



The effect of white noise and “coloured” noise on cognition and sleep

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Abstract - The past decade has seen an increasing number of reports in the scientific community of auditory white noise (WN) benefiting rather than hindering cognition and/or sleep in some adults and children. These reports have been enthusiastically extended by reports in the non-scientific community of different “coloured” noises benefitting different aspects of cognition and/or sleep. This paper reviews the scientific literature to find equivocal evidence for WN facilitating some cognitive processes, little-to-no evidence for WN benefitting sleep, and no evidence for different “coloured” noises benefitting different aspects of cognition or sleep. These findings suggest any effects of noise on cognition and/or sleep are likely to depend on complex interactions between noise type and cognitive and/or sleep processes in a manner that varies across different adult and child populations.

1 INTRODUCTION

Noise is commonly thought to be detrimental for humans with small amounts hindering cognition and large amounts causing noise-induced hearing loss (e.g., Ronsse & Wang, 2010; Shield & Dockrell, 2003). But can noise be beneficial for humans? Researchers investigating the phenomenon of stochastic resonance (SR) suggest the answer could be yes if the noise is stochastic (having a random probability distribution that can be analysed statistically but not predicted precisely) and not too loud, and the system processing the noise is non-linear and threshold-based (Moss, Ward, & Sannita, 2004).

The simplest example of how stochastic noise can benefit humans is through the activation of threshold (non-dynamical) stochastic resonance (SR) for detecting a subthreshold pure tone (sinusoidal) sound. In this scenario, the subthreshold pure tone does not trigger a response from the auditory nervous system because its tonal peaks do not surpass the system’s threshold. However, by adding a small amount of stochastic noise, such as white noise (WN: equal power per frequency across the audible range) or broadband noise (BBN: equal power per frequency across a broad range), the pure tone sound can elicit a system response by elevating the tonal peaks above the system’s threshold. Although these new “threshold crossings” are noisy, they retain information about the subthreshold signal peaks that would otherwise be absent if the crossings were randomly caused by the noise alone or if excessive noise had been added to the pure tone sound (Moss, Ward, & Sannita, 2004).

A possible neural mechanism for how stochastic resonance (SR) could benefit cognition in humans comes from the moderate brain arousal theory (Sikström & Söderlund, 2007). This theory offers three propositions regarding the effect of stochastic noise on brain function. First, the brain functions optimally when it is moderately aroused (i.e., neither under- nor over-aroused) and generating the ideal amount of stochastic neural noise necessary for peak performance. Second, stochastic neural noise levels are modulated internally by dopamine, a neurotransmitter known to affect motivation, pleasure, motor control, mood, attention, and learning in humans. Third, stochastic neural noise levels could be modulated externally by presenting stochastic acoustic noise.

The properties of stochastic noise have also led to suggestions that it could benefit human sleep. These suggestions consider at least three potential psychological and psychoacoustic effects of stochastic noise. First, the noise might resemble comforting sounds (e.g., rain), which could lull some individuals to sleep (Loewy et al., 2013). Second, the noise could mask other sounds that would otherwise interfere with sleep, considering that the ear, auditory nerve, and auditory brainstem remain active and “on guard” during sleep (Fastl & Zwicker, 2007).

Third, the noise might serve as a cue for some individuals to fall asleep and possibly remain asleep (Borkowski, Hunter, & Johnson, 2001).

Recently, cautious claims in the scientific literature that human cognition and sleep could benefit from stochastic noise, such as WN, have been overshadowed by enthusiastic claims in popular literature suggesting that the type of benefit is determined by the “colour” of the stochastic noise. Given that the majority of these webpages are clearly non-scientific in nature, this paper aims to review recently published systematic reviews in peer-reviewed scientific literature to determine if stochastic noise, be it white or “coloured,” benefits cognition and/or sleep in humans.

2 METHODS

Database searches

The author (WW) searched three databases—PubMed, Scopus, and Web of Science—for articles written in English that were published in the five years prior to June 30, 2024. The search terms used were “systematic review” AND “noise” AND “cognition” OR “sleep” in the title or abstract.

Study selection

Eligible reviews had to have reviewed studies of humans presented with noise as a continuous stimulus during a cognitive task or sleep period. Noise types of WN, BBN and “coloured” noise were accepted as presented in each review. The lack of standard definitions of noise “colour” was noted. A somewhat common (but inconsistent) approach involved using an example of power-law noise that assumed the noise contained all audible frequencies with a power spectral density per unit bandwidth proportional to $1/f^\beta$ (Wikipedia contributors, n.d.). The “colour” of the noise was then described as white if $\beta = 0$ (equal power per frequency across the audible frequency range), pink if $\beta = 1$ (equal power per octave with more energy at lower frequencies), Brownian (also called brown or red) if $\beta = 2$ (more energy at lower frequencies), black if $\beta > 2$ (more energy at lower frequencies), blue if $\beta = -1$ (more energy at higher frequencies), and purple (also called violet) if $\beta = -2$ (more energy at high frequencies). Other less commonly (and more inconsistently) used approaches included describing the “colour” of the noise as grey if WN had been subjected to a psychoacoustic equal loudness curve, green if WN had been subjected to a mid-frequency bandpass filter, and velvet if the noise had been described by its density in taps/second.

Data extraction and analysis

The following variables were extracted from each eligible study: article title, authors, journal, year of publication, study purpose, results, and discussion. These variables were analysed to extract the main findings and conclusions of each eligible study.

3 RESULTS

Study selection

The search of the three databases identified three systematic reviews for review (Ghasemi et al., 2023; Riedy et al., 2021; Zhou et al., 2024). Table 1 summarises the content of each of these reviews.

Synthesis of results regarding the effect of noise on cognition

Table 2 describes the effects of noise on cognition as reported by Ghasemi et al. (2023) and Zhou et al. (2023).

Synthesis of results regarding the effect of noise on sleep

Table 3 describes the effects of noise on sleep as reported by Ghasemi et al. (2023) and Reidy et al. (2021).

Table 1 – The content of each of the three systematic reviews included in this study

	Reidy et al (2021) Noise & sleep	Zhou et al. (2023) Noise & cognition	Ghasemi et al. (2023) Noise, cognition & sleep
Number of studies/ experiments	38 studies published after 1970 - Varying research designs	43 studies published after 1978 18 between-group & 42 within-subject studies - Of 42 within-subject studies, 12 presented noise & control conditions one-week apart, 26 one-day apart, & four did not report gap duration	32 studies (one study on Macaque monkeys not included here) published after 1989 27 studies on noise & cognition - Five studies on noise & sleep 28 experimental-interventional, 3 quasi-experimental, & 1 review study
Participants	Infants, toddlers, & children (n=13), adults (n=10), patients (n=8), high school or college students (n=5), mothers (n=1), & nurses (n=1) assessed at home (n=18), in a laboratory (n=14), or in hospital (n=6)	Healthy adults aged between 18 & 65 years	2 to 167 infants or adults who were healthy or presented with ADHD, ASD, panic disorder, tinnitus, cardiovascular disease, or as hospital inpatients
Participant number	1 to 313	14 to 196	2 to 167
Noise types	WN (n=15), BBN (n=6), pink (n=2), device (e.g., fan) (n=4), variable (n=4), 75 Hz square wave (n=1), "natural masking" (n=1), ocean (n=1), USASI filtered noise (n=1), sim-music (n=1), surf (n=1), approximation of WN & variable sounds (n=1)	- WN or BBN (n=55), pink noise (n=5) - Only 36 experiments reported the duration of noise exposure, which ranged from a few minutes to an hour	- WN, although the WN could best be described as BBN in some studies - Described as "ocean waves" in two studies & "ocean/mountain stream" in one study
Noise levels	20 dB to 93 dB mostly presented continuously during nighttime sleep - Where reported (12 studies), weightings were A (n=9), Z (n=2), or C (n=1)	- Experimental: WN or BBN (n=55) or pink noise (n=5) at 55 dBA to 85 dB SPL - Controls: 25 dBA to 65 dBC (not reported in 17 experiments)	50 to 86 dB SPL
Quality of evidence	- Very low - Serious risks of bias noted in most studies	- Mixed - Risks of bias from design; age & sex distribution; & duration of noise	Not reported

Note: ADHD = Attention Deficit Hyperactivity Disorder, ASD = Autism Spectrum Disorder, USASI = United States of America Standards Institute.

Table 2 – Effects of noise on cognition

Zhou et al. (2023)	Ghasemi et al. (2023)
- Reaction time (4 experiments): 1 beneficial effect & 3 no effect - Attention tasks (11 experiments): WN showed 2 harmful effects on focused attention & dual monitoring, 1 beneficial effect on simple visual attention in a light detection task (improvement from 50 to 70 dB but decline from 80 to 90 dB), & 10 no effects. Pink noise not studied - Short-term memory (21 experiments): varying effects depending on the noise (e.g., 1 reported WN did, but 1 reported pink noise did not, improve performance on a 2-back task when presented during the whole task) & cognitive load (e.g., 1 improved recall of newly learnt words when WN presented during a learning phase, 1 impaired recall when WN presented during a learning phase, & 1 improved recall when WN presented during an encoding phase). Pink noise showed no effects in 4 experiments - Long-term memory (19 experiments): For WN/BBN, varying effects depending on the noise (e.g., 2 improved long-term memory for 70 dB WN/BBN during encoding, & 6 harmful effects for higher level WN/BBN during whole task with little effect when WN/BBN presented during the encoding phase only, & multiple interactions amongst a wide range of moderating variables). Pink noise showed no effect in 1 experiment - High(er)-order cognition (16 experiments): mixed reports of WN/BBN benefitting or impairing decision-making tasks, only occasional reports of WN/BBN impairing mathematical problem solving & processing of semantic information, & multiple reports of interactions amongst a wide range of moderating variables. Pink noise not studied	- WN (60 to 86 dB) could improve cognitive function by facilitating neural information processing to improve attention, concentration, learning, & memory (particularly sequential short-term memory) in adult students, elderly adults, & adult patients - WN could be used to treat some symptoms of ADHD in children & adults with reports of WN use improving reading & writing speed, speech recognition, controlling off-the-job behaviours, awareness, & working memory (& rarely task accuracy), but not speed of reaction & response to stimuli, in predominantly school-age children & students - WN shows some promise in adults for reducing verbal agitation in patients in nursing homes with dementia, decreasing behavioural & psychological symptoms in patients with schizophrenia with dementia, improving depression & anxiety symptoms, & decreasing heart rate in elderly patients admitted to the critical care units; & in children for reducing pain during vaccination, & developing sucking behaviours in newborns

Table 3 – Effects of noise on sleep

Reidy et al. (2021)	Ghasemi et al. (2023)
- Sleep onset latency (n=19 studies): 3 most common findings were WN/BBN or pink noise did not reduce sleep onset latency among infants, children, or college students relative to baseline (as effects were not statistically analysed, n=5 studies); did not reduce sleep onset latency among students, adults, or patients relative to baseline, a control group, or alternative experimental intervention (as effects were not statistically significant, n=3 studies); but did reduce sleep onset latency in observation studies (limited to parental- or investigator-report on infant or patient sleep, n=3 studies) - Sleep fragmentation (n=17 studies), sleep quality (n=13 studies), & sleep & wake duration (n=18 studies): WN/BBN or pink noise had no significant effect, the effects were not statistically quantified, or conclusions could not drawn due to inadequate data	Use of WN/BBN (50 to 75 dB) demonstrated positive & improving effects on the sleep & wake cycle of children & adults with improvements in falling asleep, reductions in waking events during sleep, & improved sleep quality in infants; fewer sleep onset delays & fewer night wakeups in children with ASD; & improved continuity & less arousal during sleep in adults

4 CONCLUSIONS

The current study reviewed three systematic reviews: Reidy et al. (2021; 38 studies on WN/BBN/pink noise and sleep), Zhou et al. (2023; 43 studies [60 experiments] on WN/BBN/pink noise and cognition), and Ghasemi et al. (2023; 27 studies on WN/BBN and cognition and five studies on WN and sleep). The majority of studies had used WB/BBN to provide equivocal evidence of benefits to some cognitive processes and little-to-no evidence of benefits to sleep for adults or children; five studies had used pink noise to provide no evidence of benefit to cognition or sleep in adults and children; and no studies had used other “colours” of noise. Overall, these results suggests that any effects of WN, BBN or “coloured” noise on cognition and/or sleep are likely to depend on complex interactions between noise type and cognitive and/or sleep process in a manner that varies across different adult and child populations.

Additional research is needed to determine the effects of stochastic noise on cognition and sleep in humans. The low quality and contradictory nature of the current evidence is in stark contrast to enthusiastic claims in the popular media of WN benefitting cognition and sleep generally and different “colours” of noise benefitting different cognitive and sleep processes specifically. More rigorous research is needed that makes better use of recognised measures of cognition and sleep and detailed descriptions of noises used (including level, spectrum, location, and timing) before any recommendations for the use (or not) of WN and/or “coloured” noise can be made, particularly given the potentially negative effects of too much noise on cognition, sleep and hearing.

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