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# Mysteries of the Hearing Brain: Hearing aid processing delays affect neural fidelity

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We are all familiar with challenging patients who have difficulty adjusting to amplification. Patients with relatively mild hearing loss may be particularly susceptible to these difficulties, because they are better able to hear the subtle distortions that are byproducts of hearing aid amplification. One possible source of distortion is the mixing of amplified and unamplified signals in the ear canal via leakage through open domes or large vents, resulting in a comb-filter effect (Stiefenhofer, 2022). Phase locking is disrupted when hearing aid processing delays the amplified sound by up to several milliseconds and mixes with the unamplified sounds that enter the ear canal directly. The perceptual sensation from the comb-filter effect has been described as diffused, unnatural, or metallic (Stone et al., 2008). Previous behavioral tests have shown that most listeners judge hearing aids with shorter processing delays (2 ms) to have higher sound quality than those with longer processing delays (4 or 10 ms) (Balling et al., 2020; Groth & Søndergaard, 2004). Therefore, hearing aid delay time may be an important factor in sound quality and the patient's successful adjustment to amplification.

The audiologist relies on patient feedback to resolve problems with sound quality, but many patients are unable to articulate the reasons for their dissatisfaction, due to their lack of sophisticated language to describe sound quality and a general lack of knowledge of acoustics. For this reason, objective measures of speech processing may be useful in determining the patient's source of dissatisfaction. The envelope following response (EFR) is one objective measure that can be used to evaluate the effects of hearing aid algorithms on neural speech processing. The EFR is an evoked potential that arises from midbrain and cortical sources. The frequency and timing components of the signal are closely mirrored by the EFR, and it can therefore be used to quantity neural fidelity or phase locking.

A recent study used the EFR to investigate hearing aid processing delays on neural phase locking (Zhou et al., 2023). Twenty-two participants with mild-to-moderate sensorineural hearing loss were recruited. They were fitted with three sets of bilateral hearing aids that varied in processing delays of 0.5, 5, and 7 ms. Real-ear measurement was performed, and the hearing aids were programmed based on NAL-N2 prescriptive targets (Keidser et al., 2011) for soft, average and loud inputs (55, 65, and 75 dB SPL).

The participants heard a 50-ms /da/ syllable presented through a speaker placed one meter directly in front of them. While the /da/ syllable was playing they wore the three sets of hearing aids in randomized order and watched a muted movie of their choice with subtitles. During this time a five-electrode montage recorded their responses to 8000 sweeps of the /da/ syllable. Phase locking factor (PLF) was calculated for the 100-Hz fundamental frequency in responses to each of the hearing aids. Figure 1 displays the group average PLF for the three hearing aid delays. Phase locking was stronger for the hearing aid with a 0.5-ms delay than for the hearing aids with 5- or 7-ms delays ($p < 0.001$). This effect was more apparent in some participants than in others, particularly in those with milder degrees of hearing loss. A significant delay time × pure-tone average (500 – 4000 Hz) interaction was observed ($p = 0.003$), confirming that delay time effects were strongest for participants with milder degrees of hearing loss and less noticeable for participants with moderate hearing loss.

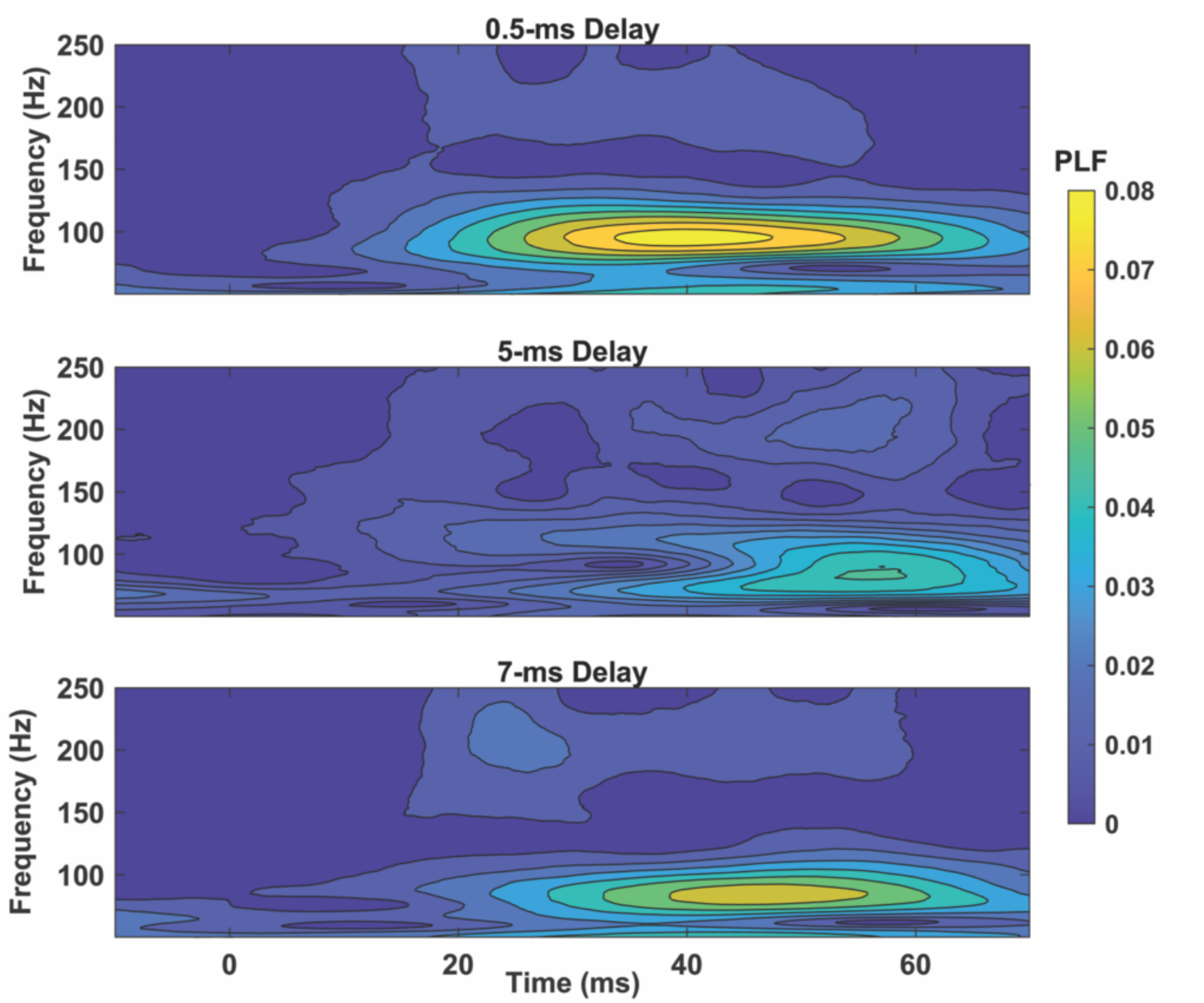


*Figure 1. Group average phase-locking factor (PLF) is displayed for hearing aids with 0.5-ms, 5-ms, and 7-ms processing delays. The hearing aid with the 0.5-ms delay had higher PLF values in the frequency region corresponding to the 100-Hz fundamental frequency of the /da/ stimulus than the hearing aids with longer delays ($p < 0.001$). Used with permission from Zhou et al. Ear and Hearing 2023.*

One might wonder how phase locking relates to real-life listening. Several previous studies have demonstrated a relationship between phase locking and speech-in-noise performance (Anderson et al., 2013; Hao et al., 2018; McClaskey et al., 2019). Therefore, one might expect a hearing aid user to experience better performance when wearing aids that produce a stronger neural representation of the speech signal. Although the benefits of shorter delay times were mostly seen in individuals with mild hearing loss, these are the people who are often unsuccessful when trying to adjust to hearing aids and measures to improve perceived sound quality should be beneficial.

This particular study did not test the effects of delay time on behavioral performance. Often, significant differences cannot be demonstrated between hearing aid technologies because the listener can compensate for differences in sound quality with increased listener effort for the duration of testing. This level of effort cannot, however, be sustained throughout the day, especially in challenging listening situations. A previous study showed that the benefits of noise reduction algorithms may not be apparent in behavioral performance but can be seen using an objective measure of listening effort (e.g., pupillometry, Wendt et al., 2017). For this reason, hearing aid manufacturers have begun to incorporate pupillometry and electrophysiology to evaluate the performance of their algorithms. These measures may be useful in verifying that algorithms designed to reduce hearing aid distortion effects, such as shorter hearing aid delay times, are beneficial to the listener. Perhaps in the future, audiologists will begin to adopt new measures to verify hearing aid performance to improve the outcomes of their hearing aid fittings.

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