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Variables To Consider When Interpreting the Impact of Monaural Amplification

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Abstract

A theoretical basis is presented for considering the current data available regarding the impact of monaural amplification over time and for the design of future prospective studies. We present a summary of essential subject parameters, amplification parameters, and test properties to be considered in this expanding area of investigation. This paper attempts to create a context in which to evaluate current findings and a framework in which to ground future investigations.

Key Words: Binaural amplification, deprivation, hearing aids, monaural amplification, nonstimulation

Amplification of only one ear may lead to "deprivation" or "nonstimulation" of the other ear. Over the past decade, several investigators have reported a late-onset auditory deprivation effect or nonstimulation effect in the unaided ears of monaurally aided, hearing-impaired individuals (Hood, 1984; Silman et al, 1984; Gelfand et al, 1987; Gatehouse, 1989a, b, 1992, 1993; Silverman 1989; Stubblefield and Nye, 1989; Silverman and Silman, 1990; Hurley, 1991, 1993; Boothroyd, 1993; Dieroff, 1993; Gelfand and Silman, 1993; Hall and Gross, 1993; Hattori, 1993; Silverman and Emmer, 1993). The majority of these reports are limited, however, by the fact that they have been retrospective and/or have been limited to a narrow array of peripheral hearing tests.

A prospective longitudinal study in this area, employing a wider spectrum of auditory tests, is certainly needed. It is important to emphasize, however, that certain essential criteria in terms of subject population and test protocol must be met if such prospective studies are to advance our knowledge of the phenomenon. The following is a critical review of subject, hearing aid, and test variables that must be considered when designing and interpreting studies relating to adult, late-onset auditory deprivation (nonstimulation).

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SUBJECT PARAMETERS

A variety of subject parameters must be considered when evaluating the potential impact of monaural stimulation. The following description highlights subject characteristics that may confound the interpretation of nonstimulation data.

Degree of Hearing Loss

Selecting for degree of hearing loss has implications on the ability to perform and interpret certain auditory tasks as well as for potential nonstimulation. The impact of nonstimulation is expected to be greater with greater hearing loss, but if higher levels of the auditory pathway are to be tested, degree of hearing loss must be limited in order to meaningfully interpret many of the tests. For instance, thresholds of 70 dB HL would be required at 4000 Hz to successfully interpret the auditory brainstem response (Selters and Brackman, 1977). A pure-tone average (PTA) over 50 dB HL would make the interpretation of the Staggered Spondaic Word Test questionable at best (Arnst, 1982).

On the other hand, if subjects with hearing loss less than 40 dB HL (PTA) are included, an effect may not be measured within 2 to 3 years of fitting (Hurley, 1991; Burkey and Arkis, 1993). In cases of mild-to-moderate hearing loss, a good portion of conversation is most likely heard quite comfortably. These subjects also would be less likely to be full-time hearing aid users (monaural or binaural), which would confound any definition of which ear is being deprived.

A compromise is required in order to include subjects expected to be impacted by nonstimulation ($\geq$ 40 dB HL PTAs) and, at the same time, expected to provide valid test results along the auditory pathway ($\leq$ 50 dB HL PTAs). Current data should be interpreted in light of the subjects' degree of hearing loss, the potential interaction of degree of loss and length of nonstimulation, and high level test procedures.

Defining Symmetry across the Auditory System

If the auditory system is not symmetrical before amplification, then asymmetry after amplification is very difficult to interpret. Due to the retrospective nature of most past investigations, only octave pure-tone and word-recognition results are available for use in defining symmetry between the two ears. When interpreting the long-term impact of monaural stimulation, it is necessary to have preliminary data indicating the status of the auditory system before monaural stimulation was introduced (Gatehouse, 1992). Only in this way can future asymmetrical findings be judged as relevant in light of original symmetry across the auditory system.

Original Choice of Monaural versus Binaural Amplification

If subjects in a study of late-onset deprivation are allowed to choose their hearing aid configuration (monaural right or left, binaural), the investigation loses control of a variety of motivators that may have prompted that choice (e.g., poor sound quality or intelligibility in one ear). Current studies of monaural stimulation include self-selected monaural and binaural hearing aid wearers, largely due to their retrospective nature. For the purposes of a longitudinal, prospective study, subjects should be identified for monaural versus binaural use at random. This type of selection raises ethical questions that should be resolved by creating a study where the amplification is provided without charge, and the subject is not prevented from purchasing a second hearing aid if desired.

Age

It is possible that age-related changes can mask changes due to nonstimulation. Individuals who present with the type of hearing loss described above, who pursue hearing aids, and who have the time to participate in a lengthy study tend to be aging adults (over 60 years of age). If these individuals are followed for 5 to 10 years in order to document a possible nonstimulation effect, they will be followed right into the age where possible general aging effects of the auditory system are found. Changes in the auditory system due to aging alone tend to manifest themselves bilaterally (Baran and Musiek, 1991). Therefore, any monaural change due to nonstimulation could be identified through systematic bilateral change if the bilateral effect is not so great as to create a floor effect on particular tests. The aging influence might, however, make it impossible to separate changes in binaural integration where separate ear scores are not available. Poor performance in this type of measure over time (e.g., masking level difference) could not be attributed to poor performance in one ear due to nonstimulation as opposed to poor performance in both ears due to aging.

Gender

There is no evidence to support or deny differences between males and females in terms of possible susceptibility to a nonstimulation effect. Binaural representation at the central level may be different between men and women, but this is not well documented. The best solution is to balance the difference between groups under investigation.

Language

Native language is an issue when central tests have been standardized with English language users. First language has not been reported in any investigation of nonstimulation to date. Of course, any language effect would be expected to manifest itself in both ears.

Handedness

The literature indicates that approximately 95 percent of right-handed individuals are left hemisphere dominant, while a one-to-one correlation of handedness and hemispheric dominance is not revealed for left-handed or ambidextrous individuals. The inclusion of only right-handed subjects would eliminate the possibility that test results were influenced by a combination of nonstimulation, ear that was aided, and hemispheric dominance. Handedness has not been reported in any investigations of nonstimulation.

Amount of Time Hearing Aids are Worn

Defining the amount of time per day and the days per week of hearing aid use is essential in establishing a premise for nonstimulation and/or acclimatization (Silman et al, 1984; Gatehouse, 1989a). If the hearing aid is not being used full time, it is questionable whether one would expect to find any ear differences, since the ears would be exposed to the same low level signal for the majority of time. The advent of hearing aids containing memory (e.g., 3M™ programmable hearing aid) provides a unique opportunity for quantifying use time in this type of investigation. The investigator downloads the usage data each month and is supplied with a histogram of hours of use in each of the memories of the hearing aid. If one uses the various memories as volume wheel control settings, an estimate of hours of use under various levels of audibility can be determined. Usage can then be applied as a covariate in the analysis of the impact of monaural stimulation.

Potential for Recovery

One must understand the time course and type of impact produced by asymmetrical stimulation under controlled conditions before investigations regarding the ability of the system to recover can be adequately addressed. Several investigators have reported various levels of recovery in subjects who received a second hearing aid after long-term monaural stimulation (e.g., Silverman and Silman, 1990; Burkey and Arkis, 1993). Investigations to date have not adequately addressed the issue that the individuals who accept a second hearing aid may be inherently different from those who reject the introduction of amplification on the previously unamplified side. In a sense, these individuals are self-selecting, because they are the ones who succeeded with the second hearing aid. One could hypothesize that individuals more severely impacted by nonstimulation might not accept a second hearing aid because of poor initial performance.

POTENTIAL IMPACT OF THE HEARING AID RESPONSE

Generally, it is assumed that if an individual is provided with amplification, the speech signal is now appreciably more audible. In an attempt to determine whether this is a safe assumption, we recruited 13 individuals fit with hearing aids in area clinics in order to quantify the amount of audibility provided by their hearing aids. Articulation indices (AI) were calculated for each of the 13 volunteers using threshold data and real-ear insertion response at use gain (specified by the subject) in order to provide some quantification of just how audible sound was at the aided ear (Mueller and Killion, 1990). Figure 1 contains the calculated AI for the left hearing aids of the binaural users and the hearing aids of the monaural users. Use of one hearing aid response for the binaural users was a result of very similar responses between binaural hearing aids. It is evident that the hearing aid responses of this group of individuals were not impressive—an average of 43 percent AI, with a range of 22 to 85 percent. For some of the monaurally aided subjects, there was actually very little difference between the aided and unaided ears in terms of calculated audibility. Recall that the AI calculation may actually predict better ability than what will be realized with amplification, considering potential distortion and internal noise that may be associated with the hearing aid (Humes, 1991).

Until Gatehouse's (1992) recent work, no mention of hearing aid response had been made in the nonstimulation and acclimatization literature. Ideally, subjects in a prospective study would be fit with hearing aids (as part of the study) that produced a predefined minimum AI

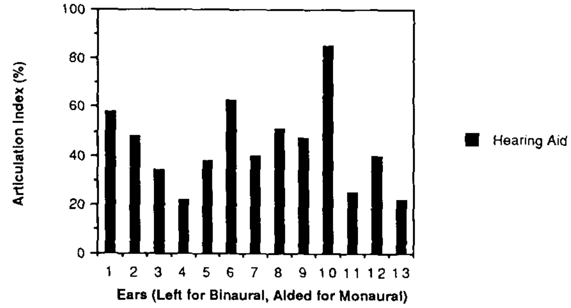

Figure 1 Calculated articulation indices (Mueller and Killion, 1990) for left hearing aids of binaural users (1–6) and hearing aids of monaural users (7–13).

level at use gain. This would remove the hearing aid as a variable, potentially impacting the ability to observe either a nonstimulation or acclimatization effect or the time course of the effect.

TEST PROPERTIES

Most studies of monaural stimulation have used word-recognition scores to determine change over time. The use of such tests has been dictated by the retrospective nature of most of these investigations. This is often the only measure of functional ability available from a routine hearing evaluation. Considering Thornton and Raffin's (1978) data, this would not be the test of choice when looking for subtle changes along the functional auditory pathway. The goal of a retrospective investigation should be to functionally assess fairly separate areas of the auditory pathway.

The major difficulty in selecting appropriate tests in the investigation of monaural stimulation is the desire to evaluate function across various levels of the auditory system in light of moderate-to-severe hearing loss. The hearing loss itself may mandate particular test parameters or cautious interpretation. The investigation of monaural stimulation over time dictates a test battery that would include the following properties: (1) absence of practice effects or numerous format versions; (2) absence of floor and ceiling effects with this subject population; and (3) control of stimulus presentation level and frequency response for suprathreshold speech tests.

The level and frequency response of the test signal must be considered in light of the frequency response that has been provided to the aided ear for stimulation. Due to the desire to measure subtle changes, the impact of any variation in stimulus presentation level must be viewed very seriously. Recent investigations regarding monaural stimulation have reported several methods for determining test stimulus presentation level, including most comfortable loudness (MCL) and 30–40 dB SL re: SRT. The various presentation methods used thus far are not completely satisfactory for several reasons: (1) they are not necessarily consistent between subjects, due to tolerance problems; (2) they do not allow for actual quantification of the final audibility of the signal; and (3) they present an entirely different frequency response from the one that the aided individual is now using on a day-to-day basis.

The theoretical goal of increasing the presentation level is to insure that the stimulus is audible to the subject. By using the audiometer attenuator, the entire signal (low and high frequencies) is amplified, which is not what the individual has been experiencing with amplification where the frequency response is shaped to the individual's hearing needs. Presentation levels for suprathreshold speech stimuli should mimic the hearing aid frequency/gain response in order to test the ear with the enhanced signal to which it has become accustomed. The best solution would be to present the speech stimuli at a normal conversation level through the actual hearing aid frequency response at prescribed use-gain setting. The individual would be experiencing the amount of audibility that is consistently produced by the hearing aid that he/she is wearing daily. Experimentally, this is easily achieved using the direct audio input (DAI) provided with behind-the-ear hearing aids, allowing monaural and/or binaural presentation. The frequency response of the hearing aid through the DAI is verified with probe microphone measurements, just as the normal microphone response is measured.

SUMMARY

The data to date regarding the impact of nonstimulation are compelling, but we will not have a well-defined view of the impact of monaural stimulation until a number of subject, hearing aid, and test variables are controlled in a prospective investigation. For the purposes of a longitudinal, prospective study, subjects meeting the variety of subject parameters described should be identified for monaural versus binaural use at random, fit with hearing aids (as part of the study) that produce a predefined minimum AI level at use gain, and tested with presentation levels that mimic their hearing aid frequency/gain response. The implementation of these subject, hearing aid, and test considerations will provide basic information regarding the functional plasticity of the adult auditory system as well as information regarding appropriate treatment recommendations for individuals with bilateral sensorineural hearing loss.

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