Hearing-aids Induce Plasticity in the Auditory System: Perspectives From Three Research Designs and Personal Speculations About the Future

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Technologies like prosthetic limbs and cell phones are artifacts that operate as interfaces between the human mind and environment. These artificial creations can change brain functionality and structure that influence behavior, which means the environment plays a major role in how people think and behave. Interestingly, this model can be reversed: brain organization can determine behavior that in turn can manipulate the environment (Breedlove, S. M. et al., 2005, p. 6). The brain-behavior relationship reveals the brain's adaptive nature, known as neuroplasticity (Breedlove, S. M. et al., 2005, p. 8), and the extent to which the human biology can conform to and change their environment. The topic of plasticity is important because if the environment can be controlled to alter behavior, then neuroscientists can modify environmental variables and observe changes in brain function. This process is known as behavioral intervention (Breedlove, S. M. et al., 2005, p. 7), which allows researchers to better understand neurological and psychological disorders in order to improve various brain-related human conditions (Breedlove, S. M. et al., 2005, p. 12).

Sensorineural deafness, for instance, is a neurological abnormality that is usually the result of aging and exposure to "noise pollution and loud sounds" (Breedlove, S. M. et al., 2005, p. 271). It is often characterized by the loss of high frequency pitches due to damaged and/or decreased numbers of inner hair cell receptors in the cochlea (Breedlove, S. M. et al., 2005, p. 259). Nevertheless, sensorineural deafness can be treated with sensorineural hearing-aids, an interface fitted in the ear that amplifies sound waves in the environment and converts sound energy to electrical energy via an amplifier and microphone that is delivered to the ear canal

(Audibel Hearing Health Services, 2015). This activates neural communication where the signal is carried from the neurons in the ear to the auditory cortex in the brain by electrical impulses passed from one neuron to the next (Breedlove, S. M. et al., 2005, p. 261). When hair cells are damaged, they can not effectively convert sound energy to electrical energy, so a hearing-aid manages this conversion for the wearer.

Electronic hearing-aids have been investigated for their effect on inducing plasticity in the auditory system most notably within the brainstem. The brainstem is an important part of the auditory system because it contains critical auditory pathways to the brain, such as the superior olivary nuclei which “[provides] the first binaural output to the superior olivary complex” from the left and right cochlear nuclei (Breedlove, S. M. et al., 2005, p. 262). More specifically, the brainstem “may participate in the integration of hearing reflexes” (Emanuel, D. C., 2009). Past research findings discovered physiological changes in the brainstems’ response to auditory stimuli. One such study by Piers Dawes et al. (2013) examined the brainstems’ intensity and latency response on experience with hearing-aid use. Latency and intensity were measured because they are identifiable components of the interaction between sound energy and auditory cells. Measuring latency, the time of arrival of sounds (Dawes et al., 2013), provides insight to how efficient the auditory system takes in and interprets sound energy. Likewise, measuring intensity, the amplitude of a sound wave, reveals how apt the auditory system can capture sound, which influences perceived loudness (Dawes et al., 2013). These signals, called Wave V, emitted from the brainstem were detected by recording electrodes applied to a participant’s scalp in Dawes et al.’s experiment (2013). If there is significant change in these signals after hearing-aid use, then this means there could be structural change in the auditory system. In addition, with this biological psychology approach, Dawes et al. used a click stimulus that contained an array of frequencies of pure sounds to provoke the brainstem (Dawes et al., 2013). It is important to note that the auditory pathways are grouped and laid out sequentially with cells that respond from lowest to highest frequencies (Breedlove, S. M. et al., 2005, p. 263), such that certain pitches incite certain brainstem feedback, which can then be recorded. This allows for more precise execution of sounds and readings from exact location on the frequency map. Dawes et al. found that brainstem latency measures were lower and that amplitude measures were higher in the group wearing monaural hearing-aids (2013). Since the readings displayed change, stronger evidence exists toward brainstem plasticity influenced by hearing-aid practice.

A similar study was conducted by Limor Lavie et al. (2014) to research the impact of monaural and binaural hearing-aids among elderly individuals with high-frequency sensorineural hearing loss. Dichotic listening and speech-in-sound tests were administered to measure perceptual abilities in word identification (Lavie et al., 2014). Speech-in-sound tests measure working memory through a person's ability to track keywords in a sentence amidst background noise, whereas dichotic listening tests measure attention through a person's selective hearing (Lavie et al., 2014). With this cognitive psychology approach, Lavie et al. hypothesized that scores of these two test would increase for participants fitted with hearing-aids, and that if a score on one of the tests increase, the other would also increase because of their correlation (Lavie et al., 2014). The background behind this reasoning comes from the idea that gains in the auditory system via hearing-aids stimulates the deprived brain by feeding more auditory information, which can lead to improved working memory and attention (Vickers, 2011). According to Thomas Vickers (2011) as recorded in his article, *Auditory Recognition Cues in*

Word Memorization & Recall, hearing words during a word recall test can "improve scores because the subject is performing a recognition task using [spoken words]". Thus, if a hearing impaired participant can not properly hear a word, their ability to recall the word and their overall performance would decline. That is, enhanced hearing comes with improved sound localization due to increased auditory system stimulation (Lavie et al., 2014) that precedes better attention. Lavie et al.'s results revealed that hearing-aid wearers improved the most on dichotic listening tests, and that the word identification test scores also increased in hearing-aid groups (2014). This change in cognitive performance reveals an indirect and potential relationship with the brain's reorganization and a participant's hearing abilities, so that if psychological factors change due to hearing-aid use, then there is proof of auditory plasticity.

Evidence of plasticity in the auditory system can also be studied by measuring perception of loudness in relation to mechanical ear behavior (Munro et al, 2007). Kevin J. Munro et al. (2007) researched this correlation by measuring the biological reflex threshold, which is a middle ear muscle contraction that occurs without conscious effort when a sound wave hits the eardrum (Emanuel, D. C., 2009). Reflex thresholds can be measured by administering pure tones and steadily increasing sounds and observing changes in contraction. Participants' subjective experience of loudness discomfort was measured as a means of comparing the biological variable: reflex threshold-a lower level and mechanical part of the auditory system, with the psychological variable: loudness discomfort-a higher level and conscious part of the auditory system (Munro et al, 2007). Thus, changes in perceived loudness discomfort reveals changes in higher levels of the auditory processing system since conscious matter is grounded in the physical brain. Furthermore, if measurements in loudness discomfort correlates with reflex thresholds, then there is direct evidence for auditory plasticity (Munro et al, 2007). This was Munro et al.'s reasoning behind their research, which was fairly supported by their findings that indicate the ear fitted with the hearing-aid had a higher sensitivity towards sounds and that the reflex threshold measurements corresponded concurrently.

The above experiments by Dawes et al., Lavie et al. and Munro et al. executed different designs that had their own strengths and weaknesses. Dawes et al. and Lavie et al. measured both monaural and binaural hearing-aid use. An advantage to this design as opposed to testing only unilaterally is having a comparison basis. For instance, Lavie et al. found that dichotic listening scores were better in the bilateral group than the unilateral group (2014). This result may have been due to improved sound localization and thus improved ability to focus on a key word. In addition, Dawes et al. found that amplitude scores had greater gains in the group wearing monaural hearing-aids, but only in the left ear (2013). This result may have been triggered by ear asymmetry where the right ear often has an advantage over the left (Lavie et al., 2014). Greater improvement in the left ear is a reasonable outcome because the right ear does not have as much to gain. For this reason, Dawes et al.'s findings parallel previous research on ear asymmetry, so that even though their results were not statistically significant, there is enough evidence to speculate the efficacy of hearing-aid use on auditory plasticity. As well, the benefit of studying monaural hearing-aid effect is perhaps an increased ability to observe plasticity differences in the fitted ear from the non-fitted ear. Studying the effects of hearing-aid use on an individual can be less complex than studying a large cohort with much variability.

Nonetheless, variability would increase generalizability of a result. Perhaps a research design that utilizes a random assignment process to split the hearing-aid tested group from the control group could weaken confounding variables that gave rise to doubts in the above researches, including how quickly a participant acclimatizes to their hearing-aid. Randomization would then include participants of any age and level of hearing impairment. Furthermore, future studies would greatly benefit from investigating the effects of binaural hearing-aids on the superior olivary nuclei, since they play an integral role in localization of sounds by comparing sound differences between the two ears (Breedlove, S. M. et al., 2005, p. 262). Because frequency readings are sharper at higher levels of the auditory system (Breedlove, S. M. et al., 2005, p. 262), examining areas like the medial geniculate nucleus would also allow for improved accuracy readings on how well the auditory system responds to an incoming sound. With these approaches, perhaps measuring plasticity in the auditory system can be even more precise to further technological advancement of hearing-aids.

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