Human Factors and Wearable Technologies, Vol. 175, 2025, 1–11
https://doi.org/10.54941/ahfe1006353

Quiet But Not Quite: The Limitations of Active Noise Canceling Headphones in Open Offices

Elizabeth R. Merwin, Brandon D. Dreslin, Allysa Hayden, Mary Bender, Maissane Aik, Toni Butler, Noah J. Robbins, and Alex Chaparro

Embry Riddle Aeronautical University, Daytona Beach, FL 32114, USA

ABSTRACT

Today's work environments are becoming increasingly dynamic, with open office spaces gaining popularity due to their cost-effective design and potential for facilitating collaboration and stronger teams. Despite these benefits, open office spaces are often noisy and distracting to employees, especially when they include high levels of irrelevant speech (IS). Literature has shown that the presence of speech unrelated to an individual's current task has detrimental effects on performance and well-being (Colle & Welsh, 1976). Strategies to mitigate noise in open office workplaces, such as using headphones with active noise cancelation (ANC), have been implemented and are becoming recognized for their effectiveness in reducing general auditory distractions (Mueller et al., 2022). While ANC headphones work particularly well in filtering out lower sound frequencies and consistent noises such as those in an office, the technology has limitations in disrupting higher-frequency sounds like human speech (Beaman, 2005). This interaction results in an auditory experience where IS is clearer than before the implementation of ANC. The presence of IS has been shown to decrease an employee's ability to write (Sorqvist et al., 2012), accurately recall information (Marsh et al., 2008), and comprehend what they are reading (Sorqvist et al., 2010). Since these tasks are essential to most office jobs, ANC headphones alone might not be enough to effectively mitigate the negative effects of IS. To address this limitation, this paper proposes the addition of a steady masking noise (i.e., white noise) while using ANC headphones. This method would allow the ANC to filter out IS and other complex high-frequency sounds by providing a uniform acoustic environment. This review aims to provide a comprehensive examination of the effectiveness of ANC headphones with and without masking technology in mitigating distractions caused by IS in open office environments. By synthesizing existing research, this review will highlight the theoretical and practical implications of ANC technology, including its potential benefits and limitations for enhancing employee performance, productivity, and well-being.

Keywords: Active noise cancelation, Irrelevant speech, Noise masking, Employee performance, Open office spaces

INTRODUCTION

In recent years, open office space environments have become more common throughout companies and have gained popularity due to their cost-effective design. Transitioning from an individual workspace to an open office workspace allows employees to improve subordinate/superordinate interactions and enhance collaboration (Nagy & Dunay, 2023). While these spaces offer many benefits, they also present challenges that can hinder employees' abilities and reduce productivity. One significant concern is noise management, which has garnered considerable attention from researchers and employers alike. Noise can have negative consequences such as a lack of acoustic privacy, a deterioration of co-worker relationships, physiological issues, and diminished work performance (Haapakangas et al., 2018). Recent advancements in active noise canceling (ANC) technology have prompted headphone companies to recommend their products for open office settings to reduce distractions from external noise and increase employee performance (Williams, 2024).

As companies continue to use open office space designs, understanding the effects of noise and irrelevant speech (IS) on employees' overall performance and well-being is vital. Jafari et al. (2019) highlight how increased noise levels correlate with decreased cognitive performance and memory. Moreover, noise frequency, duration, rhythm, and dynamics significantly influence the psychophysiological effects of sound (Kjellberg, 1990). Low-frequency noises tend to have a pronounced effect on one's overall health and psychological well-being which is particularly relevant since much of the background noise in office settings falls within a low-frequency range (Araújo-Alves et al., 2020). Lin et al. (2006) found that ANC headphones effectively block low-frequency sounds, making them useful for reducing common sources of noise in open office spaces. Given the varying levels, frequencies, and pitches of human conversation, it is unclear whether ANC headphones can effectively reduce distractions from IS and competing dialogue in open office spaces (Radun et al., 2024). We examine the challenges associated with noise in open office settings and offer recommendations for addressing these issues through noise reduction techniques.

Noise in Open Offices

Beginning in the mid-20th century, companies began transitioning from traditional office spaces, which are characterized by private working areas, to open office spaces (OOSs) (Brennan et al., 2002). OOSs are commonly defined as large, open work areas shared by four or more people, where workstations are arranged in groups with minimal physical barriers, such as walls and partitions (Danielsson & Bodin, 2008). The transition to OOSs was driven by companies seeking flexible workspaces (i.e., the ability to adapt to changes such as the size of an organization) while reducing cost and enhancing communication, collaboration, and employee productivity (Lai et al., 2021; Lütke Lanfer et al., 2021). However, the open nature of this office design presents significant challenges for noise and its harmful effects on employee productivity, efficiency, health, and satisfaction (Brennan et al., 2002; Kupritz, 2003; Lai et al., 2021).

Seidman and Standring (2010) define noise as any unwanted sound or combination of sounds that adversely affects mental, psychological, or physical health. Noise from typing, rolling chairs, conversations, air conditioning, and other sources is a byproduct of OOSs and a notable source of employee annoyance (Brennan et al., 2002; Lai et al., 2021). Understanding the detrimental effects of unavoidable noise requires a clear grasp of sound's physical properties.

Sound results from pressure changes in a medium (such as air) due to turbulence or vibration. Sound intensity and frequency are expressed in decibels (dB) Hertz (Hz) for sound intensity and frequency, respectively. Noise with higher intensity (i.e., > 30 dB) has a greater effect on worker performance compared to noise with lower intensity, especially when the noise has an intermittent schedule (Szalma & Hancock, 2010). Suter (1991) discovered that the duration of a sound and its temporal distribution (i.e., how it is spaced over time) contribute to disrupted concentration and productivity in office settings.

Several types of temporal disruptions, including continuous, intermittent, and impulsive sounds, may distract open office workers. Continuous sounds, such as a steady noise like the background hum of an air conditioner, are typically less distracting because their intensity and frequency vary less. Intermittent and impulsive sounds (occasional phone rings or sudden, unexpected door slams, respectively) are more disruptive because they lack predictability (Szalma & Hancock, 2010).

There is also an interaction between the type of sound and its frequency. For example, intermittent sounds (e.g., the sharp clicking of a computer mouse or the rapid tapping of keyboard keys) are more noticeable in an office environment than the continuous rumble of a nearby copier. In this example, the sounds are higher frequency and intermittent, making them more likely to capture attention. Conversely, the copier's lower frequency noise and continuous nature are less likely to draw attention or cause distraction. Non-continuous sounds prevent workers from habituating to the noise in their environment, leading to lapses in attention and workflow (Szalma & Hancock, 2011).

Speech-related noise is particularly prevalent in OOSs and has been shown to negatively impact concentration and performance more than non-speech noise (Szalma & Hancock, 2011). Given that intermittent IS is the most distracting type of office noise, its characteristics and effects on employee performance in OOSs must be explored further (Appel-Meulenbroek et al., 2020).

Effects of Irrelevant Speech (IS) on Performance

IS refers to conversations unrelated to the current task, which may hinder task performance (Beaman & Jones, 1997; Jones & Macken, 1993; LeCompte et al., 1997). It has been shown to have disruptive effects on tasks that require semantic and serial processing, such as reading (Sörqvist et al., 2010), information search (Jahncke et al., 2011), writing (Sörqvist et al., 2012), and recall (Marsh et al., 2008). Additionally, tasks that utilize episodic memory (e.g., events and experiences), short-term memory, and rehearsing are more susceptible to the detrimental effects of IS due to the cognitive conflict between simultaneously processing the meaning of speech and performing these tasks (Jahncke et al., 2011). Since work in OOSs typically involves some combination of these processes, understanding the effect of IS on performance is imperative to creating successful workplaces.

IS negatively affects concentration, memory, and productivity by diverting cognitive resources from the task to the conversation, leading to distractions and making it more difficult to maintain focus (Di Blasio et al., 2018). Hughes et al. (2007) found that IS negatively impacts immediate recall and disrupts cognitive processes in regions of the brain associated with auditory processing, such as the superior temporal cortex. This makes it more difficult for individuals to filter out distractions, leading to slower reaction times and more errors in tasks that require sustained attention. Banbury and Berry (1998) further demonstrate these implications by revealing that employees exposed to background conversations had more difficulty concentrating, resulting in longer task completion times and a higher frequency of mistakes than employees in quieter environments. The cognitive interference caused by the additional task of filtering out distracting speech affects immediate task performance and contributes to mental fatigue, exacerbating stress levels and diminishing overall job satisfaction. Di Blasio et al. (2019) support this finding, indicating that workers in noisy environments reported significantly lower job satisfaction, often leading to higher absenteeism and turnover rates. Given these negative consequences, effective noise-cancelation strategies are necessary for reducing workplace distractions and improving employee well-being.

Existing Noise Cancelation Strategies

The negative impacts of noise and IS extend to workplace dynamics and employee well-being. When employees experience interruptions and struggle to concentrate, their cognitive load increases, decreasing performance and lowering resilience to further distractions (Varjo et al., 2015; Yuan & Zhong, 2024). This concern is particularly pronounced in collaborative workspaces, where team members engage in complex tasks requiring deep focus. Since irrelevant conversations are uniquely distracting in an open office setting, companies have explored strategies to mitigate their effect and improve employee performance.

One approach to reducing noise is to alter the office layout by adding sound-absorbing pads to help dampen noise in open office environments. Di Blasio et al. (2019) emphasize that designing environments with acoustics in mind—such as incorporating soft materials and optimizing spatial layout to minimize sound transmission—can significantly enhance focus and productivity. Attempts at implementing this strategy revealed only partial success. While sound-absorbing material successfully absorbs low-frequency noise in the environment, it is less effective in absorbing higher-pitched and intermittent sounds like IS. This can create the perception that the voices of others in the room are louder and more distracting than before (Balazova et al., 2008). Thus, an effort to eliminate noise can potentially negatively affect performance and unintentionally amplify the effects of IS.

Despite efforts to improve working conditions in OOSs, current strategies to modify the office environment have been less than successful in addressing this issue. Rather than altering the work environment, some employees opt to use active noise-canceling technology while working. According to a report from Research and Markets (2023), the demand for ANC headphones continues to grow year by year. Adopting this employee-centric approach in offices to attenuate the effects of noise and IS, as opposed to modifying the layout of the entire office, may improve performance and preserve the collaborative benefits of OOSs. This approach will be reviewed in the following section to evaluate its efficacy.

Use of Active Noise Canceling Headphones

Originally developed for aviation and industrial settings, noise-canceling headphones are thought to reduce auditory distractions in open office spaces. These headphones utilize both passive noise-canceling and active noise-canceling (ANC) methods. Passive noise canceling relies on the physical design (e.g., cushioned ear cups) to block external sound by creating a barrier between the ear and the environment (Shalool et al., 2016). ANC technology uses microphones to detect external noise and generate inverse sound waves that neutralize steady, low-frequency sounds, such as the hum of air conditioning or machinery (Hoshina et al., 2022). By reducing consistent background noise, ANC headphones help employees concentrate better, experience less cognitive fatigue, and improve productivity (Jahncke et al., 2011).

Although ANC headphones effectively reduce low-frequency and consistent background noise, human speech remains challenging for ANC technology due to its varied frequency and modulation (Lin et al., 2006). While ANC headphones can reduce the intensity of irrelevant speech, they often fail to diminish its intelligibility. As such, the distracting nature of perceptible speech persists even though the environment may feel quieter. ANC technology may even enhance speech intelligibility because it filters out lower-frequency background noise more effectively, leaving the higher-frequency components of speech more prominent and easier to understand (Radun et al., 2021).

These limitations suggest that ANC headphones are not a comprehensive solution for mitigating distractions from irrelevant speech. While overall noise levels are reduced, they do not address the critical signal-to-noise ratio necessary for distinguishing relevant sounds from distractions. The inability to neutralize speech intelligibility means that ANC headphones alone may not significantly improve workplace performance in environments with frequent conversations. Thus, a more effective solution is needed to manage distractions caused by irrelevant speech.

Combination of Active Noise Canceling Headphones With Masking Sound

We argue that ANC alone is insufficient for creating an optimal open office workspace. Instead, an alternative solution involves integrating masking noise with ANC to leverage the benefits of stochastic resonance (SR). Originally observed in physical and biological systems, SR is a nonlinear phenomenon in which the presence of a controlled level of background noise enhances neural signal processing rather than degrading it (McDonnell & Ward, 2011; Moss et al., 2004). Applied to auditory perception, SR can improve cognitive performance by optimizing signal transmission in the presence of background noise (Herrmann, 2024). Masking noise (e.g., white or pink noise) operates on this principle, strategically reducing the salience of irrelevant speech while simultaneously facilitating auditory processing (Sikström & Söderlund, 2007). This approach is particularly relevant given findings that low-intensity white noise within a signal-to-noise ratio (SNR) of 10–15 dB can enhance cognitive performance, especially for individuals with attentional difficulties (Othman et al., 2019; Söderlund et al., 2010). Properly calibrated masking noise can reduce the intelligibility of disruptive speech without introducing new distractions (Loewen & Suedfeld, 1992). However, improperly tuned noise may become a cognitive burden, decreasing task performance and underscoring the importance of precise implementation (Balazova et al., 2008; Ellermeier & Zimmer, 1997). By integrating masking noise into ANC technology, we propose a hybrid solution that mitigates low-frequency background noise and the disruptive effects of intelligible speech. This dual-layered approach could create a more effective auditory environment for focused work, addressing ANC's existing limitations while maximizing the cognitive benefits of SR.

Unlike complete noise cancelation conditions, which can create an unnatural or isolating auditory environment, masking noise reduces discomfort because it maintains a more natural acoustic balance (Hong et al., 2020). It also enables users to stay attentive to critical auditory cues (e.g., alerts and warnings) while reducing distractions. By providing a stable auditory backdrop, masking noise prevents sudden speech from being as cognitively intrusive. Furthermore, a hybrid system could offer personalized noise control, allowing users to fine-tune their acoustic environment to match their preferences. Masking noise enhances speech privacy, benefiting the wearer and their colleagues by making workplace conversations less intelligible to unintended listeners. For example, one of the authors of this article purposefully plays sound tracks of heavy rain and thunderstorms through their ANC headphones to mask the sound of their colleagues talking in adjoining offices. These advantages may make the combination of ANC and masking noise an effective solution for creating a comfortable and privacy-centered auditory environment in professional settings.

DISCUSSION

This paper explores the challenges workers face in modern OOSs and examines the limitations of existing noise mitigation strategies. Given the shortcomings of current methods, merging ANC technology with low-level masking noises to conceal IS may prove more effective. ANC technology filters out low-frequency, continuous background noise, which reduces distractions caused by office equipment and ambient environmental sounds. However, ANC alone struggles to attenuate high-frequency, transient noises such as human speech, which remain a primary source of cognitive interference in OOSs. Introducing masking noises will reduce speech intelligibility, thereby decreasing the disruptive effects of IS and lowering the cognitive load associated with filtering out distractions. This dual-layered approach has the potential to enhance worker concentration, reduce mental fatigue, and improve overall performance in OOS environments.

While ANC headphones present a cost-effective and practical noise mitigation strategy, their implementation requires careful consideration of potential psychosocial consequences. Because OOSs are designed to foster collaboration, widespread adoption of ANC headphones may inadvertently hinder team communication and increase social isolation. It is crucial to investigate how ANC technology can be integrated into collaborative environments without compromising interpersonal interactions. Future research should explore strategies for balancing individual focus and team dynamics, ensuring that ANC and masking noise solutions enhance both productivity and workplace cohesion.

CONCLUSION

Companies have transitioned to open office space designs to reduce overall costs and improve interactions among colleagues. However, these environments can also create distractions. Noise, specifically irrelevant speech, can be distracting in open office spaces and often leads to negative consequences, such as poor overall performance from employees. Although strategies such as sound-absorbing pads, masking noises, and noise-canceling headphones have been implemented to mitigate the effects of increased noise, they have had little success in improving working conditions. The use of ANC headphones showed promise and was perceived well by employees, however, while they were effective at reducing low-frequency noise, they were less adept at managing the high-frequency disruptions caused by human speech. This resulted in the same auditory issue as using sound-absorbing pads in which IS was perceived to be clearer than before they used the ANC headphones. Thus, our study proposes the introduction of masking noise alongside ANC technology. The combination of these two methods should provide a more uniform acoustic environment, hopefully improving focus and task performance.

ACKNOWLEDGMENT

The authors would like to acknowledge Kaitlin E. Deboth and Zachary Young for their support during the conceptualization of this project.

REFERENCES

Appel-Meulenbroek, R., Steps, S., Wenmaekers, R., & Arentze, T. (2020). Coping strategies and perceived productivity in open-plan offices with noise problems. *Journal of Managerial Psychology, 36*(4), 400–414. https://doi.org/10.1108/jmp-09-2019-0526

Araújo-Alves, J., Neto-Paiva, F., Torres-Silva, L., & Remoaldo, P. (2020). Low-frequency noise and its main effects on human health—A review of the literature between 2016 and 2019. *Applied Sciences, 10*(15), 5205. https://doi.org/10.3390/app10155205

Balazova, I., Clausen, G., Rindel, J., Poulsen, T., and Wyon, D. (2008). Open-plan office environments: A laboratory experiment to examine the effect of office noise and temperature on human perception, comfort and office work performance. *Indoor Air*. 17–22.

Banbury, S., & Berry, D. C. (1998). Distraction of office-related tasks by speech and office noise. *British Journal of Psychology, 89*(2), 499–517. https://doi.org/10.1111/j.2044–8295.1998.tb02699.x

Beaman, C. P., & Jones, D. M. (1997). Role of serial order in the irrelevant speech effect: Tests of the changing-state hypothesis. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 23*(2), 459–471. https://doi.org/10.1037/0278-7393.23.2.459

Beaman, P. (2005). Irrelevant sound effects amongst younger and older adults: Objective findings and subjective insights. *European Journal of Cognitive Psychology, 17*(2), 241–265. https://doi.org/10.1080/09541440440000023

Brennan, A., Chugh, J. S., & Kline, T. (2002). Traditional versus open office design. *Environment and Behavior, 34*(3), 279–299. https://doi.org/10.1177/0013916502034003001

Colle, H. A., & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior, 15*(1), 17–31. https://doi.org/10.1016/S0022-5371(76)90003-7

Danielsson, C. B., & Bodin, L. (2008). Office type in relation to health, well-being, and job satisfaction among employees. *Environment and Behavior, 40*(5), 636–668. https://doi.org/10.1177/0013916507307459

Di Blasio, S., Shtrepi, L., Puglisi, G. E., & Astolfi, A. (2019). A cross-sectional survey on the impact of irrelevant speech noise on annoyance, mental health and well-being, performance and occupants' behavior in shared and open-plan offices. *International Journal of Environmental Research and Public Health, 16*(2), Article 280. https://doi.org/10.3390/ijerph16020280

Di Blasio, S., Vannelli, G., Shtrepi, L., Masoero, M. C., & Astolfi, A. (2018). A subjective investigation on the impact of irrelevant speech noise on health, well-being and productivity in open-plan offices. In *Proceedings of the Euronoise* (pp. 1883–1890).

Ellermeier, W., & Zimmer, K. (1997). Individual differences in susceptibility to the "irrelevant speech effect". *The Journal of the Acoustical Society of America, 102*(4), 2191–2199. https://doi.org/10.1121/1.419596

Haapakangas, A., Hongisto, V., Varjo, J., & Lahtinen, M. (2018). Benefits of quiet workspaces in open-plan offices – evidence from two office relocations. *Journal of Environmental Psychology, 56*, 63-75. https://doi.org/10.1016/j.jenvp.2018.03.003

Herrmann, B. (2024). Minimal background noise enhances neural speech tracking: Evidence of stochastic resonance. *bioRxiv*, 2024–06. https://doi.org/10.1101/2024.06.19.599692

Hong, J. Y., Ong, Z.-T., Lam, B., Ooi, K., Gan, W.-S., Kang, J., Feng, J., & Tan, S.-T. (2020). Effects of adding natural sounds to urban noises on the perceived loudness of noise and soundscape quality. *Science of the Total Environment, 711*, Article 134571. https://doi.org/10.1016/j.scitotenv.2019.134571

Hoshina, T., Fujiyama, D., Koike, T., & Ikeda, K. (2022). Effects of an active noise control technology applied to earphones on preferred listening levels in noisy environments. *Journal of Audiology & Otology*, *26*(3), 122–129. https://doi.org/10.7874/jao.2021.00612

Hughes, R. W., Vachon, F., & Jones, D. M. (2007). Disruption of short-term memory by changing and deviant sounds: Support for a duplex-mechanism account of auditory distraction. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(6), 1050–1061. https://doi.org/10.1037/0278-7393.33.6.1050

Jafari, M. J., Khosrowabadi, R., Khodakarim, S., & Mohammadian, F. (2019). The effect of noise exposure on cognitive performance and brain activity patterns. *Open Access Macedonian Journal of Medical Sciences, 7*(17), 2924–2931. https://doi.org/10.3889/oamjms.2019.742

Jahncke, H., Hygge, S., Halin, N., Green, A. M., & Dimberg, K. (2011). Open-plan office noise: Cognitive performance and restoration. *Journal of Environmental Psychology, 31*(4), 373–382. https://doi.org/10.1016/j.jenvp.2011.07.002

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(2), 369–381. https://doi.org/10.1037/0278-7393.19.2.369

Kjellberg A. (1990). Subjective, behavioral, and psychophysiological effects of noise. *Scandinavian Journal of Work, Environment & Health, 16*(1), 29–38. https://doi.org/10.5271/sjweh.1825

Kupritz, V. (2003). Accommodating privacy to facilitate new ways of working. *Journal of Architectural and Planning Research, 20*(2), 122–135.

Lai, L. W. C., Chau, K. W., Davies, S. N. G., & Kwan, L. M. L. (2021). Open space office: A review of the literature and Hong Kong case studies. *Work, 68*(3), 749–758. https://doi.org/10.3233/wor-203408

LeCompte, D. C., Neely, C. B., & Wilson, J. R. (1997). Irrelevant speech and irrelevant tones: The relative importance of speech to the irrelevant speech effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*(2), 472–483. https://doi.org/10.1037//0278-7393.23.2.472

Lin, J. H., Tang, S. T., Han, W. R., Chuang, C. Y., Liu, P. T., & Young, S. T. (2006). Evaluation of speech intelligibility for feedback adaptive active noise cancellation headset. In *2006 International Conference on Biomedical and Pharmaceutical Engineering* (pp. 24–29). IEEE.

Loewen, L. J., & Suedfeld, P. (1992). Cognitive and arousal effects of masking office noise. *Environment and Behavior, 24*(3), 381–395. https://doi.org/10.1177/0013916592243006

Lütke Lanfer, S. S., Becker, C., & Göritz, A. S. (2021). Well-being in open space offices: The role of office features and psychosocial working conditions. *Work, 68*(2), 317–332. https://doi.org/10.3233/wor-203378

Marsh, J. E., Hughes, R. W., & Jones, D. M. (2008). Auditory distraction in semantic memory: A process-based approach. *Journal of Memory and Language, 58*(3), 682–700. https://doi.org/10.1016/j.jml.2007.05.002

McDonnell, M. D., & Ward, L. M. (2011). The benefits of noise in neural systems: Bridging theory and experiment. *Nature Reviews Neuroscience, 12*(7), 415–426. https://doi.org/10.1038/nrn3061

Moss, F., Ward, L. M., & Sannita, W. G. (2004). Stochastic resonance and sensory information processing: A tutorial and review of application. *Clinical Neurophysiology, 115*(2), 267–281. https://doi.org/10.1016/j.clinph.2003.09.014

Mueller, B. J., Liebl, A., Herget, N., Kohler, D., & Leistner, P. (2022). Using active noise-cancelling headphones in open-plan offices: No influence on cognitive performance but improvement of perceived privacy and acoustic environment. *Frontiers in Built Environment*, *8*. https://doi.org/10.3389/fbuil.2022.962462

Nagy, M. R., & Dunay, A. (2023). Employee satisfaction in open office environment. 12-Th International Conference of Management Sustainability – Security – Quality Book of Proceedings, 192–196. https://doi.org/10.17512/cut/9788371939563/30

Othman, E., Yusoff, A. N., Mohamad, M., Abdul Manan, H., Giampietro, V., Abd Hamid, A. I., Dzulkifli, M. A., Osman, S. S., & Wan Burhanuddin, W. I. D. (2019). Low intensity white noise improves performance in auditory working memory task: An fMRI study. *Heliyon, 5*(9), Article e02444. https://doi.org/10.1016/j.heliyon.2019.e02444

Radun, J., Kontinen, V., Keränen, J., Tervahartiala, I. K., & Hongisto, V. (2021). Benefits of active noise-cancelling headphones in offices. In *Congress on Noise as a Public Health Problem*.

Radun, J., Tervahartiala, I. K., Kontinen, V., Keränen, J., & Hongisto, V. (2024). Do active noise-cancelling headphones' influence performance, stress, or experience in office context? *Building and Environment, 266*, Article 112102. https://doi.org/10.1016/j.buildenv.2024.112102

Markets, R. A. (2023, March 1). Noise Cancelling Headphones Market Report 2022: Technological Advancements and Miniaturization of Electronic Components Bolsters sector. GlobeNewswire News Room. https://www.globenewswire.com/news-release/2023/03/01/2618567/28124/en/Noise-Cancelling-Headphones-Market-Report-2022-Technological-Advancements-and-Miniaturization-of-Electronic-Components-Bolsters-Sector

Seidman, M. D., & Standring, R. T. (2010). Noise and quality of life. *International Journal of Environmental Research and Public Health, 7*(10), 3730–3738. https://doi.org/10.3390/ijerph7103730

Shalool, A., Zainal, N., Beng Gan, K., & Umat, C. (2016). An investigation of passive and active noise reduction using commercial and standard TDH-49 headphones. In *2016 International Conference on Advances in Electrical, Electronic and Systems Engineering (ICAEES)* (pp.606–609). IEEE. https://doi.org/10.1109/ICAEES.2016.7888118

Sikström, S., & Söderlund, G. (2007). Stimulus-dependent dopamine release in attention-deficit/hyperactivity disorder. *Psychological Review*, *114*(4), 1047–1075. https://doi.org/10.1037/0033-295x.114.4.1047

Söderlund, G. B., Sikström, S., Loftesnes, J. M., & Sonuga-Barke, E. J. (2010). The effects of background white noise on memory performance in inattentive school children. *Behavioral and Brain Functions, 6*, Article 55. https://doi.org/10.1186/1744-9081-6-55

Sörqvist, P., Halin, N., & Hygge, S. (2010). Individual differences in susceptibility to the effects of speech on reading comprehension. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition, 24*(1), 67–76. https://doi.org/10.1002/acp.1543

Sörqvist, P., Nöstl, A., & Halin, N. (2012). Disruption of writing processes by the semanticity of background speech. *Scandinavian Journal of Psychology, 53*(2), 97–102. https://doi.org/10.1111/j.1467-9450.2011.00936.x

Suter, A. H. (1991). Noise and its effects. *Administrative Conference of the United States*. https://windaction23.s3.amazonaws.com/attachments/3795/Noise%20and%20Its%20Effects%20-%20Suter%201991.pdf

Szalma, J. L., & Hancock, P. A. (2010). A meta-analytic review of the effects of noise on performance: Moderating effects of task and noise characteristics. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 54*(19), 1660–1664. https://doi.org/10.1177/154193121005401963

Szalma, J. L., & Hancock, P. A. (2011). Noise effects on human performance: A meta-analytic synthesis. *Psychological Bulletin, 137*(4), 682–707. https://doi.org/10.1037/a0023987

Varjo, J., Hongisto, V., Haapakangas, A., Maula, H., Koskela, H., & Hyönä, J. (2015). Simultaneous effects of irrelevant speech, temperature and ventilation rate on performance and satisfaction in open-plan offices. *Journal of Environmental Psychology*, *44*, 16–33. https://doi.org/10.1016/j.jenvp.2015.08.001

Williams, T. (2024). If you work from home, Noise-Cancelling headphones are a must. Forbes. https://www.forbes.com/sites/terriwilliams/2023/11/09/if-you-work-from-home-noise-cancelling-headphones-are-essential/

Yuan, X., & Zhong, L. (2024). Effects of multitasking and task interruptions on task performance and cognitive load: considering the moderating role of individual resilience. *Current Psychology*, 1–11. https://doi.org/10.1007/s12144-024-06094-2