An Overview of Techniques of Acoustic Analysis for the Detection of Obstructive Sleep Apnea

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Abstract— *The primary focus of this review article is to investigate acoustic analysis techniques for detecting obstructive sleep apnea (OSA). OSA causes the upper airway to collapse partially or entirely during sleep, which reduces oxygen saturation. The existing diagnostic techniques for obstructive sleep apnea, such as polysomnography, are hindered by the challenges related to their cost, invasiveness, and limited accessibility. Alternative non-invasive and economical diagnostic methods are therefore required. The purpose of this review study is to analyse the strengths and limitations of the current acoustic analysis techniques as more accessible, non-invasive, and cost-effective approaches to detect OSA. Acoustic analysis, which examines the acoustic features of speech, snoring, and breathing, has the potential to serve as a diagnostic method for OSA. This study thoroughly examines the possibility of snoring and speech acoustic traits as diagnostic indications for obstructive sleep apnea, using both automated classification methodologies and acoustic analytic tools (MDVP and Praat). By analysing the existing research outcomes, this article offers a comprehensive overview of the advancements in acoustic analysis for OSA detection. Further research is needed in speech and OSA analysis, considering clinical factors and acoustic properties to establish a comprehensive understanding.*

Keywords— **Acoustic analysis, Obstructive Sleep Apnea, Speech, Voice analysis, Non-invasive**

I. INTRODUCTION

Obstructive Sleep Apnea (OSA) is a condition that can result in a reduction in oxygen saturation in sleep which is brought on by the entire or partial collapse of the upper airway(Slowik et al., 2022). OSA is considered to affect 10% of the population; 14% of men and 5% of women (Young et al., 2004). For those who are obese, greater prevalence rates of OSA are shown (Jehan et al., 2017). The effects of untreated OSA can be severe, and they can include daily drowsiness, cognitive decline, cardiovascular issues, and a lower quality of life (Barletta et al., 2019). A clinical study (Laratta et al., 2017) states that polysomnography (PSG) is the gold standard method for identifying OSA, which is an overnight sleep study carried out in a sleep lab. It requires the concurrent recording of seven or more data channels, such as respiratory, electrocardiogram (ECG), and electroencephalogram (EEG) channels. PSG is a time-consuming method that involves continuous recording of several tests to identify different phases of sleep, as well as arousals, movement, and cardiac arrhythmia. It is normally carried out in a sleep lab environment (O'Mahony et al., 2020). Therefore, the expensiveness, invasiveness, and restricted availability are some obstacles to PSG. As a result, there is a rising demand for alternative diagnostic techniques that are non-invasive, economical, and simple to use in both clinical and research contexts. The occurrence of apneas and hypopneas when sleeping apnea-hypopnea index (AHI), obtained from a sleep study, is the current method, used to determine the severity of OSA(Li et al., 2023). However, there is a weak correlation between daytime symptoms and AHI, and the limitations of using AHI alone to assess disease severity (O'Mahony et al., 2020) have led to the development of personalized diagnostic strategies. The requirement for more practical and efficient diagnostic techniques has resulted from the rising prevalence of OSA in both individuals and society.

Another popular diagnosing method is Home Sleep Apnea Testing (HSAT) devices. These devices are used at home to collect information on sleep-related factors such as breathing pauses, heart rate, blood oxygen levels, sleep posture, and snoring severity (Penzel et al., 2018). They might not be as accurate and thorough as in-lab investigations, and issues like insufficient sleep length or a failure to recognize awake could provide results that are false negative.

Emerging techniques for the diagnosis of OSA include wearable sensors and equipment, which can monitor the body's mobility, blood oxygen levels, breathing patterns, and heart rate. It is common for them to have user-friendly, non-intrusive designs. In addition, cardiac-based monitoring systems, biomarkers, acoustic and airflow devices, and actigraphy (O'Mahony et al., 2020) have been developed as alternatives to traditional monitoring of OSA which provides simplicity and the possibility of remote evaluation and treatment.

As mentioned above, acoustic analysis is one substitute technique for OSA diagnosis. Studies have shown that OSA patients have anomalies in their upper airway structures. These changes affect how voices are produced and resonate,

which leads to the emergence of peculiar vocal characteristics (Espinoza-Cuadros et al., 2015).

The objective of this review is to conduct a comprehensive assessment of the literature on the application of acoustic analysis to the diagnosis of obstructive sleep apnea. The many auditory characteristics that have been studied will be covered, along with their potential as diagnostic markers. We will also go through the reliability, accuracy, and clinical usefulness of several acoustic analysis techniques, as well as their benefits and drawbacks. This review seeks to offer an overview of the advancements made in acoustic analysis for OSA detection and emphasize the gaps and problems that still need to be addressed by synthesizing and assessing the body of available research.

II. ACOUSTIC ANALYSIS

The upper respiratory tract components and the central nervous system collaborate to create speech. Any disease that alters the upper respiratory tract's resonance and articulation may have an impact on the perception and acoustics of the voice (Jin et al., 2015). Patients with OSA may differ in their upper respiratory morphology in structural and functional ways from individuals who are healthy and do not have OSA. The principal way that these modifications affect voice production is through resonance (Eckert and Malhotra, 2008). Acoustic data can be easily obtained using low-cost microphones, either noncontact or contact-based, requiring only one to two sensors. Importantly, this method does not disrupt the patient's sleep quality, allowing for continuous monitoring throughout the night. The exploration of acoustic characteristics in snoring as a potential marker for OSA started nearly two decades ago (Jin et al., 2015), reflecting the longstanding interest in this area of research. These factors highlight the potential value and feasibility of acoustic analysis as a diagnostic tool for OSA.

A. Acoustic Analysis-Snoring

OSA is known to cause loud snoring. It happens when the air passes through a constricted or obstructed airway. However, not everyone who snores suffers from sleep apnea (Patil et al., 2019). These modifications aid in the emergence of distinctive vocal characteristics. Chronic snoring can cause dryness and irritation in the upper respiratory system, which can have an adverse effect on the health of the vocal folds and cause problems with phonation (Yaslıkaya et al., 2022). According to a new study, those who snore for a prolonged period have weaker voice quality than those who do not.

A recent study (Sebastian et al., 2021) has introduced an automated classification technique that uses an LDA (Linear Discriminant Analysis) classifier to identify and categorize OSA-related snoring occurrences from nocturnal audio recordings. An effective non-invasive method for locating blockage locations in OSA patients is to use the acoustic features of snoring that are linked to the condition. This cutting-edge methodology gives new perspectives on the investigation of acoustic analytic methods in the context of OSA diagnosis and sheds light on the possible application of snore-related auditory characteristics as diagnostic markers.

There has been research done to discover if the acoustic analysis of snoring noises may be utilized to identify blockage locations in people with sleep apnea (Koo et al., 2017). Using a smartphone to capture snoring noises and a Drug-induced sleep endoscopy (DISE) obstruction level measurement, they concentrated on the study of formant frequencies. 32 male patients made up the research group. For each subject, spectrogram pattern, strength (dB), fundamental frequencies (F0), and formant frequencies of the snoring noises were examined.

However, snoring by itself cannot establish the existence or severity of OSA since it can occur in persons who do not have sleep-disordered breathing.

B. Acoustic Analysis-Breathing

Airway consistency affects how loudly a person breathes when they are asleep. Respiratory collapsibility rises when upper airway dilator muscle activity falls, resulting in louder noises. Apnea occurrences don't generate any sound, but repeated opening and closing can. Smaller, irregular noises are produced during hypopnea, making it possible to identify respiratory episodes from sleep sounds. Assessment of the severity of OSA has been the focus of studies on the acoustic properties of breathing noises. Finding specific apneic and hypopneic occurrences, however, allows for a more precise diagnosis. A recent study (Cho et al., 2022) has aimed to recognize the best options for sound feature selection and noise processing. Considering those two aspects, four regression models were created using the Random Forest technique to provide binary classifications for apnea-hypopnea index levels. Another research (Tiron et al., 2020) has been conducted to evaluate the performance of the app technology, which can monitor certain sleep phases, respiratory rate, snoring, and OSA patterns using cutting-edge digital signal processing (DSP) technology and artificial intelligence (AI) algorithms to detect the breathing patterns. (Le et al., 2023) presented a real-time OSA prediction model, which can be applied in a noisy domestic environment that can detect apnea conditions by breathing sounds that occur during sleep. These detecting techniques need to be further investigated and validated to ensure the reliability and clinical applicability.

C. Acoustic Analysis-Speech

Another new technique is voice analysis, which examines acoustic features to identify possible OSA warning symptoms. According to recent research, mouth breathing and structural alterations in the articulation region cause OSA patients to have irregular vocal cord vibration, which

impairs glottis closure, makes it difficult to pronounce words, makes them hoarse, and causes other vocal problems (Tao et al., 2009). Two subject groups in total were recruited for the investigation. 46 healthy individuals who did not exhibit any symptoms such as excessive daytime drowsiness, loud snoring, witnessed bouts of breathing stoppage during sleep, sudden awakenings accompanied by shortness of breath, or waking with a dry mouth or sore throat comprised the normal group. The patient group consisted of 75 individuals with a severe OSAHS diagnosis. The purpose of the study was to evaluate voice issues in OSAHS (obstructive sleep apnea and hypopnea syndrome) patients using acoustic analysis software; MDVP and PRAAT and compare the outcomes. Many professionals agree that MDVP is the acoustic analysis application that is utilized and quoted the most in clinical and research settings. On the other hand, PRAAT is open-source software that has the support of several researchers and medical experts. Using these acoustic analytical techniques, the fundamental frequency (F0), jitter, shimmer, and noise-to-harmonics ratio (NHR) were all assessed objectively. These elements are crucial for assessing voice quality and can provide insightful data on voice-related OSAHS issues. While there were significant differences in NHR between the normal group, the study team found that there were no statistically significant differences in F0, jitter, or shimmer between the two audio analytic instruments. However, in OSAHS patients, the values of F0, jitter, shimmer, and NHR were different between MDVP and PRAAT. They discovered that MDVP and PRAAT differentiated the OSAHS group more effectively. They also noticed that the characteristics reported by the two acoustic software tools varied significantly. Nevertheless, the connection and stability were strong.

Patients with OSAHS tend to mouth breathe more frequently than other people (McKeown et al., 2021). When OSAHS patients open their lips for prolonged periods, the inhaled airflow from the nasal cavity is lost, causing the vocal cord surface to dry up. According to (Yaslıkaya et al., 2022), the threshold voltage of vocalization increases when the moisture in the liquid layer on the surface of the vocal cords diminishes, and the vocal cords may become harmed when the pressure reaches a particular level.

In another study (Zamora-Molina et al., 2021), the researchers aimed to determine the severity of OSA and the frequency with which vocalization would be impacted by oxygen saturation levels below 90% during polysomnography (CT90%). The chosen patient group, whose ages ranged from 18 to 60, was divided into four categories according to how severe their OSA was: normal, mild, moderate, and severe. For two vowels, the longest possible pronunciation duration was 5 seconds. Using PRAAT, they generated the Jitter, Shimmer, harmonics-to-noise ratio (HNR), and F0 values for 72 patients. They concluded that if obstructive sleep apnea (OSA) worsened, the voice's quality may as well. A decrease in voice quality may be linked to an increase in CT90% (the percentage of sleep time with low oxygen saturation levels), and it may also be utilized as a predictor of voice problems in future investigations.

The acoustic characteristics of voice emission in the supine and sitting positions, as well as their differences, were examined in recent research (Zamora-Molina et al., 2021) to see if they may help diagnose OSA in individuals who have a strong suspicion that they may have the condition. They said that their outcomes were comparable to those of the study team (Tao et al., 2009). The study on acoustic analysis of obstructive sleep apnea that has previously been published provides crucial insights into how to assess and categorize voice issues in OSA patients. Nevertheless, despite the current studies, further research and improvement are still required in this field. It has been shown that there is little correlation between the vocal frequencies of the vowels and the AHI score (Montero Benavides et al., 2016).

Nonetheless, these findings emphasize how crucial it is to consider the mediated or indirect effects of clinical factors while doing speech and OSA research. It is essential to think about using other acoustic properties or factors in the study in addition to the frequency analysis of vowel recordings. By examining elements including the amplitude, duration, pitch, and spectral features of speech signals, one may acquire a thorough understanding of the acoustic profile connected to OSA.

III. DISCUSSION

The study shows that acoustic analysis has the potential to be a significant tool for the identification and diagnosis of obstructive sleep apnea (OSA). The use of acoustic markers from both speech and snoring patterns has become a viable method for assessing OSA. The results of this research show that acoustic analysis has the potential to address some of the drawbacks of current diagnostic techniques, such as the labour- and cost-intensive nature of polysomnography (PSG), which is the gold standard. Additionally, the use of acoustic analysis provides a non-intrusive and economical method that enables continuous monitoring in a typical sleeping environment. The study emphasizes the need to consider a variety of acoustic factors, including fundamental frequency, jitter, shimmer, and noise-to-harmonics ratio, to thoroughly analyze voice-related difficulties in OSA patients. A typical OSA symptom, snoring, might shed light on the existence and severity of the disease. According to studies, people with OSA have distinctive acoustic features in their snoring patterns that may be recognized by automated classification systems. Furthermore, speech analysis has proven to be effective in identifying probable OSA warning signs such as abnormal vocal cord vibration and articulation issues. Another aspect of acoustic analysis

concentrates on the sounds of sleep breathing to comprehend respiratory episodes connected to OSA. AI algorithms and methods like Random Forest regression strive to produce precise classifications and real-time OSA predictions. Validation, however, is essential for dependability and clinical application. Voice-related OSA concerns have been identified using acoustic analytic techniques such as formant frequency analysis and voice quality evaluations. To fully comprehend the acoustic profile related to OSA, it is crucial to consider additional acoustic aspects aside from frequency analysis. Additionally, there is still no clear correlation between voice frequencies and the apnea-hypopnea index (AHI) score (Montero Benavides et al., 2016). The benefits of using acoustic analysis methods for OSA diagnosis are straightforward. The availability of inexpensive microphones, whether noncontact or contact-based, enables ongoing patient sleep quality monitoring and supports the detection of probable OSA signs. However, it's important to recognize the limits of current sound analysis techniques. Even if improvements have been made, it is still difficult to establish clear diagnostic standards across various investigations. The requirement for standardization to achieve accurate and repeatable findings is highlighted by the variability in acoustic software tools like MDVP and PRAAT. Furthermore, future research is needed to determine the relationship between auditory markers and recognized clinical signs as the apnea-hypopnea index (AHI). Also, the new advancements should investigate other acoustic characteristics such as amplitude, duration, pitch, and spectral components.

IV.CONCLUSION

As a non-invasive and affordable approach for diagnosing obstructive sleep apnea, acoustic analysis has potential. Speech and snoring analyses have shed important light on the acoustic traits connected to OSA. Accurately identifying OSA-related snoring occurrences is possible with automated classification techniques. To establish the therapeutic utility and reliability of acoustic analytic techniques, more study and development are necessary. Future research should investigate the relationship between auditory characteristics and OSA severity and consider the mediated effects of clinical variables. Acoustic analysis has the potential to supplement already used diagnostic procedures and aid in the creation of more useful and effective diagnostic tools for OSA.

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