NEURONEST WHITE PAPER 01

Sound as a tool for sleep.

What the evidence supports, what NeuroNest builds, and what we are still testing. Written for people who want the mechanism and the numbers, not a promise.

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01

Summary

Night-time noise disturbs sleep, and it is the change in sound, not the loudness, that wakes the sleeping brain. A steady sound floor reduces that change. That is acoustic masking, and it is the mechanism NeuroNest is built on.

- **Established.** Environmental noise at night disturbs sleep and carries a health cost.[1,2,3] Sudden change above the background, not peak level, is what triggers arousals.[4]
- **Supported, context dependent.** A steady broadband sound reduced arousals in people exposed to recorded intensive-care noise,[4] shortened sleep onset in a transient-insomnia model,[5] preserved sleep time in coronary-care patients,[6] improved objective wake-after-sleep-onset in New Yorkers in loud homes,[7] and settled four in five newborns within five minutes.[8]
- **Mixed.** Two systematic reviews rate the overall evidence for continuous noise as a sleep aid as weak and inconsistent.[9,10] A 2026 laboratory study found that pink noise at 40 to 50 dBA reduced REM sleep in young healthy adults and that earplugs did more to protect sleep from intermittent noise.[11,12]
- **Emerging.** Precisely timed sound pulses can deepen slow-wave sleep and, in some studies, improve overnight memory.[13–17] This needs brain monitoring in real time. No passive track does it, including ours.
- **What NeuroNest does with this.** Produces steady, event-free environments, measures each one from its master, matches every sound to the same loudness, and asks users to test it on their own room for five minutes rather than take a claim on trust.

02

The problem: a noisy night

Noise is one of the most common and least addressed causes of poor sleep. A 2014 review in *The Lancet* concluded that environmental noise exposure disturbs sleep, causes daytime sleepiness, and raises the occurrence of hypertension and cardiovascular disease.[1] The World Health Organization's night-noise evidence base, updated in 2022 with 36 studies and more than 170,000 survey responses, produced exposure-response curves showing the probability of being highly sleep disturbed rising with outdoor night-time levels from aircraft, road and rail traffic.[2] A separate review notes that the perturbations nocturnal noise causes look much like those of endogenous sleep disorders, and that they are followed by next-day sleepiness, mood change and reduced cognitive performance.[3]

The modern bedroom adds its own sources: traffic through single-glazed windows, neighbours through thin walls, a partner, a dog, a phone, a bin truck at five. Most people treat this as something to endure. It is, in fact, one of the few variables in sleep that can be changed tonight.

03

What the sleeping brain does with sound

The auditory system does not switch off during sleep. The thalamus keeps gating sensory input and the cortex keeps evaluating it. A brief sound during non-REM sleep can evoke a K-complex, a single large slow wave, and the review that compared stimulation methods found sound to be the most effective sensory modality for

evoking them, because auditory pathways have privileged access to the thalamocortical system during sleep.[14] That same sensitivity is why a sudden sound can pull a sleeper from deep sleep toward lighter stages without fully waking them.

Two facts about this gating matter for design. First, deep sleep is front-loaded: the first cycles of the night carry most slow-wave sleep, and REM grows toward morning.[14] Sound used at the start of the night therefore meets the brain where recovery is strongest. Second, the brain habituates to a constant, predictable signal and stops allocating attention to it, while it keeps responding to change. A steady sound becomes part of the room. A door does not.

04

The mechanism: raise the floor

The clearest demonstration is a small polysomnography study from 2005. Volunteers slept under three conditions: a quiet baseline, recorded intensive-care-unit noise, and the same ICU noise with mixed-frequency white noise added. Their arousal index rose from 13.3 per hour at baseline to 48.4 per hour with ICU noise, and fell back to 15.7 per hour when white noise was added.[4] The authors then checked what determined each arousal. It was not the peak level. It was the change from background to peak, which was the same in both noise conditions at about 17.6 dB. White noise worked by lifting the background, so that fewer events crossed that change threshold.[4]

Masking raises the floor. It does not build a wall.

Acoustic masking does not block sound. It lifts the background level so that intruding sounds have less contrast to stand out against. A masker only needs to be slightly louder than the distraction to be effective, and turning it up far past that point mostly costs hearing comfort.

Three properties of the ear make this specific rather than blunt. The cochlea analyses sound in overlapping critical bands, so a masker covers sounds in or near the same band and not others. Masking also works forwards and backwards in time by roughly 100 to 200 milliseconds, which is part of why a continuous background covers the moments around a sound as well as the sound itself. And hearing is not flat: it is most sensitive between about 2 and 5 kHz, so maskers are designed around weighted curves, not raw level.

Two consequences follow. A masker should match the intrusion: speech lives mostly between 200 Hz and 5 kHz, so a speech-weighted bed covers conversation at a lower overall level than broadband noise of the same loudness; traffic rumble sits low, so a low-weighted bed suits it better. And the right level is set during the distraction, not in a quiet moment, raised only until the intrusion stops pulling at you. That level is lower than most people expect.

05

The evidence, graded

NeuroNest sorts claims into four tiers and says which is which. The sleep evidence sits across all four.

Established

Well-supported principles

Environmental noise at night disturbs sleep and has downstream health effects.[1–3] The change from background to peak, rather than peak level, is what determines whether a sound causes an arousal.[4] Masking itself is textbook psychoacoustics and has been engineered into offices and hospitals for sixty years.

Supported

Meaningful evidence, context dependent

Noisy wards. In the ICU-noise study above, added white noise restored the arousal index to near baseline.[4] In a coronary care unit, 60 patients were followed over three nights: the control group's total sleep fell from 7.08 to 4.75 hours, while the group given white noise at 50 to 60 dB kept their sleep time, 6.69 versus 6.92 hours.[6]

Falling asleep. In a randomised crossover trial of 18 healthy adults sent to bed 90 minutes early to model transient insomnia, broadband sound from two room speakers at 46 dB cut the median time to stage 2 sleep from 19 to 13 minutes, a 38 percent reduction. Those who reported trouble initiating sleep at home also reported better subjective sleep quality and fewer arousals.[5]

Loud homes. Ten New Yorkers recruited from a sleep clinic for noise-related sleep complaints used a bedside sound machine for one week between two baseline weeks. Wake after sleep onset, measured by actigraphy, improved significantly during the sound week.[7] Small, within-subject, and the kind of real-world setting most of us sleep in.

Newborns. In a randomised trial of 40 neonates aged two to seven days, 80 percent fell asleep within five minutes with white noise, against 25 percent spontaneously.[8] See the safety section before applying this to any baby.

Mixed
Reviews and contrary findings

A 2021 systematic review covered 38 studies of continuous noise and sleep. Results ranged from improved to disrupted sleep, and the authors graded the quality of evidence that continuous noise improves sleep as very low, citing differences in noise characteristics, sleep measurement, adherence and controls.[9] A 2022 review of 34 studies found 19 with positive findings and concluded there was no strong evidence either way.[10]

The most rigorous recent test is a seven-night laboratory study of 25 healthy adults, mean age 28, published in 2026. Intermittent environmental noise reduced N3 deep sleep. Continuous pink noise at 40 or 50 dBA reduced REM sleep, and adding it on top of the noise worsened sleep structure despite small, dose-dependent reductions in fragmentation. Foam earplugs mitigated nearly all the noise effects up to the loudest 65 dBA events. Subjective sleep, alertness and mood were worse after both the noise and the pink-noise nights.[11] The companion analysis found pink noise did reduce aircraft-noise arousals and awakenings in a dose-response manner, but earplugs did more, and that a crying baby and a fire alarm were the sounds most likely to wake people.[12]

Emerging
Promising, still developing

Timed stimulation. Brief sound pulses delivered in phase with the up-state of the sleep slow oscillation enhanced the oscillation, the coupled spindle activity and overnight declarative memory; the same pulses out of phase did nothing.[13] In 13 adults aged 60 to 84, phase-locked pink-noise pulses raised slow-wave and spindle activity during stimulation and improved morning recall.[15] A meta-analysis of 10 studies and 177 participants found a small pooled memory effect, $g = 0.25$, that reached significance only for phase-locked stimulation in young adults, $g = 0.44$.[16] In older adults, effects appear to need several nights to show.[17]

This is a different thing from playing a sound all night. It requires reading the EEG and timing each pulse to a wave. The review of methods identified it as the safest and most practical route to slow-wave enhancement, and open-loop continuous sound as the less effective one.[14] NeuroNest's environments are not closed-loop stimulation and we do not describe them as such.

Experimental
Areas NeuroNest is investigating

Rhythmic modulation beneath a bed, the role of low frequencies in comfort over long sessions, heart rate and heart rate variability during the wind-down, and perceived sleep onset. On attention rather than sleep, rapidly amplitude-modulated sound supported sustained attention in a 2024 peer-reviewed study, most in listeners with attention difficulties,[18] and the stochastic-resonance account of why added noise helps some people with ADHD while hindering others has behavioural support.[19] On binaural beats, a 2023 systematic review found the entrainment evidence inconsistent across 14 studies,[20] which is why NeuroNest does not sell them.

06

What the mixed results tell us

The disagreement in the literature is real, and most of it is explained by three variables that the positive and negative studies set differently.

- **Level.** The 2026 study ran pink noise at 40 and 50 dBA, against a 46 dB broadband bed in the onset trial and a quiet-room baseline near 30 dBA. Continuous sound at the upper end of that range is a stimulus in its own right, and REM reduction at 50 dBA is a plausible cost. The NeuroNest protocol sets level during the distraction and as low as still works, which in a bedroom is usually well under the lab's lower condition.
- **Who, and what for.** The clearest benefits appear where there is a problem to solve: a ward, a loud city flat, a transient insomnia model, a newborn. The clearest costs appear in young, healthy, good sleepers in a controlled lab, where a quiet baseline is already available. A sound floor has nothing to fix in a quiet room.
- **Timing.** Sleep onset is where the mechanism is strongest and the evidence most consistent. All-night playback is where the REM question arises. That is why the protocol below starts with an onset window, and treats all-night use as a deliberate choice for intermittent night-time noise rather than the default.

One more honest point. Earplugs beat pink noise in the 2026 lab study up to 65 dBA. For a snorer or a loud street, foam earplugs plus a low sound floor is a stronger combination than either alone, and we say so in the app.

07

Design principles that follow

1. **Steady beats interesting.** A masker you stop noticing is working; one you enjoy is probably still occupying attention. NeuroNest beds avoid events, melodies and surprises on purpose.
2. **Match spectrum to intrusion.** Speech-weighted for voices, low-weighted for traffic and plant hum, broadband only when the intrusion is unpredictable.
3. **Seamless loops.** A gap or a click at a loop point is an event, and an event is exactly what a masker exists to cover. Every NeuroNest environment loops without a seam.
4. **One loudness across the library.** Every environment is normalised to the same integrated loudness, so switching sounds never means a jump in level.
5. **Measure, do not describe.** Each environment carries numbers read from its master so a deep bed and a bright one can be compared honestly, by the user, not by adjectives.
6. **Do not stack.** Layering rain over brown noise over a fan raises total level and adds fluctuation. One well-matched spectrum at a modest level beats three at once.

08

What NeuroNest measures

Every environment in the library is analysed from its master recording. The app shows these numbers in the player as the sound profile. The table below is the current library, measured October 2026.

Environment	Ingredients	Tilt dB/oct	Colour	Steadiness	Loudness
Field of Flowers	Meadow, wind, crickets	-6.6	Brown, 80% brown 20% deep brown	0.43	-23 LUFS
Rainforest Observatory	Rain, forest, birdsong	-11.3	Deep brown	0.42	-23 LUFS
Underwater Sanctuary	Water, low hum	-14.9	Deep brown	0.82	-23 LUFS
Fire & Rain	Fire crackling, cabin, water	-7.4	Brown, 53% brown 47% deep brown	0.69	-23 LUFS
Tribal Warmth	Drums, fire crackling	-8.8	Deep brown, 92%	0.67	-23 LUFS
Brown Noise	Brown noise, low hum	-11.1	Deep brown	0.75	-23 LUFS
White Noise Blanket	White noise	-8.4	Deep brown, 80%	0.90	-23 LUFS

How to read it. Tilt is the slope of the spectrum: white noise is flat at 0 dB per octave, pink falls at about 3, brown at about 6. Every bed in the library measures deeper than textbook brown, including the one named White Noise Blanket, which is a texture name, not a spectral one; the number is the truth. Steadiness is the fraction of the signal with no events against the floor, so Underwater Sanctuary and the two noise beds are the most featureless and the rainforest, with its birds, the least. Loudness is integrated level to the broadcast standard, identical across the library by design. Loops run 20 minutes seamless at 48 kHz, delivered as AAC with an edit list so the join carries no gap.

The honest finding from measuring our own library is that nothing in it is bright. For voices in an office that is a weakness we are addressing with a speech-weighted bed; for sleep it is the right place to be, since low-weighted sound is what people tolerate at a low level for hours.

09

A sleep protocol

This is the routine NeuroNest recommends. It is built from the evidence above and from what people report when they test it. It is not a treatment.

1. **Start 20 to 30 minutes before lights out.** Use the sound as a wind-down cue, not a rescue when you are already lying awake. Habituation takes a couple of minutes; start before the noise you are covering starts.
2. **A speaker in the room, not earbuds.** Diffuse sound across the room is the point. Place the speaker between you and the noise: near the window for the street, on the bedside table for a snorer.
3. **Set the level while the noise is happening.** Raise it only until the intrusion stops pulling at you, and no further. If you can hold a conversation over it, it is not too loud. If you are still consciously hearing it after a minute, it is.

4. **Pair it with slow breathing.** Box breathing, four counts in, hold, out, hold, or an extended exhale. Slow breathing below ten breaths a minute raises heart rate variability and shifts the autonomic balance toward rest in a systematic review of 15 studies.[21] A longer exhale is the simplest version.
5. **Onset first; all night by choice.** If your room is quiet once you are asleep, let the sound fade after 45 to 60 minutes. If your problem is noise through the night, a seamless loop at a low level, with no timer, is what covers the 5 am truck. For loud, irregular noise, add foam earplugs.[11,12]
6. **Give it three nights, then turn it down.** The first night a new sound is a new event. By the third you stop hearing it. From there, lower the level each week to the quietest setting that still covers the problem.

10

Safety and limits

Hearing. Exposure is a dose, not a volume. Widely used guidance treats 85 dBA over eight hours as the reference dose, with safe time roughly halving for every 3 dB above.[1] A masking bed at bedroom levels sits tens of decibels below that; loud music for an hour does not. Keep earbud use lower than speaker use, and treat muffled hearing or ringing after a session as direct feedback that the level was too high.

Babies. Infant sleep machines are effective and popular, and they can be dangerous at their maximum settings. When 14 commercial machines were measured at full volume, all exceeded 50 dBA at 30 cm, the recommended limit for hospital nurseries, and three exceeded 85 dBA.[22] Any sound used for an infant should be placed well away from the cot, at a low setting, and only with your paediatric guidance. NeuroNest does not market to infants.

REM. Continuous pink noise at 40 to 50 dBA reduced REM sleep in healthy young adults in the laboratory.[11] We do not know whether lower levels or different spectra carry the same cost in people with a noise problem. Until we do, the protocol favours low levels and onset use, and the app will keep saying so.

Insomnia and sleep disorders. Sound can make a noisy room easier to sleep in. It is not a treatment for insomnia, apnoea or any sleep disorder, and NeuroNest is not a medical device. If sleep is poor most nights for more than a few weeks, see a doctor.

11

What we are testing next

Claims on this site stop where the evidence stops, so the way forward is to generate evidence of our own, carefully and in public.

- **The five-minute experiment.** On neuronesthub.org a visitor chooses a task and a sound, listens for five minutes, and rates distraction, settledness and mind-wandering before and after, with a yes or no on whether they would keep listening. Submissions are anonymous and stored only on explicit consent. Once the sample is large enough to mean something we will publish the aggregate, labelled as self-report, not as an outcome claim.

- **A sleep version.** A pre-sleep check-in and a morning one, with level and environment logged by the app, so that the onset-versus-all-night question gets real-world data rather than lab data alone.
- **Objective measures.** An actigraphy pilot in people who sleep in noisy homes, modelled on the New York design,[7] is the smallest study that would say something useful about NeuroNest specifically. We are looking for a university partner.
- **A speech-weighted bed.** The library's measured weakness for daytime voices. In production.

Nothing in this document is a promise of better sleep. It is a description of a mechanism that is well understood, an honest reading of evidence that is mixed, and a product designed so that you can find out for yourself.

12

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NeuroNest White Paper 01, version 1.0, 14 October 2026. Library measurements from the NeuroNest master recordings, October 2026. Study figures are taken from the cited abstracts and papers; where a paper reports medians or group means, those are the figures quoted. This document will be revised as the five-minute experiment and the sleep check-in accumulate data. Corrections: neuronestaudio@gmail.com.