with type 2 diabetes can be caused by psychological, age, disease, and other factors.(1) Psychological factors: Patients lack of understanding of type 2 diabetes, worry about poor blood sugar control and

complications, resulting in a heavier psychological burden, may appear different degrees of anxiety or depression, thus affecting sleep. Through a survey of 3010 participants.(2) Age factor:Elderly patients with type 2 diabetes had poor sleep quality. In addition, from the perspective of traditional Chinese medicine, the function of the five viscera in the elderly has gradually deteriorated, and the five viscera function is the basis of sleep activities.The five viscera hide essence, and only when the essence of the five viscera is abundant will there be a sufficient source for its qi and chemical activities.(3) Disease factors: Patients with type 2 diabetes have poor blood sugar control, increased nocturia, neuralgia and serious complications caused by diabetes, such as heart, brain, kidney, foot lesions **[13]**, which may lead to sleep disorders.(4) Other factors: The sleep quality of type 2 diabetes patients is also affected by sleep habits, sleep environment and other factors.

In recent years, studies have shown that there is a close link between sleep quality and the development of diabetes. Sleep disturbances can affect the quality and duration of sleep, which in turn can adversely affect type 2 diabetes.Sleep disorders may promote the progression of type 2 diabetes through a variety of mechanisms, such as decreased glucose utilization in the brain, altered orexin response, and overactivation of the hypothalamic-pituitary-adrenal axis **[14]**.This results in poor self-care (i.e., reduced medication adherence **[15]**) and impaired decision-making (unhealthy diet and sedentary behavior) **[16]**.In 2017, the American Diabetes Association first recommended sleep pattern and duration assessment as part of a comprehensive medical assessment for people with diabetes **[17]**.Therefore, sleep disorders in older people with type 2 diabetes are a public health concern that is critical for preventing and controlling the onset and development of diabetes and its complications.

Modern medicine believes that the quality of sleep can be judged from many aspects, these indicators reflect the changes and states of the human body during sleep from the side, these indicators are:1)Sleep cycle: includes falling asleep, light sleep, deep sleep and rapid eye movement sleep. For example, patients with insomnia show an increase in light sleep and a decrease in deep sleep in the sleep cycle, causing a decline in sleep quality.2)Sleep time: People with restless leg syndrome may have difficulty falling asleep because of discomfort in their lower limbs, which may extend the time it takes to fall asleep and reduce the total amount of sleep.3)Heart rate: During sleep, the heart rate usually drops,

especially during deep sleep stages. The change of heart rate can reflect the change of sleep quality and sleep stage.4)Respiratory rate: Respiratory rate generally becomes more stable during sleep. Abnormal breathing rate may be related to sleep disordered breathing.5)Body temperature: Your body temperature usually drops slightly during sleep. Changes in body temperature can affect the timing of falling asleep and waking up.6)Body movement: Quality sleep is usually accompanied by less body movement, especially during deep sleep. Too much physical activity can cause sleep disruption, affecting sleep continuity and depth. For example, the involuntary limb movements of patients with restless leg syndrome during sleep may affect the quality and continuity of sleep.7) Eye movement (EOG) : Sleep is divided into rapid eye movement sleep (REM sleep) and non-REM sleep (NREM sleep). Eye movement signals can be used to detect rapid eye movement (REM) sleep, helping to determine sleep cycles and sleep stages.8)Sound: Monitoring breathing sounds and snoring during sleep can help diagnose sleep apnea syndrome (OSA).

In order to effectively monitor human blood sugar while ensuring the health of patients,In Britain, SugarBEAT, a new non-invasive glucose meter developed by NemauraMedical.Its first model can be connected to a smartwatch and received CE certification in 2016. The principle is a combination of microfluidic and electrochemical sensors, using a non-irritating soft silicon gel glued to the skin.The patch monitors glucose through a transmitter and transmits data at regular intervals of 5 minutes. The electronic current in the sensor draws the interstitial fluid to the surface and analyzes glucose levels, enabling dynamic monitoring with high flexibility.

With the development of deep learning technology, people are trying to combine it with the diagnosis and treatment of diabetes to achieve monitoring and auxiliary treatment..Ihnaini et al. **[18]** adopted integrated deep learning model and data fusion technology for diabetes prediction, and the accuracy, accuracy and sensitivity of the model on the fusion data set were 99.64%, 100%, and 99%**[19]**.Zhao Nan et al. **[20]** analyzed an image of diabeticfootulcer (DFU) based on a deep learning method, built an intelligent measurement model for diabeticfootulcer and conducted a preliminary verification. They applied deep learning to DFU area measurement for the first time in China, realizing the application of deep learning in DFU care.In order to realize early prevention of diabetic peripheral neuropathy (DPN) and assist doctors in early diagnosis and decision making, Hou Wei et al.

[21] proposed a DPN prediction model based on one-dimensional convolutional neural network.Deep learning has achieved good results in the research of diabetes and its complications, and there are also relevant studies in sleep staging, sleep quality estimation and improvement, sleep wake detection, sleep disordered breathing recognition, etc.However, research on sleep disorders in elderly patients with type 2 diabetes based on deep learning is still insufficient, one of the reasons may be that it is difficult to collect group data on sleep disorders in elderly patients with type 2 diabetes.

In order to ensure the health of patients and effectively monitor human blood sugar, this paper designed a real-time monitoring and analysis system for elderly type 2 diabetes based on deep learning model.The system captures patients' physical signs and environmental information through sensors, links them with relevant factors reflecting sleep quality, and finds the internal relationship between the two through deep learning models, so as to achieve real-time monitoring and prediction of patients' sleep quality changes, make judgments on their sleep quality and provide personalized treatment and care programs.The contributions of this paper are as follows:

1. Use deep learning model to analyze sleep quality and related factors affecting sleep;
2. Introduce time series to better reflect the changes in patients' sleep quality;
3. The sensor technology is used to analyze and judge the sleep quality more accurately.

3 | Implementation plan

3.1 | Model building

We will build a deep learning model that combines the extracted features and the patient's sleep disorder to create a predictive model. The model is designed to predict patients' sleep problems and provide analysis, assessment and early warning of the corresponding problems.

3.2 | Model input

We used patients' general data, physical information, and medication as input to the model. General information included: age, sex, weight, duration of type 2 diabetes; Physical information includes: blood glucose concentration, blood pressure, lipids, kidney function, vision, complications, medication status (refers to the time after the patient's medication).We ignored the impact of environmental factors on sleep quality, not because

environmental factors are not important to sleep quality, but at present, most wards keep the temperature and humidity in a stable range, so the impact of the environment can be almost ignored in the actual scene.In order to facilitate data processing, complications were quantified and numbered to represent different complications. In this regard, several common complications such as cardiovascular disease, kidney disease, retinopathy, foot disease and ketoacidosis were considered.In order to better reflect the physical changes of patients after medication, the time after medication is used in the time dimension instead of the traditional time series. Such data processing method increases the correlation between time and medication situation and enables the model to better learn the characteristics of data.We sampled the data according to the clinical practice. The blood glucose of hospitalized diabetic patientswas generally measured during fasting and after three meals.After the sensor collects the data, we use three different models to process the obtained data, converting it into feature vectors of the same format. Then, the resulting features are further processed. This process can be represented as:

$$Y = M\left(\alpha \cdot M_1\left(G;\theta_i\right) + \beta \cdot M_2\left(P_i,\theta_i^{'}\right) + \gamma \cdot M_3\left(D_i,\theta_i^{''}\right)\right), \quad (1)$$

Among them, M_1, M_2, and M_3 are models for processing different types of data, θ_i, $\theta_i^{'}$, and $\theta_i^{''}$ are the weights of different data within the same data group, and α, β, and γ are the weights of different modules. Y represents the output of the model.

3.3 | Model output

The model takes the patient's sleep cycle, sleep time, heart rate, respiratory rate, body temperature and body movements as outputs, which also reflect the patient's sleep status.In order to ensure the objectivity of the results, the model does not directly judge the sleep status of the patients, but calculates and explores the relationship between physical information and medication and sleep indicators, and then judges and evaluates the sleep status of the patients under the sleep indicators through existing methods.The structure of whole model is shown as Fig.1.

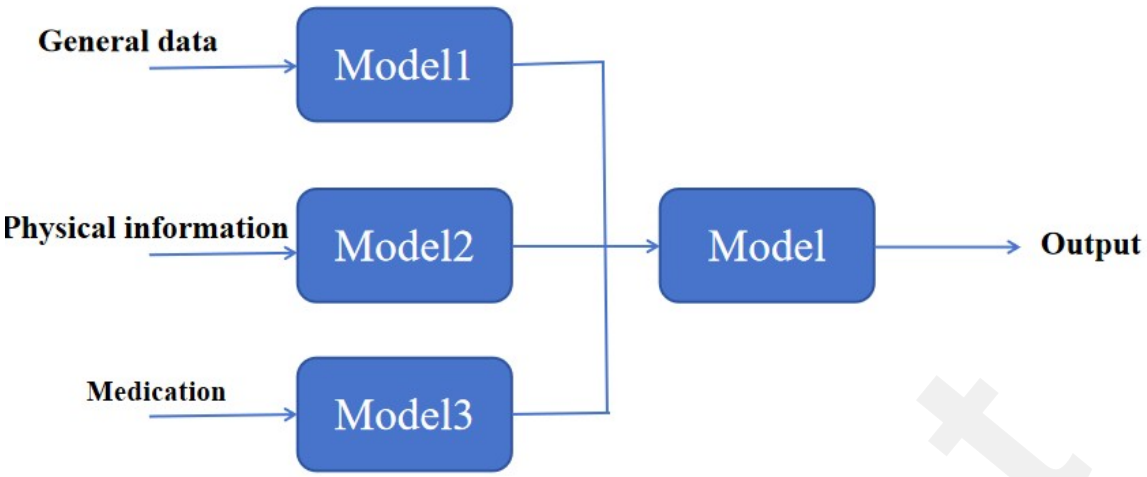

Fig1. The structure of model.

After collecting a large number of data samples of normal and abnormal physiological parameters from medical sensors and clinical medical records, deep learning models preprocess the data, including data cleaning, standardization, and feature extraction, to extract meaningful features from the raw data.Consider that there are individual differences among elderly patients with type 2 diabetes, including differences in age, sex, weight, course of disease, lifestyle, etc. These differences may lead to changes in normal physiological parameters or different responses to abnormal physiological parameters.Therefore, we can build an individualized baseline model, through the personalized model training in supervised learning methods, using the individual's historical data and characteristics as input, to predict the normal range of the individual and form personalized physiological parameters.

In addition, based on clinical data, deep learning models can monitor and analyze patients' sleep data in real time, and trigger an early warning mechanism when a patient's sleep disorder is detected, notifying the relevant medical staff or taking timely measures to deal with the sleep disorder.At the same time, deep learning models need to be continuously optimized to improve the accuracy and reliability of their detection of sleep disorders.

3.4 | model validation

We validate the trained model and evaluate its performance on the new data. This can be done by splitting the data set into a training set and a test set, using the test set to evaluate the performance of the model.

4 | Discussion

The development and proliferation of AI is likely to lead to healthcare services being unregulated, posing challenges to government regulation of healthcare. Therefore, it is essential to establish appropriate regulatory mechanisms. At present, some countries and regions have introduced laws, policies and principles that apply or may apply to the use of artificial intelligence for health. These include data protection laws and existing laws and policies relating to health data to safely and effectively introduce AI into medical and care systems that support healthcare Settings. Data protection law is a "rights-based approach" that provides standards for regulating data processing, both protecting the rights of individuals and establishing obligations for data controllers and processors.It is well known that the European Union's (EU) General Data Protection Regulation (GDPR) requires strict data security and data protection, and Federal Learning (FL), combined with differential privacy (DP) and Secure Multi-party Computing (SMPC), can create sufficient security to meet the legal requirements of the GDPR **[22]**. It not only solves the need for the introduction of artificial intelligence technology into the field of health, but also ensures the privacy of data. The Ibero-American Data Protection Network, which consists of 22 data protection authorities, has published General Recommendations for the Processing of Personal Data in Artificial Intelligence **[23]** and specific guidelines on compliance with the principles and rights for the protection of personal data in AI projects **[24]**.Currently, more than 100 countries have data protection laws in place. Existing laws and policies relating to health data are also being refined. The Committee of Ministers of the Council of Europe issued a recommendation to Member States in 2019 **[25]** on the protection of health-related data.

5 | Conclusion

In this paper, with the continuous progress of sensor technology, we can obtain more comprehensive physiological data, including blood sugar, heart rate, breathing and other information. Deep learning models can integrate data from sensors, showing strong potential in medical data analysis. Deep learning and sensor technology offer new possibilities for type 2 diabetes management, laying the foundation for personalized, refined treatment. But we must also seriously address the challenges of data privacy and security. We must carefully address the relevant ethical and privacy issues, while maintaining a careful exploration of new technologies to achieve the greatest societal and patient benefits.

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