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White noise as a possible therapeutic option for children with ADHD

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ABSTRACT

Attention deficit/hyperactivity disorder (ADHD) is a condition that affects many children and adults throughout the world. ADHD symptoms have been associated with changes in catecholamine release. Current therapies for ADHD have a variety of limitations that invite additional therapeutic options. White noise therapy has previously been utilized to improve sleep and aspects of cognition in a variety of patient populations. Through a proposed phenomenon called stochastic resonance, white noise may have the ability to improve symptoms in children with ADHD. Empirically, white noise therapy has been able to improve certain tasks affected by ADHD symptoms, including speech recognition and reading and writing speed. Not all tasks affected by ADHD are improved, however, and significant logistical challenges remain before this therapy could be realistically implemented. In this review, there appears to be evidence that white noise therapy could be beneficial for patients with ADHD, and therefore further research is encouraged to establish parameters for maximum therapeutic benefit.

1. Introduction

Attention deficit/hyperactivity disorder (ADHD) is a debilitating condition with a reported prevalence in the United States of 5–7%, however the actual prevalence is likely even higher.[1] ADHD does not affect all populations equally, as children that are poorer are more likely to be diagnosed with ADHD and boys are more likely than girls to be diagnosed.[2] ADHD is most commonly diagnosed with criteria determined in the DSM-5.[3] The primary symptoms are inattention and hyperactivity/impulsivity that is present prior to age 12 and in multiple settings, such as school and home.[3] Along with these defining symptoms, people with ADHD often have specific auditory symptoms.[4–7] Children with ADHD have been shown to perform worse in auditory processing compared to children without ADHD,[4] and when presented with auditory stimuli, children with ADHD experience more profound working memory deficits compared to unaffected children.[5,6] This deficit in working memory has been shown to have consequences in auditory perception, such as lowering the ability to detect and process speech in background noise.[7] This review aims to look at current therapies for ADHD, look at noise therapy, and see if white noise (WN) therapy has a possible application for children with ADHD.

It is important that ADHD symptoms are treated; if left unchecked, patients have been found to have a variety of aspects of their life negatively affected, including educational performance, career opportunities, and social interactions.[8] Whereas academics are certainly not the only area of life affected by not treating ADHD, it is the easiest to measure negative effects. Achievement tests (e.g. standardized tests) and academic performance as a whole (e.g. grades or years of schooling completed) have been reviewed in children with untreated ADHD and those without ADHD, and both outcomes were negatively impacted.[9] This can, not only negatively affect the child's current academic life, but also academics down the road and their future careers.[9] Also, those untreated are at increased risk of developing depression, anxiety, bipolar disorder, and alcohol or drug misuse.[10] Symptoms of ADHD have been tied to a variety of neurochemical changes, especially catecholamine release.

2. Dopamine and ADHD

The relationship between catecholamine release (dopamine and norepinephrine) and ADHD has been well established.[11] More specifically, low tonic dopamine (DA) release has been implicated in ADHD symptoms.[12] Low tonic levels have been theorized to lead to more resetting of working memory and changing behaviors when new information is presented. In contrast, high tonic levels leads to maintaining working memory (needed for tasks where delayed responses are needed) or keeping on-task behavior.[13]

Hypofunctioning of two of the three branches of the DA system (the

Abbreviation: DA, dopamine; MPH, methylphenidate; CBT, cognitive behavioral therapy; WN, white noise; SR, stochastic resonance; SNR, signal to noise ratio; MBA, moderate brain arousal

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mesolimbic and mesocortical branches) lead to many symptoms seen in ADHD.[11] Reduced activation of the reward center (ventral striatum and nucleus accumbens), in people with ADHD leads to increased reward seeking and that can manifest as impulsivity and hyperactivity.[14,15] These pathophysiological changes pose a daunting challenge to treat people suffering from ADHD.

2.1. Current treatments for ADHD

Patients with ADHD have a variety of pharmacological and nonpharmacological options. Stimulants are currently the recommended pharmacotherapy with the most evidence for children aged 6 and up with ADHD.[16] Typically, 70% of patients will see a positive change of short-term symptoms with stimulant therapy.[17] Acting to increase DA, stimulants (typically methylphenidate (MPH) or amphetamine) lead to improved attention and decreased distractibility.[18] Language comprehension skills, which require sustained mental effort, are also increased by MPH.[19] Amphetamine has been shown to be more efficacious than MPH, and increases speed and accuracy of tasks of children with ADHD.[20,21] Although there are definite benefits to stimulants, this class of medication has significant negative effects as well.

Parents of children with ADHD could be concerned with giving their child a stimulant with abuse potential. Untreated ADHD can lead to an increased risk of alcohol or drug abuse, however, treating ADHD symptoms with stimulants have not been shown to increase (or decrease) risk of alcohol or drug abuse.[22,23] Parents may also wonder how long their child should be on therapy, as average length of therapy with stimulants is varied but a literature review found the length to be 97.8–254.2 days. Discontinuation was mostly due to adverse events (73%), but symptom relief was also a significant reason (17%).[24]

Although stimulants are an effective treatment for symptoms of ADHD, they are not without their limitations. Appetite, insomnia, stomach ache, headache, and dizziness are common side effects of stimulants.[25] And yet despite these effects, 5–22% of those with ADHD and stimulants are said to misuse or abuse the medications, although the risk for abuse is primarily in those that already abuse substances.[26] Additionally, not all symptoms are well treated with stimulants, as they have very little effect on performance of attention tests.[27] Also, it has been reported that 25% of children fail to reach normal academic performance on stimulants, demonstrating a need for additional therapy.[28] Stimulants have also showed no effect on many academic measures after 8 years of use.[29] There may be long term neural changes as well, as stimulant usage can permanently alter neuroanatomy in rats.[31] The Multimodal Treatment Study of Children with Attention-Deficit/Hyperactivity Disorder (MTA) study from 2017 found that long-term use of stimulants can have a height reducing effect in developing children, as well as minimal reduction in the symptom severity in adults.[32] Not all limits of these medications are adverse effect based.

Untreated ADHD has a negative impact on several academic measures like grades and college enrollment.[9] Ideally, pharmacotherapy would improve academic performance. Pharmacotherapy generally treats the symptoms of ADHD well, but concrete data on actual improvements in academic performance are more controversial. There have been conflicting reports on whether there is improvement or no change in academic performance with a single mode of treatment, like solely pharmacotherapy.[9] Therefore, it is becoming increasingly more critical to examine nonpharmacological therapies for ADHD as either an add-on or monotherapy to alleviate symptoms.

Several nonpharmacological options exist for the treatment of the symptoms of ADHD. Working memory training has shown promise for short-term improvements in verbal and nonverbal working memory tasks. These effects either do not carry over to the long-term (verbal working memory) or possibly carried over to the long-term (visuospatial working memory) and are not generalizable to other tasks like word decoding and arthmetic.[33] Of several dietary treatments, only fatty acid supplementation had statically significant improvement of symptoms that were blinded and no/low pharmacologic intervention. Others, such as artificial food color exclusion did not meet statistical significance under those conditions and antigenic dietary restriction did not have enough data to analyze with those conditions.[34] Looking at cognitive treatments, neurofeedback and child/parent/teacher training did was not effective when blinded and computer training has not had enough data to draw conclusions.[34,35] The primary nonpharmacological option remains cognitive behavioral therapy (CBT).[36] CBT is used to train patients to control the symptoms of ADHD through education and talking through issues.[37] CBT tries to change negative impacts of ADHD like procrastination and negative thoughts about the future.[38] CBT can provide significant benefit when paired with stimulant therapy, however it has only been considered possibly effective for controlling symptoms of ADHD alone.[37] Because of their limited utility, it remains important to explore further nonpharmacologic options.

3. White noise as therapy

WN is sound that occurs when a large variety of audible frequencies are played at a constant intensity. True white noise is often approximated by rainfall and radio static, and is often described as pleasant sounding.[39] WN therapy has been used in a variety of medical applications, including to improve sleep in several patient populations. Intensive-care unit (ICU) patients experienced less arousal and greater sleep latency with WN added onto typical ICU noise.[40] A review concluded that after looking at 5 studies of children and infants with sleep problems, that were given WN therapy as treatment, a majority showed positive results and none showed negative results.[41] Along with these sleep benefits, WN has been shown to improve behavioral and psychological symptoms of dementia in elderly people with schizophrenia.[42] Additionally, WN can provide cognitive benefits in healthy individuals. WN improves results on word recall and visuo-spatial tasks in young and elderly participants.[43] WN has shown a similar effect to that of DA on speed of word recognition; however it is just unknown if WN is actually modulating DA or it produces the effect in a different manner.[44] Additionally, researchers found that participants demonstrated improved new word recall with WN compared to silence.[45]

In addition to the benefits of WN in adults, it has been used to improve attention in children, with some caveats. In one study, after teachers ranked their students by attention level, the students ranked more inattentive were helped more by the WN therapy and children who were ranked high were impeded by WN therapy.[46] Another study showed the same phenomena of WN working for sub-attentive and hindering for super-attentive children, but also showed that increasing volume could improve attention in more inattentive children.[47] The normal-attentive ranked children were seemingly not affected much by any three of the varying levels of WN.

3.1. White noise in ADHD

WN has been shown to have some benefit in treating ADHD symptoms.[48] Some of this benefit appears to be improving language. In one study, children with ADHD were tested to see if WN would affect their speech recognition in noise, a known symptom of ADHD. They were tested with the Hagerman test, a speech identification test, at their school (to preserve a more natural environment). Binaural WN at 65 dB did improve speech recognition in ADHD, however, the authors admitted that other noises from the classroom could have potentially interfered.[49]

Reading and writing speed can also be improved by WN. Children with ADHD were asked to perform a timed reading and writing task in three noise conditions, quiet, 70 dB WN, and babble (random words). Most of the children (69%) were on stimulant medication but were asked to withhold their medications on the day of the test. The children hearing WN wrote more words and took less time to read the passage than the quiet and babble groups.[50]

WN therapy also seems to improve impulsivity. In a small study, researchers tested children to see if off-task behavior could be affected by WN. Off-task behavior was measured every 15 s and then judged if the children were working on a prescribed task or not. Children with ADHD and on stimulant therapy were tested under three conditions: control, headphones only, and headphones with 75 dB WN playing binaurally. Observers measured off-task behavior for 15 min assignments to look for verbal, motor, or passive off task behavior. They found that passive off-task behavior was significantly lowered by WN, however the authors did admit that the WN may have simply reduced auditory distractions that caused the passive off-task behavior.[51] WN may also have benefits in children with ADHD in other areas of impulsivity as well. In a button-pressing test, reaction time to press and vigilance (withholding presses) were examined during 77 dB WN therapy. WN improved vigilance in children with ADHD, but did not affect reaction time.[52] In another study examining reaction time in children with ADHD, researchers found no improvement with WN, but when they separated the groups by medicated and non-medicated, they found that WN significantly improved reaction time in medicated children and impaired those not medicated. The authors suggested that WN level might not have been optimal to see benefits in the non-medicated group, following the inverted U function of SR theory.[53]

In another study examining impulsivity, children with ADHD were tested against children without in 80 dB of pink noise (a modified version of white noise where higher frequency sounds are played at a slightly lower volume) versus no noise. They were tested whether they would pick smaller short-term rewards over larger long-term rewards. The ADHD children were found to pick the smaller short-term rewards regardless of pink noise added. This suggests that some aspects of impulsivity are not affected by noise therapy.[54]

Finally, working memory was shown to be positively affected by WN therapy. Children with ADHD were tested against non-ADHD children to see if their working memory could be improved by 80 dB binaural WN. The three test conditions were with WN, both WN and stimulants, and with stimulants. They were given three working memory tasks: word recall, visuo-spatial, and verbal 2-back (a word order recall test) tasks. The researchers found that the children with ADHD were benefited by WN in two of the three working memory tasks (2-back was unaffected).[55]

There does seem to be tangible, reproducible benefits from WN for specific tasks that are effected in ADHD, but some tasks affected by ADHD seem to be unaltered, such as reaction time.[52] Additionally, it appears that the WN only improves performance while the WN is playing and the long-term effects are currently unknown. Furthermore, although reading and writing speed can be improved, comprehension (accuracy) was not.[50] Variability in study size and design also limit the conclusions that can be drawn regarding efficacy.[14] Therefore, WN therapy may play a role in improving task performance of activities negatively impacted by ADHD, but will likely not become a substitute for currently available therapies.

To summarize the data from these studies, WN helps children in certain tasks and not in others. It seems that WN helps with language recognition, reading and writing speed, certain off-task behavior, vigilance, and some working memory tasks. It is not clear what WN's effect is on reaction time. Finally, WN does not seem to improve choosing larger long-term rewards over smaller short-term rewards, reading and writing accuracy, and word order recall. Further testing should be performed to see if other areas of ADHD symptomology like hyperactivity and focusing are affected. Also, seeing if there are long-term effects on school performance would be helpful. Benefits and limitations of WN therapy might be explained with a better understanding of how WN is theorized to be helping.

4. Mechanism of action of white noise therapy

Stochastic resonance (SR) is a well-documented phenomenon in psychophysics that has been theorized to be the mechanism behind the beneficial effects of noise therapy. SR occurs when a signal that is normally too weak to be detected, can be boosted by adding WN to the signal. SR increases the signal to noise ratio (SNR) of a transmission that allows the signal to be distinguished better by the detector (in the case of ADHD the detector would be the auditory system).[56] Studies have found that WN affects different people in different ways, providing benefit to children with impaired attention, while possibly impairing children with better attention. This phenomenon has been theorized to be explained using SR, which, (not directly through DA release but indirectly through an increase in neural noise) can influence DA in the brain.[12] The theory that SR influences DA is controversial, as in a rodent model DA was unaffected by SR, but a human fMRI study showed dopaminergic activation in the brain after SR.[57,58]

The reason for differential benefits of WN in people with ADHD has yet to be completely elucidated. However, the Moderate Brain Arousal (MBA) model has been proposed that could possibly provide some explanation to the phenomenon.[12] The MBA model of DA says that people with ADHD have lower tonic levels of DA,[59] which makes their phasic release more prone to hyperactivation via environmental stimuli.[30] This low level of tonic DA, according to the MBA model, corresponds to low level of neural noise in people with ADHD, lowering the SNR and reducing performance. The model suggest that perception of external noise can also influence this internal noise in the neural system.[12] Experimentally, an optimal noise level should exist for optimal cognitive performance.[48] Thus, it is proposed that for every individual, some amount of noise is beneficial, and too much or too little is detrimental. SR increases performance along an inverted U shaped curve.[60] Because people with ADHD typically have low tonic DA and low internal noise, the MBA model says their SR curve is shifted to the right. Therefore, more external noise is needed for people with ADHD to achieve optimal cognitive performance.[12] This model is not, however, without problems. Some studies have suggested that their data did not corroborate the MBA model, but their data could have arisen from a suboptimal volume of WN.[50,52,53] While SR is one theory for explaining the benefits of WN, it is not the only one.

Auditory masking occurs when a sound obscures the detection of another sound.[61] WN could act as a masking sound and block out other background sound and make it undetectable. Not being able to detect background noise could be beneficial to people with ADHD by removing that distraction. Auditory masking and SR are both possible theories that try to explain the benefits seen with WN therapy, however, both have limited data and additional studies are needed to draw significant conclusions.

5. Conclusion

WN has demonstrated possible benefits as a potential add-on to treatment for ADHD for a variety of reasons. It is noninvasive, has minimal side effects, and has demonstrated efficacy for certain tasks.,[48–53,55,62] Additionally, stimulant medications do not affect the brain's auditory processing centers, suggesting that WN might show benefit in patients whose symptoms are not completely resolved by stimulant therapy.[63] Maximum benefit of WN seems to occur when it is presented as meaningless noise binaurally in the 65–80 dB range.[49] There are significant gaps in literature regarding WN therapy in ADHD, including patient specific guidelines for use and the creation of a best practice protocol for administration. Despite these gaps, WN therapy in the classroom would not be prohibitively challenging to implement. Teachers or parents could set up a listening center with headphones or at least play some music or run a fan when children are working.[64] With further research, hopefully WN could play a role in the complex problem that is treating the millions of children who struggle with ADHD every year.

Declarations of interest

None.

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