COMPARATIVE AUDIO ANALYSIS OF NORMAL AND PATHOLOGICAL HEART SOUNDS: A FOCUS ON MITRAL REGURGITATION

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ABSTRACT

The recent changes in utility structures, development in renewable technologies and increased

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INTRODUCTION

1.1 INTRODUCTION

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CHAPTER II

LITERATURE REVIEW

2.1 LITERATURE REVIEW

Cardiac auscultation is pivotal in clinical diagnosis, providing critical insights into cardiovascular health. This practice has remained bread and butter in clinical examinations due to its ability to identify different characteristics of cardiac sounds to differentiate between physiologic and pathologic sounds (Dornbush & Turnquest 2023). Cardiac activity has been extensively and precisely mapped to its anatomical functions. The first heart sound (S1) is associated with the closure of the mitral and tricuspid valves, while the second heart sound (S2) relates to the closure of the pulmonary and aortic valves (Wang et al. 2016). Disruptions in normal heart physiology can result in the emergence of abnormalities such as murmurs, gallops, or even a third heart sound (S3), each indicative of specific underlying cardiac pathology. Murmurs, categorised as high-frequency noise-like sounds, are often pathological (Yazdani et al. 2016). Mitral Regurgitation (MR), a form of valvular abnormality causing retrograde flow of blood from the left ventricle into the left atrium, produces a distinctive apical holosystolic murmur (Douedi & Douedi 2024). Cardiac auscultation remains integral to clinical diagnosis, with distinctive audio signals for each pathology. This allows a window of opportunity to use more advanced technology to identify patterns within these audio signals.

Digital phonocardiography (PCG) has recently gained recognition as a sensitive yet objective alternative to traditional auscultation. It enables the detection of heart sounds that are inaudible to the human ear and allows for the quantification of these pathologies through the physiological waveform (Reyna et al. 2022). Utilising techniques such as Fast Fourier Transform (FFT) can provide a basic frequency of the contents of the heart sounds. FFT includes information on the frequency domain of audio signals and can give an idea about the frequency component and frequency spectrum of heart sounds (Singh & Anand 2007). Debbal (2020) successfully mapped out the frequency-temporal pattern of heart sounds using the Short-Term Fourier Transform (STFT) technique, where S1 and S2 register a 10 Hz to 200 Hz and 20 Hz to 250 Hz frequency, respectively. By understanding normal physiology, pathological changes can be identified better. Murmurs, in particular, usually have a higher peak murmur frequency of 200 Hz to 410 Hz (Donnerstein 1989).

Temporal analysis of heart sounds adds value to the analysis and comparison between normal and pathological heart sounds. Spectrograms (STFT) are particularly valuable for diagnosing systolic murmurs associated with mitral regurgitation, as they reveal persistent energy between S1 and S2 that corresponds to the regurgitant jet. Utilising these methods, PCG has been proven to be an objective and sensitive detector of inaudible heart sounds (Reyna et al. 2022).

The literature clearly highlights the evolution of cardiac auscultation from purely clinical skill to a digitally enhanced method. Techniques such as Fast Fourier Transform and spectrograms (STFT) have been proven to be effective in visualising spectral characteristics of heart sounds, particularly in differentiating normal heart sounds and pathological murmurs such as those caused by mitral regurgitation. However, most studies focus on automated classification of heart condition or general spectral patterns of murmur types. There remains a lack of focus on interpretable comparison between physiological and pathological heart sounds using straightforward, explainable waveform analysis such as FFT and Spectrograms. This study seeks to address these gaps by presenting a simplified, comparative time-frequency analysis of normal and MR heart sounds by relying on visually interpretable waveform plots, timer outputs, FFT, and spectrograms. It aims to bridge the gap between signal processing tools and their direct application in clinical reasoning, teaching, and learning.

CHAPTER III

METHODOLOGY

3.1 DATA ACQUISITION AND PREPROCESSING

This study involved a comparative time-frequency analysis of two heart sound recordings: one from a healthy individual and another from a patient with clinically diagnosed mitral regurgitation (MR). The primary objective was to identify and contrast the temporal and spectral features characteristic of normal and pathological heart sounds using signal processing techniques.

The two sets of audio data were obtained from thinklabs.com, a company that provides clinically accurate heart sounds for teaching and learning. Both sound files were downloaded and converted to .wav format for processing. Both audio's sample rate and bit depth are 44100 Hz, and 16 bits with two-channel audio. The recordings were first converted to monophonic signals by isolating the left audio channel using the mono() function from the tuneR package in R. To standardise the analysis duration, both recordings were trimmed to the first 3 seconds using the cutw() function.

3.2 METHOD OF ANALYSIS

3.2.1 Time-Domain Analysis

Waveform plots were generated for both recordings to observe the amplitude patterns over time. Key temporal features, such as the timing and spacing between the first (S1) and second (S2) heart sounds, were qualitatively assessed. To further quantify the timing of sound events, the timer() function was employed on the smoothed envelope signals, with thresholds and msmooth parameters optimised to accurately detect S1, S2.

3.2.2 Frequency-Domain Analysis

The Fast Fourier Transform (FFT) was used to compute the power spectral density of each recording. A unique function to plot the frequency against the strength was used across the entire 3-second segment, revealing dominant frequency bands. The frequency spectra between the normal and MR heart sounds were compared to identify peak frequency shifts and spectral broadening associated with the pathological murmur.

3.2.3 Time-Frequency Analysis

Spectrograms were produced using the spectro() function from the seewave package, employing a window length (wl) of 256 and 75% overlap to balance temporal and frequency resolution. The frequency range was limited to 0–500 Hz (flim = c(0, 0.5)) to focus on diagnostically relevant content. Time limits (tlim = c(0, 3)) were kept consistent across both plots to allow direct visual comparison. Spectral energy patterns corresponding to S1, S2, and murmurs were identified and interpreted.

This multi-level approach—spanning time, frequency, and time-frequency domains—enabled a holistic comparison between normal and MR heart sounds, supporting visual and analytical differentiation of pathophysiological features.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 NORMAL VISUALIZATION OF AUDIO PLOT

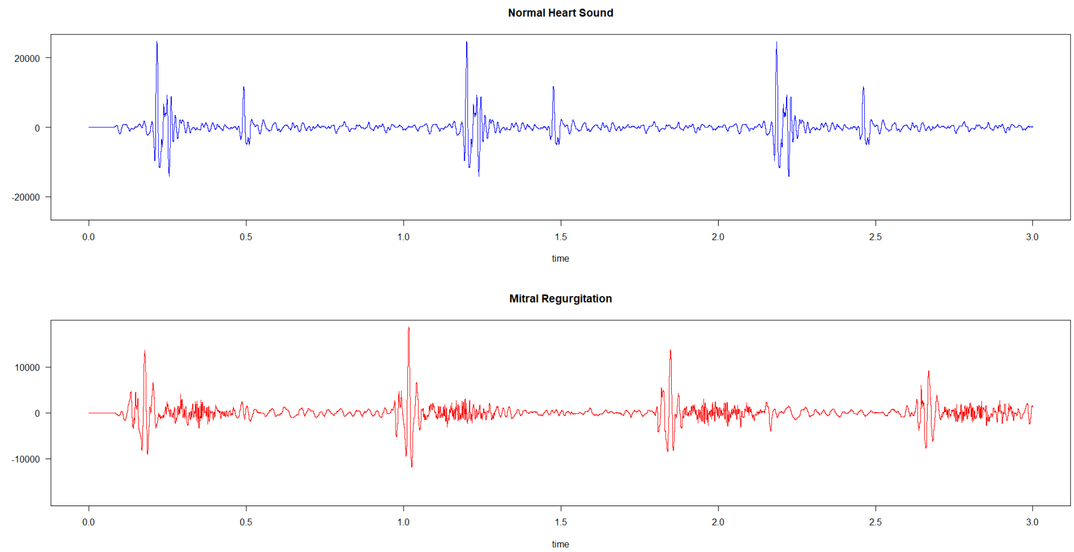

Figure 1 Wave Plot of Heart Sounds

Figure 1 compares normal and mitral regurgitation (MR) heart sounds over 3 seconds. The waveforms reveal distinct temporal and morphological differences characteristic of pathological valvular dysfunction. The upper panel represents a normal heart sound; each cardiac cycle is marked by two prominent sound waves corresponding to the first (S1) and second (S2) heart sounds. These sounds are separated by a period of brief silence, indicating the absence of turbulent flow during systole. The sharp amplitude suggests efficient physiology of valve closure with normal hemodynamic flow within heart chambers.

This contrasts with the bottom panel, which illustrates the typical mitral regurgitation heart sound, marked by an initial S1 but indiscernible S2 peak. A continuous low-amplitude acoustic activity occupies the segment typically filled with silence from the laminar blood flow. The persistent signal corresponds to a pansystolic murmur, a hallmark of mitral regurgitation caused by the retrograde blood flow from the left ventricle to the left atrium during systole, often caused by valvular dysfunction. The waveform analysis shows effective differentiation between normal and pathological heart sounds.

4.2 TIMER ANALYSIS

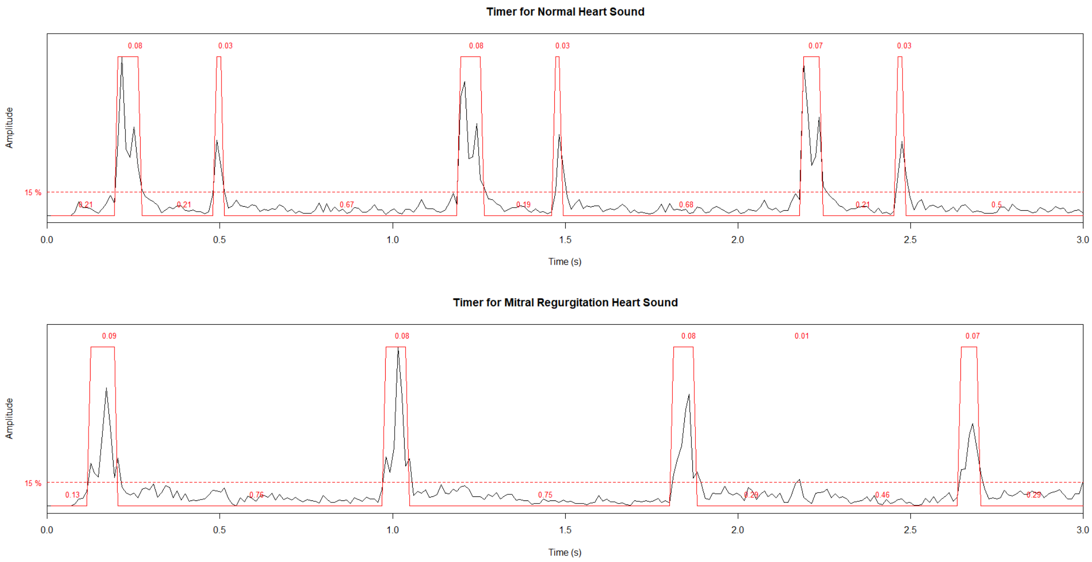

Figure 2 Timer Plot of Heart Sounds

Complementing the waveform comparison, the timer plots in Figure 2 offer quantitative analysis of the temporal structure and duration of the acoustic events in both the normal and MR heart sounds. The plots visualise the signal envelope and highlight segments that pass a defined amplitude threshold (15%), identifying them as sound events.

The timer plot for the normal heart sounds (top panel) shows regular, sharply bounded acoustic events. Each cardiac cycle displays two amplitude outbursts, S1 and S2, with short durations, 0.08 and 0.03 seconds, respectively. Each cardiac cycle is followed by well-defined intervals of 0.67-0.68 seconds. This regular alternating effect reflects normal cardiac physiology, with efficient valvular mechanisms highlighted by the consistency in timing and separation.

Conversely, the MR timer plot (bottom panel) exhibits prolonged low-amplitude activity between the main peaks, indicating possible underlying pathology during systole. While S1 is still present, S2 appears barely discernible with noisier inter-sound intervals extending over longer durations of 0.75 between S1s. This reflects the presence of pansystolic murmur, consistent with the pathophysiological features of mitral regurgitation.

These timer plots reinforce the distinction between normal and pathological heart sounds by quantifying temporal events and providing an objective measure of murmur.

4.3 FREQUENCY ANALYSIS

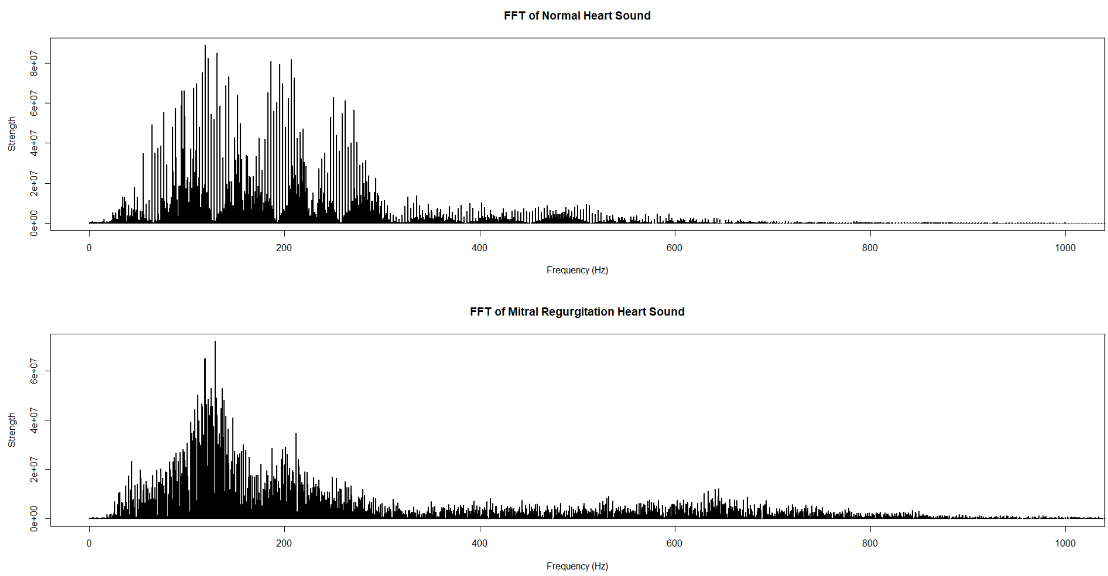

Figure 3 Fast Fourier Transform of Heart Sounds

To further elucidate the spectral characteristics of heart sounds, the Fast Fourier Transform (FFT) plots in Figure 3 provide insight into the frequency-domain distribution of acoustic energy in both normal and MR signals. The FFT quantifies the signal strength across a range of frequencies, highlighting dominant frequency components.

The normal heart sound spectral energy is concentrated within the 50 – 250 Hz range, with multiple sharp and distinct peaks. This indicates that the majority of the acoustic power is confined towards the lower frequencies reflecting the mechanical closure of heart valves with minimal turbulence. Beyond 300 Hz, the signal strength rapidly declines forming a narrow band of normal heart sound energy.

The FFT of the MR heart sounds shows a broader spectral distribution with energy extending up to 600 Hz. While the peak cluster signals remain at 250 Hz, the energy is more widespread with a less sharp peak. This broader and flatter spectral profile is consistent with the turbulent flow of regurgitant blood during systole, which produces a continuous murmur of complex high-frequency components. Together, these FFT plots reinforce the distinction between structured, low-frequency characteristics of normal heart sounds, and disorganised, wide-band spectrum of MR.

4.4 SPECTOGRAM

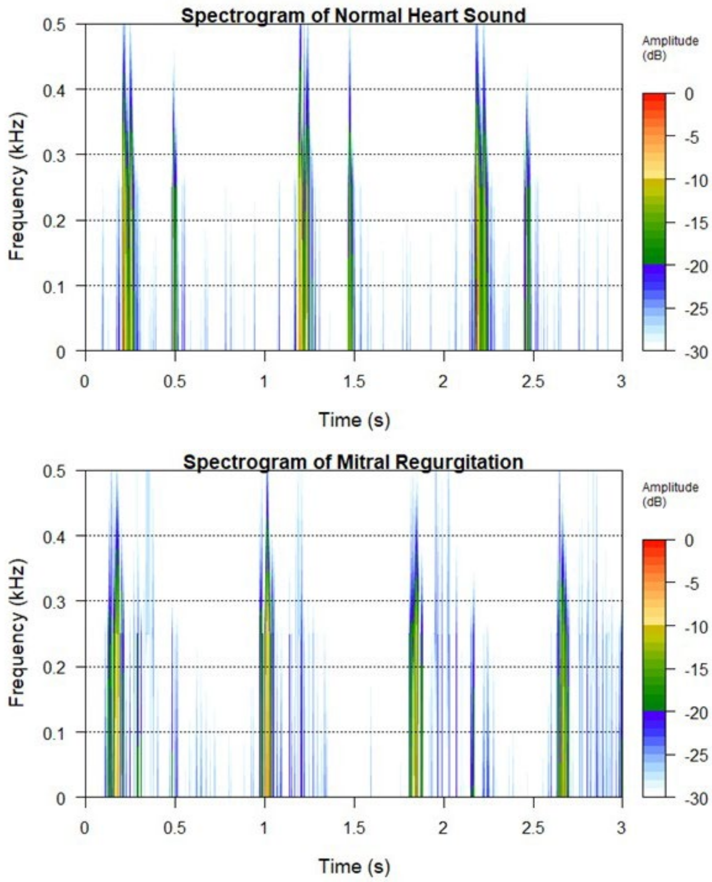

Figure 4 Spectogram of Heart Sounds

Building upon the waveform and timer analyses, the spectrograms provide a time-frequency representation of the heart sounds, capturing both the temporal and spectral evolution of acoustic energy. These plots visualize how sound intensity (in dB) is distributed across different frequencies (0–500 Hz) over the 3-second recording window for both normal and mitral regurgitation (MR) heart sounds.

In the normal heart sound spectrogram (top panel), the acoustic energy is concentrated in brief, high-intensity bursts, corresponding to the first (S1) and second (S2) heart sounds. These appear as vertical bands of high amplitude, primarily between 100–200 Hz, and are sharply defined with clear separation in time, reflecting the discrete, non-continuous nature of normal valve closures. Between each S1 and S2, and particularly during diastole, the spectrogram shows minimal activity, indicating the absence of turbulent flow or murmurs.

In contrast, the mitral regurgitation spectrogram (bottom panel) demonstrates a more diffuse and continuous spread of acoustic energy, particularly in the 100–300 Hz range. While the initial peaks associated with S1 and S2 are still visible, they are less sharply defined. More notably, there is persistent low- to mid-frequency energy throughout systole, filling the gap between S1 and S2. This sustained energy corresponds to the pansystolic murmur caused by backflow of blood through the incompetent mitral valve, and its spectral pattern is less discrete and more smeared than in the normal case.

Together, these spectrograms reinforce the diagnostic difference between normal and pathological heart sounds. The discrete, rhythmic patterns of the normal heart are replaced in mitral regurgitation by spectrally dispersed, continuous energy patterns, highlighting the utility of time-frequency analysis in identifying and characterizing murmurs.

CHAPTER V

CONCLUSION AND FUTURE WORKS

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