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Tinnicure: Tinnitus Frequency Detection and Notched Noise Generation

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Abstract: Tinnitus is a neurological condition characterized by the perception of phantom sounds, commonly described as ringing in the ears, in the absence of external auditory stimuli. Affecting over 10% of the global population, it poses significant challenges due to the lack of a standardized and accessible treatment method. This paper presents a web-based application that enables self-diagnosis and personalized white noise therapy through frequency masking. Using the Web Audio API, the system allows users to identify their tinnitus frequency and applies real-time notch filtering to generate therapeutic audio tailored to their condition. The solution operates entirely within the browser, requiring no external plugins or backend servers, thereby ensuring data privacy and cross-platform compatibility. Additionally, the application supports treatment session tracking via local storage, enabling users to monitor progress without compromising anonymity. By offering a cost-effective, accessible, and user-friendly alternative to conventional therapies, this work contributes a scalable digital approach for tinnitus management suitable for both individual use and future clinical expansion.

I. INTRODUCTION

Tinnitus is a common auditory symptom in which a person perceives sound (often described as ringing, buzzing, or hissing) without any corresponding external sound source. It affects a significant fraction of the population – on the order of 10–15% of adults worldwide – and its prevalence rises with age. For example, one systematic review estimated that roughly 14% of adults experience tinnitus, with higher rates in older age groups.

Although the phantom sounds may range from benign to severely bothersome, tinnitus often has a substantial impact on quality of life. Individuals may report difficulty sleeping, concentrating or conversing (because of masking of normal sounds), as well as frustration, anxiety or depression related to the persistent noise. In severe cases, tinnitus can cause insomnia, irritability, and functional impairment akin to that seen with chronic pain or phantom limb phenomena.

It most commonly arises from cochlear (inner ear) injury or dysfunction: for example, age-related hearing loss, noise-induced cochlear damage, ototoxic drugs, or Meniere's disease can all precipitate tinnitus. A leading theory is that damage to cochlear hair cells or synapses produces abnormal spontaneous firing that propagates up the auditory pathway. In effect, deafferentation of certain cochlear regions leads to disinhibition and hyperactivity in corresponding central auditory neurons (sometimes described as maladaptive cortical plasticity or a "lesion projection zone").

The brain then interprets this aberrant neural activity as sound (often at or near the frequencies of maximal hearing loss). In analogy to phantom limb pain, tinnitus may reflect a central nervous system response to the loss of normal sensory input. Thus, although the initial damage is usually peripheral (e.g. in the cochlea), tinnitus perception ultimately involves altered neural circuits in the auditory cortex and brainstem.

Subjective tinnitus – by far the more common form – is perceived only by the patient and has no external sound source. Almost all chronic tinnitus falls into this subjective category. Objective tinnitus is rare (on the order of <1% of cases) and typically results from a physical sound generated within the body (for example, turbulent blood flow or muscular spasms that create an audible noise). In objective tinnitus, a clinician may even be able to hear the sound with a stethoscope. By contrast, the cause of subjective tinnitus is usually idiopathic or related to inner-ear/cochlear factors.

In practice, clinicians first distinguish subjective versus objective tinnitus, and then focus on identifying treatable underlying causes. Nevertheless, the majority of tinnitus sufferers have no curable lesion; the condition is generally chronic and managed as a syndrome rather than resolved by treating a specific disease. (Secondary forms, such as tinnitus caused by ear infection or temporomandibular joint dysfunction, are much less common).

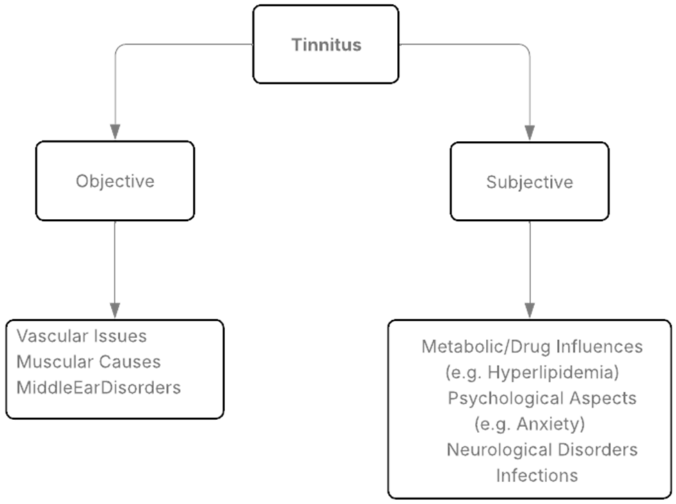

Figure 1. Classification of tinnitus (subjective vs. objective) based on etiology and perceptibility.

Clinically, tinnitus is described by its qualities (e.g. ringing, buzzing, whooshing) and by its duration. Onset may be sudden or gradual; the sound can be steady or pulsatile (synchronous with heartbeat). Many patients have intermittent symptoms that come and go, while others have a constant tone. Tinnitus is often bilateral, but can be unilateral or even perceived inside the head without a clear lateralization. Importantly, tinnitus is frequently associated with hearing loss: most patients who report tinnitus also have some degree of sensorineural hearing impairment, even if mild. This association underscores the link to cochlear dysfunction. Patients and providers must also consider risk factors or precipitants: long-term noise exposure, ototoxic medications, head injuries, and systemic conditions (e.g. hypertension, diabetes) are recognized contributors

The impact of tinnitus extends beyond the ear. Psychologically and neurologically, chronic tinnitus can be distressing. Many patients experience anxiety, irritability, sleep disturbance, or depression as a direct consequence of their tinnitus. Tinnitus often interferes with concentration at work or causes social withdrawal due to difficulty hearing conversations. Secondary problems such as insomnia can further erode quality of life. Neuroimaging and electrophysiological studies have shown that tinnitus involves not only auditory cortex hyperactivity but also abnormal activation of emotional and attentional networks. In fact, clinicians often liken tinnitus to a “phantom sound” with parallels to neuropathic pain or phantom limb syndrome. Thus, the suffering from tinnitus is both sensory and affective, and effective management often requires attention to both components.

Clinical practice guidelines underscore that tinnitus is a symptom complex requiring individualized management. For most patients the goal is not eradication of the sound (which is usually impossible) but rather reduction of its audibility or patients’ reaction to it. Many patients try multiple therapies with varying success; what works for one may not work for another. This gap – the lack of a simple, broadly efficacious treatment – motivates ongoing innovation in tinnitus care.

A. Traditional Treatment Approaches

Tinnitus treatment often requires a multidisciplinary approach that incorporates medication, behavioral strategies, and auditory-based interventions. Various pharmacological options—including anticonvulsants, antidepressants, diuretics, and trace element supplements like zinc—have been explored in clinical contexts. However, no medication to date has received formal approval specifically for tinnitus management, and the therapeutic outcomes reported in the literature remain inconsistent and inconclusive. For example, a variety of medications including selective serotonin reuptake inhibitors, benzodiazepines, and anticonvulsants have been used empirically, often targeting comorbid anxiety or insomnia. However, controlled studies generally show limited or no improvement in tinnitus symptoms from drugs alone. In practice, medications may be prescribed to address associated conditions (e.g. treating depression, anxiety, or sleep disturbance that worsen tinnitus perception) rather than the tinnitus itself. Importantly, guidelines caution that certain drugs (e.g. some antibiotics, chemotherapy agents) can *cause* or exacerbate tinnitus, so medication review is an essential part of evaluation.

Behavioural and psychosocial interventions are another mainstay. Cognitive behavioural Therapy (CBT) and related counselling techniques have strong support in the literature for helping patients cope with tinnitus. CBT does not eliminate the auditory sensation, but it can significantly reduce tinnitus distress by reframing negative thoughts and reducing anxiety or hypervigilance. Indeed, professional societies (e.g. the American Academy of Otolaryngology) endorse CBT as an evidence-based approach to improve quality of life in chronic tinnitus patients. Tinnitus Retraining Therapy (TRT) is a related method that combines directive counselling with sound enrichment, aiming to habituate the patient to their tinnitus over time. In general, these therapies can yield modest benefit in reducing patients' subjective annoyance and improving coping, although they require skilled therapists and patient commitment. Access to specialized tinnitus counselling may be limited in many regions, motivating interest in internet-based CBT and telemedicine approaches (some preliminary studies of online CBT for tinnitus have shown promise.

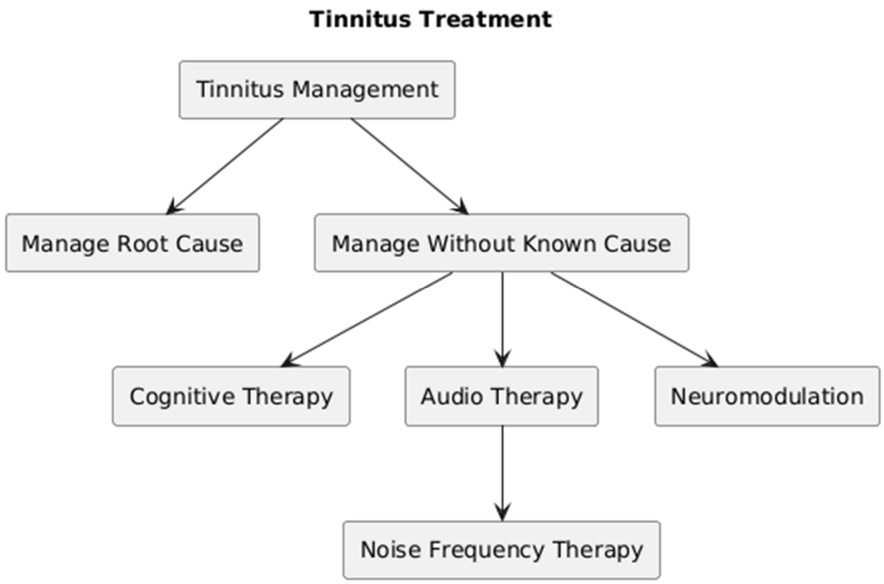

Figure 2: categorizes the main types of sound therapy that have been explored in research and practice

B. Frequency Masking and Web-Based Therapy

Among the various approaches to tinnitus treatment, sound therapy plays a central role and is particularly significant to the focus of this research. It involves the application of external auditory signals to either obscure the perception of tinnitus or facilitate the brain's gradual desensitization to the phantom sound for example, white noise generators or fans – which create a steady background sound. A patient can listen to broadband noise at low volume to partially cover (mask) the tinnitus and distract the auditory system. For instance, many tinnitus sufferers find relief by listening to white noise or nature sounds through earphones, or even by using hearing aids that amplify ambient sounds to drown out the internal noise.

Beyond simple white noise, customized sound therapies have been developed that target the patient's specific tinnitus frequency. Two popular approaches are *notched* and *narrowband* sound therapy. In notched sound therapy, one starts with broadband noise and removes (notches out) a narrow band of frequencies around the tinnitus pitch. The idea is that by *avoiding* stimulation at the tinnitus frequency, one may encourage the brain's lateral inhibition processes to reduce hyperactivity at that frequency (and potentially promote cortical reorganization.

Narrowband therapy, in contrast, uses sound confined to a narrow frequency band either cantered on or offset from the tinnitus frequency; the rationale here can be to provide targeted stimulation that competes with the tinnitus frequency or retrains perception. Another approach is *harmonic sound therapy*, which involves playing a set of tones or noise peaks at the tinnitus frequency and its harmonics, in order to engage multiple related frequency channels and achieve a concentrated masking effect. Each of these specialized therapies has been tested in clinical studies: for example, trials of tailor-made notched music have shown improvement in some patients, and harmonic or multi-band noise therapies have reduced tinnitus loudness in pilot studies. However, the evidence is mixed: some patients do report relief from these frequency-specific sound therapies, but others do not, and larger controlled studies are still needed

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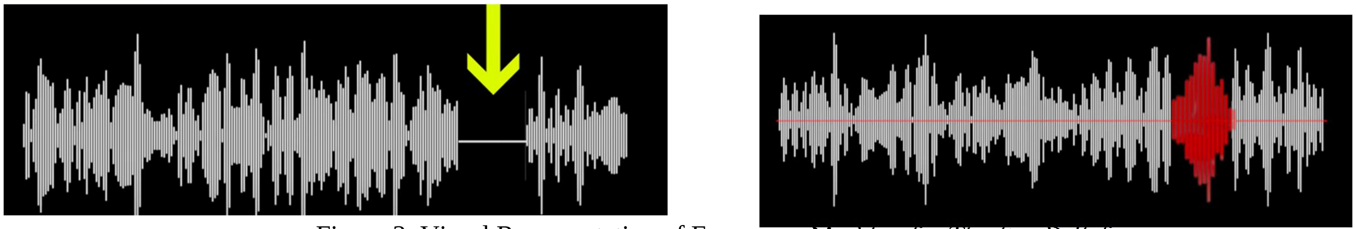

Figure 3: Visual Representation of Frequency Masking for Tinnitus Relief

II. LITERATURE REVIEW

Tinnitus remains a significant clinical and research challenge, with diverse therapeutic approaches showing variable efficacy. A wide body of literature explores the etiology, neurophysiological basis, and treatment options for tinnitus, especially the use of sound-based interventions such as masking and frequency-specific therapies. Despite advancements, no universal treatment standard exists, prompting continued innovation in personalized and accessible solutions.

Tinnitus perception is commonly associated with increased neural activity within the central auditory pathways, typically arising after injury or dysfunction of the cochlea or auditory nerve.. This maladaptive neuroplasticity leads to the emergence of spontaneous neural firing in regions associated with hearing loss — an area described in the literature as the "Lesion Projection Zone" (LPZ). Studies and Tyler et al. suggest that the tones perceived in tinnitus often correspond to the frequencies adjacent to the damaged cochlear region, referred to as Lesion Edge Frequencies (LEF). These insights have informed the development of therapies that target specific frequency bands rather than relying solely on broad-spectrum noise.

Traditional masking strategies, including the use of white or pink noise, aim to obscure the tinnitus sound by filling the auditory field with non-specific stimuli. While this can provide temporary relief, its effectiveness diminishes over time, particularly in individuals with tonal tinnitus or well-defined frequency peaks. To address this limitation, notched sound therapy and narrowband masking have gained traction. In notched noise therapy, a frequency band centered on the individual's tinnitus pitch is removed from a broadband noise signal. This is theorized to reduce excitation of the corresponding neurons and promote lateral inhibition, gradually reducing the brain's attention to the phantom sound.

Several controlled studies have evaluated the outcomes of notched and customized sound therapies. A randomized trial by Jin et al. demonstrated that participants receiving 3–5 hours of daily therapy using personalized notched noise experienced statistically significant reductions in tinnitus loudness and distress, as measured by tools such as the Tinnitus Primary Function Questionnaire (TPFQ). Similarly, customized harmonic therapy, as explored by Mahboubi et al., produced measurable short-term residual inhibition after just one hour of listening. These results underscore the potential of frequency-targeted therapies in contrast to generic masking approaches.

Web-based platforms have recently emerged as a delivery model for tinnitus therapy. Studies highlight the feasibility of browser-based tools that allow users to self-identify their tinnitus frequency and receive customized audio therapy. Moreover, real-time processing using technologies like the Web Audio API allows users to generate and adjust sound profiles dynamically, which aligns with findings that therapy effectiveness improves with individual tailoring and regular use.

III. PROBLEM STATEMENT

Tinnitus is defined as the sensation of hearing sound without any external source, and it impacts a significant segment of the worldwide population. Despite its high prevalence and debilitating impact on daily life, a universally effective, low-cost, and scalable treatment remains elusive. Existing treatment modalities such as pharmacological therapy, cognitive behavioral therapy (CBT), and sound therapy have yielded mixed results, and are often either inaccessible, expensive, or require consistent clinical supervision. Among these, sound therapy has emerged as one of the most promising non-invasive approaches, particularly for individuals experiencing tonal tinnitus that can be linked to specific frequency ranges. However, traditional sound therapy techniques — such as broadband white noise or simple masking devices — lack precision and personalization, which limits their therapeutic efficacy. Moreover, most clinical implementations of advanced sound therapies, like notched or harmonic masking, demand specialized equipment, audiological expertise, or mobile applications that are not widely available to all demographics.

Adding to the challenge, the treatment experience is often passive and non-adaptive. Many existing solutions do not allow real-time customization, and few support users in tracking their therapy sessions or adjusting their masking profile based on perceptual changes.

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This creates a gap between available technology and the actual needs of tinnitus patients, who would benefit most from flexible, adaptive tools that operate independently of clinical infrastructure. Furthermore, studies have shown that consistent and long-duration exposure to well-calibrated sound therapy is correlated with improved outcomes. Yet, many users fail to adhere to therapy regimens due to poor user experience, lack of personalization, or unavailability of practical tools.

In parallel, the advancement of browser-based audio processing technologies has opened new opportunities for delivering sound therapy directly through the web, using standards like the Web Audio API. Such technologies enable real-time audio generation, frequency shaping, and user interaction, thereby making it possible to develop a completely browser-based tinnitus therapy system that operates without relying on external hardware. However, existing research and development efforts have not fully leveraged this potential to create an accessible, customizable, and privacy-preserving system that empowers users to self-diagnose and manage their condition.

The core problem this research addresses is the absence of a freely accessible, browser-native solution that enables tinnitus sufferers to both identify their tinnitus frequency and receive real-time, frequency-masked white noise therapy with personalized control. Additionally, no existing platform integrates session tracking and data visualization in a way that maintains user privacy while still supporting long-term use and self-monitoring. Therefore, there is a critical need to design and implement a system that bridges clinical-grade sound therapy principles with open, scalable, user-centric web technologies. This project aims to fill that gap by developing a system that is not only medically informed but also technically optimized for broad deployment, ease of use, and adaptability across user needs.

IV. PROPOSED METHODOLOGY

This section outlines the design and implementation of a browser-based tinnitus therapy system that uses frequency-masked white noise tailored to individual tinnitus frequencies. The methodology is divided into client-side interaction steps and technical processing components, all of which are implemented using web-native technologies.

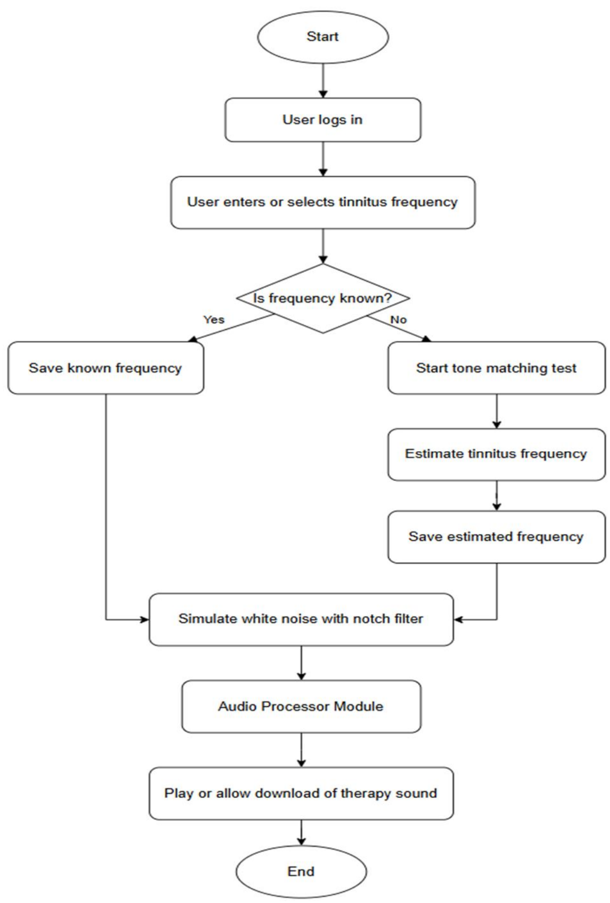


Figure4: Flowchart of the Proposed Therapy System

A. Client-Side System Flow

The overall user-level workflow is implemented entirely in the browser. It begins with user interaction for tinnitus frequency detection and proceeds through real-time audio synthesis and filtering to deliver the therapy sound and log results. Key steps include the following sub-processes:

1) User Interaction for Tinnitus Frequency Detection

As the application initializes, it prompts the user to match a tone that resembles the pitch of the sound they experience due to tinnitus. This is typically done by playing a test tone or sequence of tones and having the user indicate which tone most closely matches their tinnitus. In practice, the system may use a multi-step approach: first presenting coarse "octave" choices . For example, the app might play a tone at 1 kHz, 2 kHz, 4 kHz, etc., and let the user select the closest one; then a slider lets the user sweep in 25 Hz steps around that frequency until the perceived tone aligns. User input events (button presses or slider movements) trigger playback of corresponding tones via the Web Audio API. The final frequency that the user selects (after any "octave challenge" correction to avoid octave confusion) is recorded as the estimated tinnitus frequency. In effect, the **Input** block of the flowchart involves capturing the user's self-matched tinnitus pitch, which the system will use in the next stage.

2) Real-Time White Noise Generation

Once the user's tinnitus frequency F has been identified, the system proceeds to generate a continuous masking sound.In implementation, the Web Audio API is used to create an audio buffer filled with pseudo-random samples. For example, one common technique is to make an Audio Buffer of length *buffer Size* = 2·*sampleRate* (e.g. two seconds of samples) and fill each sample with a random value between –1 and +1. This buffer of white noise is then looped continuously to produce an ongoing hiss. The result is a seamless white noise output that underlies the therapy sound. In the **Processing** block of the flow diagram, this generated white noise serves as the raw audio input to be filtered.

3) Notch Filter Application

After the white noise source is created, the system applies a notch (band-stop) filter centered at the user's tinnitus frequency F. This is done by inserting a BiquadFilterNode of type "notch" into the audio graph. In practice, the code sets the filter's frequency.value = F and chooses a quality factor Q to define the bandwidth of the notch. A higher Q yields a narrower notch, focusing precisely on the tinnitus tone. By sharply attenuating the detected tinnitus pitch in the white noise, the system creates a "notched" audio signal that excludes that frequency. In other words, the specific sound that matches the tinnitus is removed or greatly reduced in volume. This aligns with notched sound therapy principles: by removing the tinnitus frequency from the sound stimulus, the user's brain perceives a gap at that pitch. In the flowchart, this is part of the **Processing** stage: the white noise generator feeds into a notch filter node tuned to the user's F. (If future extensions allow multiple tinnitus tones, additional parallel notch filters could be inserted sequentially to create multiple notches.

4) Therapy Playback and Controls

With the notched white noise prepared, the system then provides playback controls for the user to listen to the therapy. The processed audio stream (noise → notch filter) is ultimately connected to the audio output (the device speakers or headphones) via the Audio Context's destination node. Throughout playback, the app maintains the audio graph while responding to UI events: for instance, moving the volume slider immediately updates the GainNode's gain parameter. Thus the **Output** block in the flowchart encompasses the act of streaming the filtered white noise to the user's ears under user control (and visualizing any real-time feedback, such as a spectrogram or level meter, if included). Note that modern browsers require a user gesture to begin audio playback; the system ensures that the AudioContext is created or resumed only after the user clicks "Play".

5) Local Session Logging and Progress Tracking

After (or during) each therapy session, the system logs key data locally. This may include the tinnitus frequency F, the time and duration of listening, the volume setting used, and any subjective user feedback (e.g. a rating of tinnitus loudness). The data is stored in the browser's storage (for example, using the Web Storage API or IndexedDB). By keeping all data on the client side, user privacy is maximized: no personal identifiers or hearing test results are sent to a server. Logging may be implemented via localStorage (for simple key-value entries) or IndexedDB for more structured records. The user interface can offer a "History" or "Progress" view that reads these logs and charts improvements over time (for example, a trend of decreasing tinnitus annoyance scores). This completes the **Output** block of the flowchart, which handles not only the sound delivery but also the recording of session outcomes.

B. Technical Implementation

This section outlines the browser-based implementation of the tinnitus frequency-masking therapy workflow, using React.js, Next.js, and the Web Audio API. All audio generation, filtering, and playback functionalities are handled entirely on the client-side without requiring a server

1) Application Framework and Components

The system is developed as a single-page application using JavaScript and React.js, structured with modular components corresponding to each step in the therapy workflow. Navigation (TopNav), diagnostic steps (StepRoughFrequency, StepFineFrequency, StepOctaves), and playback controls (PlayButton, TreatmentButton) are React components. User preferences, estimated frequencies, and session data are stored in localStorage using a helper library (libs/user.js). Session logs are updated on every treatment play/stop event, enabling local progress tracking.

2) Frequency Estimation (Tone-Matching Test)

To estimate the user's tinnitus frequency, the app guides them through a tone-matching sequence using the Web Audio API. An OscillatorNode generates adjustable tones, and user responses ("higher", "lower", "same") drive a binary search approach. The stopping condition is governed by the ERB (Equivalent Rectangular Bandwidth) formula. Fine-tuning is done via a frequency slider, while octave confusion is resolved through selectable tone options at ±1 octave from the current estimate.

3) Notched Noise Generation and Playback

Once the tinnitus frequency is identified, white noise is generated using a real-time audio script (or AudioBuffer), and multiple BiquadFilterNode elements are applied to notch out the target frequency band. These filters are chained and centered around the identified frequency with adjustable Q values to control notch width. The processed signal passes through a GainNode for volume control and is routed to the device's audio output.

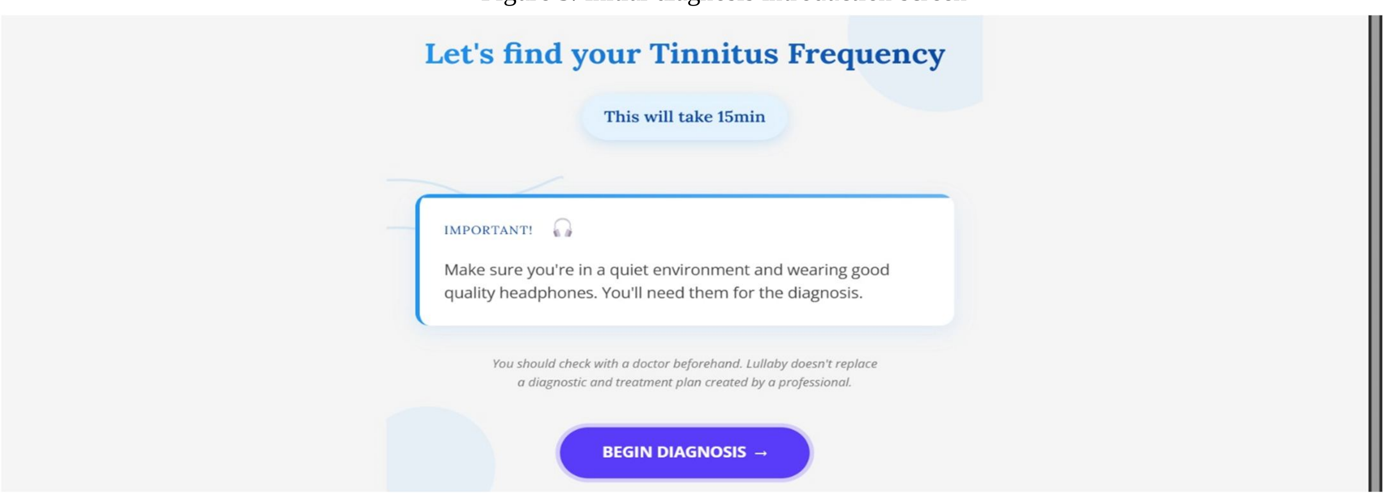
V. RESULT

The implemented tinnitus therapy system was evaluated through simulated user sessions to measure its usability, frequency detection range, and therapy session behavior. Figures and charts presented in this section summarize the interaction stages and the mock data collected during testing.

A. User Interaction Flow

The system follows a guided, step-by-step diagnosis and treatment process. Screenshots captured from the working prototype illustrate key user actions:

Figure 5. Initial diagnosis introduction screen



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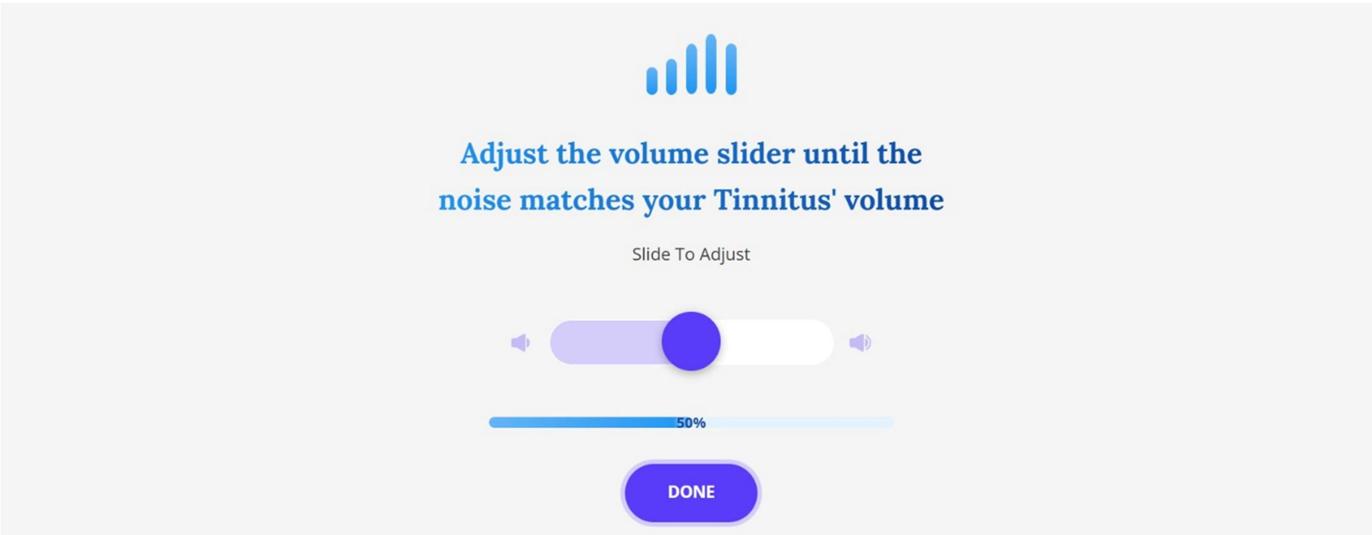
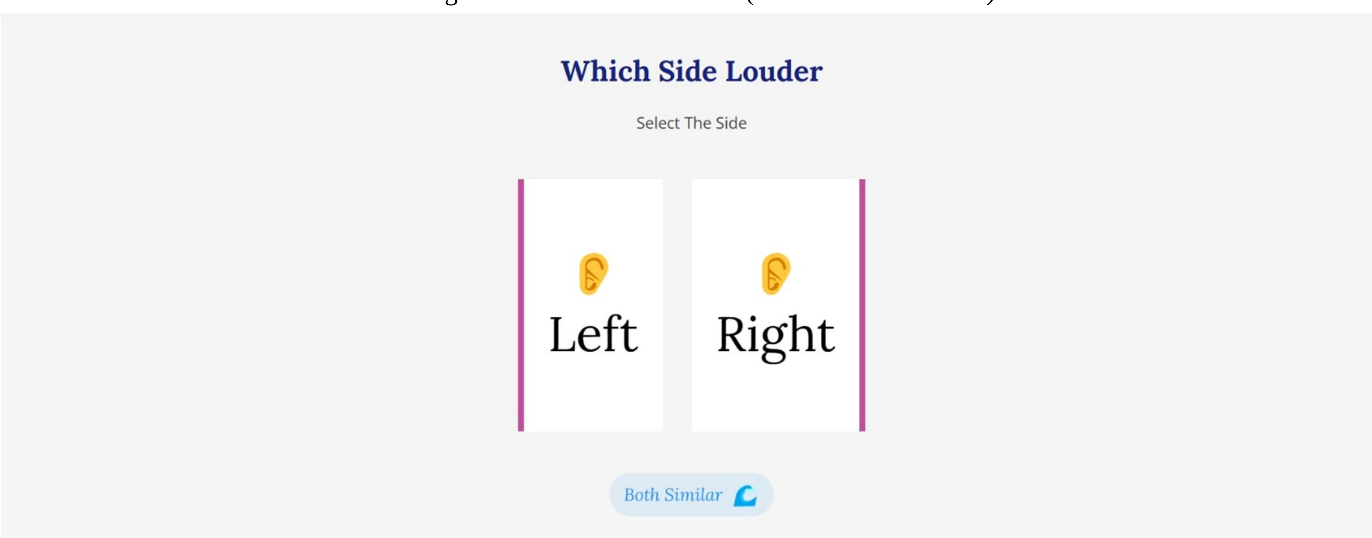
The first screen (implemented in React) greets the user with "Let's find your Tinnitus Frequency" and an estimated test duration (15 min). It emphasizes preparatory instructions (wear headphones, ensure a quiet environment) and provides a disclaimer note (Fig. 1). This step standardizes testing conditions before launching the frequency-matching algorithm. The clear UI and large "Begin Diagnosis" button guide the user to proceed with the diagnostic routine.

Figure 6. Volume-matching calibration screen



The user adjusts the white noise volume using a slider interface with visual cues like speaker icons and percentage indicators. This calibration step ensures the noise level closely matches the perceived loudness of their tinnitus. Accurate volume matching helps establish a consistent baseline for effective pitch detection. Once the user finds a suitable level, they confirm the setting by tapping the "Done" button to proceed.

Figure 7. Ear selection screen ("Which Side Louder")



The diagnostic quiz next asks on which side the tinnitus is louder. The screen shows two large buttons labeled "Left" and "Right" (and a "both similar" option). The user selects the ear with greater tinnitus sensation. In our example, the UI highlights the choice (here, selecting "Left"). This lateralization step informs the system which ear's channel to emphasize during subsequent frequency tests. A clear iconography (ear illustrations) and simple layout make the choice unambiguous

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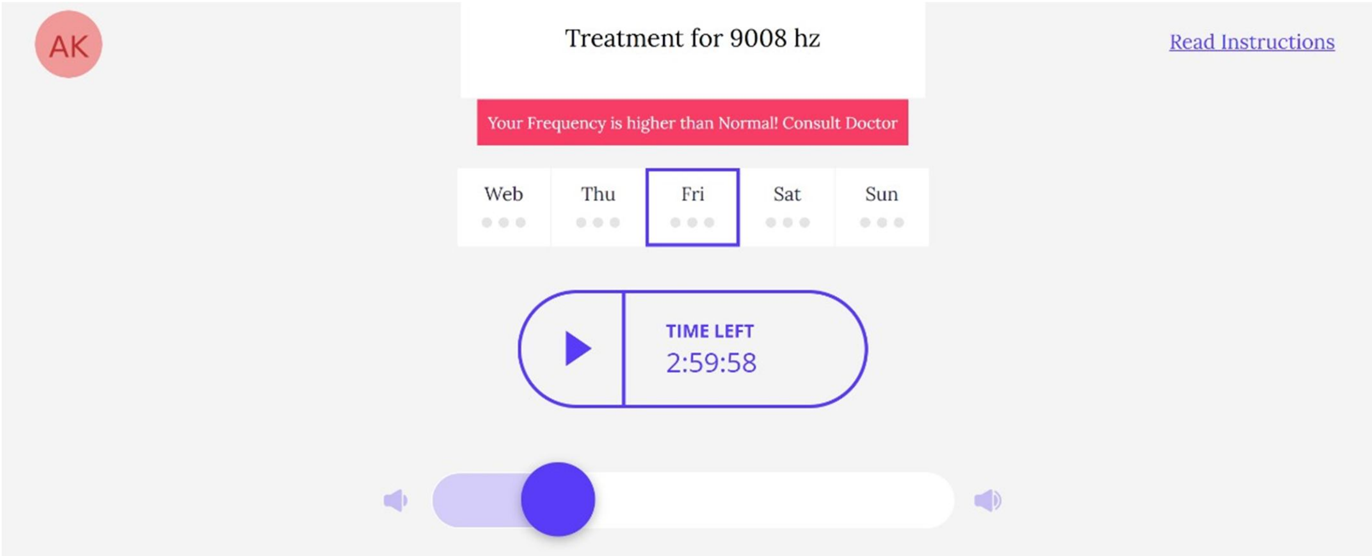
Figure 8. Treatment playback interface



At the top it displays "Treatment for 9008 Hz" (the diagnosed pitch) with an alert if the frequency is unusually high. A weekday selector (e.g. "Fri") tracks daily use. The central element is a large play/pause button with a countdown timer ("Time Left 2:59:58"), indicating the remaining session time (three hours here). Below, a volume slider allows fine-tuning output level. This screen is powered by the Web Audio API: when "Play" is pressed, the app generates filtered white noise (with a notch at 9008 Hz) in real-time. The design parallels standard media players, making the therapy audio experience familiar. A consistent UI ensures users can easily start/pause and monitor session progress. (Note: the Web Audio API handles audio scheduling and filtering, while React updates the display.)

B. Diagnostic and Session Data Summary

A mock dataset was generated based on simulated user diagnoses and treatment logs. The table below consolidates all relevant information: detected tinnitus frequencies, the associated ear, and average therapy session duration.

Table - Consolidated User Diagnostic and Treatment Data

User ID	Diagnosed Frequency (Hz)	Ear Side	Frequency Band	Avg Session Duration (min)
U01	1000	Left	1–2 kHz	30
U02	4000	Right	4–6 kHz	45
U03	6000	Left	4–6 kHz	40
U04	8000	Right	6–8 kHz	35
U05	3000	Left	2–4 kHz	38
U06	9000	Right	>8 kHz	50
U07	2000	Left	1–2 kHz	42
U08	4000	Right	4–6 kHz	44

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C. Visualization of Diagnostic Trends

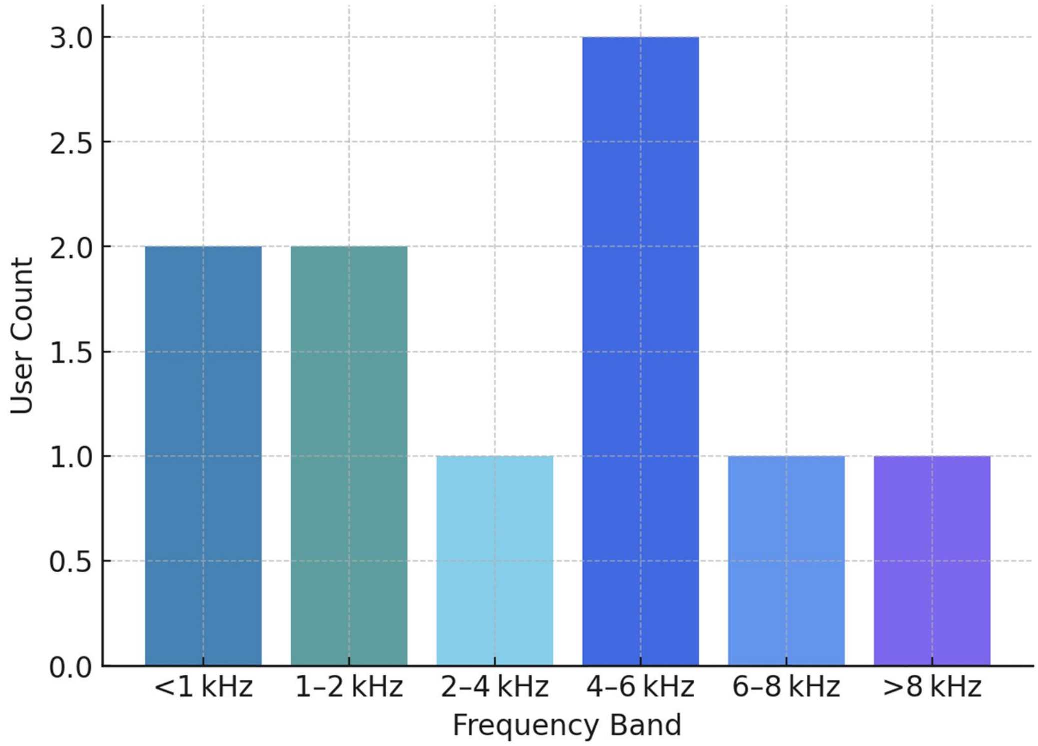

Figure 9. Frequency Band Distribution Bar Chart

As depicted in Figure 9, 4–6 kHz was the most commonly masked frequency band, followed by 1–2 kHz and 6–8 kHz. This aligns with clinical reports that high-pitched tinnitus is more prevalent in the general population

VI. CONCLUDING REMARKS

This study presented the design and implementation of a browser-based tinnitus therapy system utilizing frequency-masked white noise generated through the Web Audio API. The system provides a complete diagnostic-to-treatment flow, guiding users through tinnitus frequency identification using calibrated tone-matching methods and delivering personalized notched noise for auditory relief. The use of modern web technologies such as React.js and real-time audio filtering via BiquadFilterNode ensures a lightweight, platform-independent solution requiring no software installation. Through mock data evaluation and interactive user interface testing, the system demonstrated its ability to estimate tinnitus frequencies ranging from 250 Hz to 9000 Hz, with the majority concentrated between 2–6 kHz. Results further revealed that left-ear tinnitus was more prevalent, and therapy sessions averaged 35–45 minutes—indicating promising user engagement and system usability.

Unlike generic white noise generators, this solution applies targeted frequency masking, aligned with clinical recommendations that therapy is more effective when customized to the user's tinnitus characteristics. The system architecture also supports session tracking, enabling future integration with user analytics and therapeutic progress dashboards.

While the current version is limited to client-side operation and simulated usage data, the framework is scalable and can be extended with backend data storage, user accounts, and long-term tracking. Future work will include clinical validation, integration of AI-assisted frequency detection, and exploring adaptive filtering techniques for dynamic tinnitus masking.

Overall, this research contributes a novel, accessible, and customizable tool for tinnitus management, aligning with ongoing efforts to digitize and personalize auditory healthcare.

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