

CRITICAL BAND

Authored by
mohammad looti

November 11, 2025

RECOMMENDED CITATION

mohammad looti (2025). *CRITICAL BAND*. PSYCHOLOGICAL SCALES. Retrieved from <https://scales.arabpsychology.com/?p=68625>

CRITICAL BAND

Primary Disciplinary Field(s): Psychoacoustics, Audiology, Sensory Perception, Acoustics

1. Core Definition

The **Critical Band** is a fundamental concept in psychoacoustics, defining the functional frequency bandwidth of the auditory filter mechanism employed by the inner ear, specifically the cochlea. This bandwidth represents the range of frequencies surrounding a specific target frequency within which acoustic energy effectively interacts, either contributing to the overall perceived loudness of complex sounds or enhancing the masking effect of noise upon a pure tone. When the bandwidth of a noise increases beyond the critical band around a test frequency, the perceived loudness of the noise increases, but its masking effectiveness against the target frequency does not increase proportionally because the auditory system filters out the frequencies falling outside this specific band.

In simpler terms, the critical band acts as a perceptual filter, separating the continuous spectrum of sound input into distinct, manageable segments. If multiple frequency components of a complex sound or masking noise fall within one critical band, the auditory system processes them holistically, resulting in phenomena like simultaneous masking or summation of loudness. If the components are spread across several critical bands, they are perceived and processed more independently. This differential processing ability is crucial for tasks ranging from speech recognition in noisy environments to the accurate localization of sound sources, underscoring the critical band's role as the fundamental unit of frequency analysis in the human ear.

The width of the critical band is not constant; it varies systematically with the center frequency. At lower frequencies (below approximately 500 Hz), the critical bandwidth remains relatively constant, typically measured in the range of 90 to 100 Hz wide. However, as the center frequency increases above 500 Hz, the bandwidth widens significantly, approximating a constant percentage (typically 15% to 20%) of the center frequency. This non-linear relationship between frequency and critical bandwidth reflects the mechanical and neural organization of the basilar membrane within the cochlea, which naturally exhibits higher frequency resolution at the basal end (high frequencies) and lower resolution at the apical end (low frequencies).

2. Etymology and Historical Development

The concept of the critical band was first formally introduced and extensively explored by the American physicist and acoustics pioneer, Harvey Fletcher, in the 1940s while conducting seminal research at Bell Telephone Laboratories. Fletcher's initial work focused heavily on simultaneous masking--the ability of one sound (the masker) to hide the perception of another sound (the signal). Through meticulous experimentation, he observed a crucial threshold: as the bandwidth of the

masking noise centered around the signal frequency increased, the effectiveness of the masking increased only up to a specific limit. Once the noise bandwidth exceeded this limit, further widening of the noise spectrum did not significantly increase the masking threshold for the pure tone signal.

Fletcher deduced that this specific limit defined a physiological filter--the critical band--and that only the acoustic energy contained within this band contributes meaningfully to the masking effect of the signal. His initial measurements defined the critical bandwidth primarily through masking paradigms, providing the first quantitative framework for understanding the frequency resolution of human hearing. Fletcher's model provided the necessary foundation for subsequent developments in telecommunications and audio engineering by offering a metric for determining the necessary fidelity and bandwidth required for transmitting perceptible sounds.

Following Fletcher's pioneering work, E. Zwicker and his colleagues in Germany significantly expanded and refined the concept in the 1960s, utilizing various psychoacoustic phenomena, including loudness summation and pitch perception, to refine the measurements and create a standardized critical band scale. Zwicker's work led to the development of the widely used **Bark scale**, a unit of perceptual frequency measurement where one Bark corresponds precisely to the width of one critical band. The historical progression from simple masking experiments to the sophisticated modeling of auditory filters demonstrates a crucial shift from purely physical measurements of sound to an understanding rooted in auditory physiology and perception, solidifying the critical band as the cornerstone of auditory modeling.

3. Key Characteristics and Parameters

The operational mechanism of the critical band is defined by several key characteristics that govern how sound stimuli are processed by the cochlea. Foremost among these is the relationship between the center frequency and the bandwidth itself. As established by researchers like Zwicker, the critical bandwidth (CBW) is proportional to frequency above approximately 500 Hz, where CBW is roughly 15-20% of the center frequency (f_c). Below 500 Hz, the CBW is relatively constant, typically measuring around 100 Hz. This non-linear scaling is essential for accurately modeling human hearing perception and serves as the basis for converting physical frequency measurements (Hz) into perceptual units (Barks or ERBs).

Another crucial characteristic is the concept of **Auditory Filter Shape**. While the critical band is often approximated as a simple rectangular filter for simplifying introductory masking calculations, the actual physiological filters in the cochlea are generally asymmetrical and rounded, often modeled mathematically using a roex (Rounded Exponential) filter shape. The parameters of this complex filter shape dictate the steepness of the high-frequency and low-frequency skirts, which directly impacts how effectively noise components adjacent to the critical band are suppressed. This asymmetry often explains the phenomenon known as **upward spread of masking**, where

low-frequency sounds are highly effective at masking high-frequency sounds, while the reverse is less true, due to the biomechanical response characteristics of the basilar membrane.

The total range of human hearing, spanning approximately 20 Hz to 20,000 Hz, is typically divided into 24 distinct critical bands when using the Bark scale. These 24 bands represent the conceptual segments into which the auditory system partitions the frequency spectrum for perceptual analysis. This segmentation explains why sounds that are widely separated in frequency are perceived as distinct entities and why the total loudness of a complex sound cannot be calculated merely by summing intensity, but must instead be derived by summing the contributions within each individual critical band--a process known as specific loudness summation.

4. Relationship to Psychoacoustic Phenomena

The critical band is the fundamental explanatory mechanism for several core psychoacoustic phenomena, most notably **loudness summation** and simultaneous masking. The principle of loudness summation dictates that for a complex sound stimulus, the perceived total loudness is determined by the total energy present within each separate critical band. If a stimulus contains multiple components that fall within a single critical band, the brain integrates them, and the perceived loudness increases rapidly up to the point where the band is filled. If, however, the components are spread across several critical bands, the components are treated more independently, and the total perceived loudness increases less steeply, confirming that the critical band acts as the quantum unit of auditory processing for loudness perception.

In the context of **simultaneous masking**, the critical band explains why noise only effectively masks a tone if its frequency components are confined to the critical band centered around that tone. When a narrow band of noise is used as a masker, increasing its bandwidth increases the masking threshold of the tone until the critical bandwidth is reached. Beyond this point, any added noise energy falls outside the auditory filter tuned to the tone, and thus contributes little to the masking effect, even though the overall physical intensity of the noise is rising. This relationship--known as the energy integration within the critical band--is critically important for understanding the design of noise reduction technologies and the calculation of speech intelligibility metrics.

Furthermore, the critical band plays a crucial, limiting role in pitch perception and **frequency discrimination**. The ability to distinguish between two adjacent frequencies (the differential threshold) is intrinsically tied to the width and shape of the critical band filter. When two pure tones are presented extremely close together in frequency, the ear can only distinguish them if they excite sufficiently different regions of the basilar membrane--which typically requires them to fall outside the same, or minimally overlapping, critical bands. When two tones are placed within the same critical band and their frequencies are slightly mismatched, they produce a perception of "roughness" or beating rather than two distinct pitches, illustrating the physiological constraint

imposed by the critical band mechanism.

5. Measurement Scales and Technological Applications

To standardize and quantify the non-linear nature of the critical band, two primary psychoacoustic scales were developed: the Bark scale (Z) and the Equivalent Rectangular Bandwidth (ERB) scale. The **Bark scale**, introduced by Zwicker, segments the audible frequency range (20 Hz to 20 kHz) into 24 bands, with each unit (1 Bark) corresponding to the width of one critical band. This scale is fundamental for modeling perceived pitch and loudness, serving as the basis for calculating specific loudness and overall perceived noise levels in fields like environmental acoustics and noise pollution control, allowing engineers to correlate physical noise measurements with human annoyance or comfort levels.

The **Equivalent Rectangular Bandwidth (ERB) scale** provides a slightly more precise, modern measure related to the filtering ability of the cochlea, often preferred in current auditory research and signal processing. The ERB scale represents the width of a hypothetical rectangular filter that would pass the same amount of noise power as the actual, physiologically complex auditory filter it is intended to model. While closely related to the Bark scale, the ERB scale tends to offer a better fit for masking data and is typically used when designing digital auditory filters, as it relates more directly to the physiological tuning curves of the basilar membrane than the older Bark scale derived primarily from loudness summation experiments.

Technologically, the critical band concept is indispensable in modern **audio compression algorithms**, such as MP3, AAC, and various high-efficiency speech coders. These algorithms rely on a psychoacoustic model that calculates the masking threshold across the frequency spectrum, defined precisely by the critical bands. Since sounds falling below the masking threshold within the critical band of a dominant tone or noise are effectively imperceptible to the listener, the encoder can discard or severely reduce the resolution of the masked frequency components without a perceptible loss of quality. This process, known as perceptual coding, achieves massive data compression ratios by intelligently eliminating information that the human auditory system is physiologically incapable of detecting, based entirely on critical band theory.

6. Physiological Basis in the Inner Ear

The critical band is not merely a theoretical construct but has a tangible physiological basis within the human inner ear, specifically the cochlea. Sound waves traveling through the perilymph and endolymph fluids of the cochlea cause the **basilar membrane** to vibrate. This membrane acts as a mechanical frequency analyzer, exhibiting tonotopic organization where different segments resonate maximally at different frequencies--low frequencies cause maximal displacement primarily at the apical end (farthest from the middle ear), and high frequencies cause maximal

displacement near the basal end (closest to the middle ear).

The spatial extent of the vibration pattern on the basilar membrane corresponding to a specific frequency excitation defines the anatomical correlate of the critical band. Sensory hair cells situated along this vibrating segment transduce the mechanical energy into neural signals sent via the auditory nerve. The width of the critical band is therefore inherently linked to the physical spread of excitation on the basilar membrane. When two frequencies fall within the range that excites the same overlapping population of hair cells, they fall within the same critical band and are processed collectively by the auditory nerve fibers, leading to the integrative phenomena observed in masking and loudness experiments.

The non-uniformity of the critical bandwidth--wider at high frequencies in terms of percentage, and wider at low frequencies in absolute Hz--is a direct reflection of the physical mechanics and impedance properties of the basilar membrane itself. At the high-frequency basal end, the membrane is relatively stiff and narrow, resulting in sharper mechanical tuning. At the low-frequency apical end, the membrane is more compliant and wider, leading to broader mechanical tuning. This physical variation confirms that the critical band is a bio-mechanical constraint inherent to the structure and function of the peripheral auditory system.

7. Debates and Refinements

While the concept of the critical band remains central to psychoacoustics, modern research often utilizes the more precise term **Auditory Filter** to describe the underlying physiological mechanism. Historically, the critical band was defined operationally through perceptual experiments (masking and loudness summation), often implying a fixed, rectangular filter shape. However, contemporary auditory models, especially those using the ERB scale, recognize that these filters are highly adaptable, overlapping, and possess distinct, complex shapes (roex filters) that can change dynamically depending on the intensity of the incoming signal, reflecting the active, non-linear processing inherent in the cochlea.

One ongoing academic debate concerns the precise mathematical definition and physiological independence of these filters. While the 24 Bark bands provide a useful conceptual segmentation, the auditory system possesses continuous tuning characteristics rather than 24 discrete, isolated filters. Researchers debate the relative contributions of peripheral filtering (the mechanical critical band on the basilar membrane) versus central auditory processing (neural sharpening and cognitive organization) to the final perceived frequency selectivity. Current consensus suggests that both peripheral filtering, constrained by the critical band, and central processing contribute to the final perceptual outcomes, particularly in complex acoustic environments.

Furthermore, the classical critical band model primarily addresses simultaneous masking. Debates persist regarding how well the classical critical band model accounts for more complex temporal

phenomena, such as non-simultaneous masking (forward and backward masking) and auditory streaming, where temporal factors and cognitive organization play a larger role. These advanced psychoacoustic phenomena necessitate extended models that build upon the foundational critical band concept by incorporating temporal integration windows, spectral-temporal analysis, and higher-order cognitive segmentation abilities to fully explain the complexity of human auditory perception.

Further Reading

[Psychoacoustics \(Wikipedia\)](#)

[Critical band \(Wikipedia\)](#)

[Harvey Fletcher \(Wikipedia\)](#)

[Bark scale \(Wikipedia\)](#)

ARABPSYCHOLOGY.COM