Critical Review: Do we see auditory system acclimatization with hearing instrument use, using electrophysiological measures?

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This critical review examines acclimatization of hearing instrument use through electrophysiological measures. Studies evaluated consisted of one prospective case series, and two non-randomized clinical mixed group studies. Analysis of these studies revealed moderate evidence of acclimatization using auditory brainstem response and cortically evoked potential measures.

Introduction

There is evidence to suggest that with the introduction of amplification via a hearing instrument the auditory system is able to adapt to the new acoustic information provided (Munro, 2007). The concept that this stems from is auditory acclimatization. Acclimatization is "a systematic change in auditory performance with time that is linked to a change in the acoustic information available to the listener. It involves improvement in performance that cannot be attributed purely to task, procedural, or training effects" (Arlinger, Arlinger, S., Gatehouse, Bentle, Byrne, Cox, Dirks, Humes, Neuman, Ponton, Robinson, Silman, Summerfield, Turner, Tyler, and Willott, 1996). Much of the research looking at the acclimatization effect with hearing instrument use has used perceptual measures. Acclimatization was demonstrated in a group of monaural hearing instrument wearers, whose speech identification scores improved in the aided ear over the course of 12 weeks (Gatehouse, 1992). However, studies that use perceptual measures to determine auditory acclimatization come with a number of limitations. Many of these studies use speech test measures which come with a great deal of test re-test variability within and between subjects (Engelberg, 1967). While perceptual studies do display changes to speech measures over time, how this equates to changes within the pathway of the auditory system is unclear.

A way we can monitor specific changes within multiple levels of the auditory system is through electrophysiological measures. Electrophysiological measures are able to record electrical activity produced by the brain in response to an auditory event. These auditory evoked potentials can be measured from the level of the eighth cranial nerve up to the primary and secondary cortices of the brain. Currently, there is a limited understanding of the underlying mechanisms that cause acclimatization in adults. Another advantage of electrophysiological measures is their potential to determine the amount of plasticity within the auditory pathway. Studies have shown that children who are fitted with hearing instruments or cochlear implants earlier have better performance outcomes than those fitted later on in life (Kirk, Miyamoto, Ying, Perdew, and Zuganelis, 2000). The earlier intervention takes advantage of the presumably greater amount of plasticity there is within the auditory system, which leads to better outcome measures. What is not as well defined is the pattern of plasticity relating to the auditory system for older adults. Identifying specific age ranges where acclimatization is not as pronounced with the introduction of hearing instruments, can provide inferences about how plastic the auditory system is in the elderly hearing impaired population.

Electrophysiological measures do have a number of limitations associated with them. Stimulus parameters, electrode montage set-up, the severity and configuration of the hearing loss can all impact the waveform morphology and latency. When comparing across multiple studies, there must be consideration as to how each of these variables impact the results.

When reviewing the literature the clinician must be aware of these limitations before using acclimatization as an argument in the recommendation for amplification to their patients. This critical review will examine the evidence for acclimatization using electrophysiological measures when amplification is introduced.

Objective

The objective of this critical review is determine if there is electrophysiological evidence to support auditory acclimatization of the central auditory system, caused by hearing instrument use after a period of auditory deprivation, in the older adult population.

Methods

Search Strategy

Computerized databases including PubMed, MEDLINE and Google Scholar were searched using the following strategy: [(hearing aids) AND deprivation] AND [hearing loss] AND [plasticity OR rehabilitation] AND [evoked potentials OR auditory brainstem response OR speech recognition]). Limits were English only and human research.

Selection Criteria

Both retrospective and prospective studies in adults with bilateral sensorineural hearing loss and fitted with hearing instruments were included. Only studies using electrophysiological measures of auditory acclimatization were selected. Studies including children, and studies including cochlear implants were not selected.

Data Collection

A total of three studies met the selection criteria and were included in this review. One was a prospective case series study, while the other two were non-randomized clinical trials, consisting of both between and within group measures.

Results and Discussion

Prospective Case Series Study

Study #1: Philibert, Collet, Vesson, and, Veuillet performed a prospective study looking at the impact of amplification on acclimatization, using the auditory brainstem response (ABR) and a variety of perceptual measures. Another objective was to determine if correlations existed between the electrophysiological and perceptual results. Participants with symmetrical, sloping, sensorineural hearing loss (n=8; 50% male; mean age 74 years) and naïve to amplification, were fitted with hearing aids. Baseline measures, specifically conventional click-evoked ABRs and perceptual measurements, were performed before hearing instrument fitting, and then repeated several times post-fitting in order to evaluate acclimatization.

The effect of hearing instrument experience was analyzed using a within-subject repeated measure of analysis (RM ANOVA). A two-way RM ANOVA was performed for the electrophysiological data with ear and time as the factors. The authors found a statistically significant interaction between 'time' and 'ear' factors for wave V latency in the right ear only, over the course of the hearing instrument fitting. There was no effect for amplitude at wave I, III, and V, and no effect for latency at wave I or wave III, in either ear. The authors attributed this change to a right ear advantage, hypothesizing that the right ear is more susceptible to changes within the auditory system with the introduction of amplification.

The authors also examined the correlation between the perceptual and ABR measures. No correlation between improvements seen at the high frequency (2kHz) and high stimulus level (95dB SPL) for difference limen intensity task and the ABR measurement were observed. However, fewer subjects performed the electrophysiological testing compared to the perceptual testing. The authors did not provide information as to why these data were lacking or how it was handled in the correlation analyses.

As this study is case series study it is assigned a 3 level of evidence. Since the study design was prospective, it was possible to evaluate changes to the auditory system at specific time points after the introduction of amplification.

Other methodological issues may also have influenced the study outcomes. These issues affect both the amplification of sound used to induce acclimatization, as well as techniques used to measure electrophysiological characteristics of the auditory brainstem.

When considering the impact of amplification, the duration and type of exposure to amplified sound may be critical to inducing the acclimatization effect. Although participants were required to wear their hearing instruments for at least 8 hours a day, this was based on a self-report measure. A datalogging technique to determine how often the subjects were actually wearing the hearing instrument can provide a more accurate measure of hearing instrument use and duration of exposure to amplified sound. Furthermore, not all participants in the study were equally matched with the same hearing instrument devices or compression characteristics; six individuals had BTE hearing instruments, and two had custom products, while six had an Automatic Gain Control input (AGCi) compression strategy while two had AGCo (output) strategy. The amount of amplified sound also varied; hearing aid gain was adjusted over the course of the six months, but details regarding this variation were not provided. With different compression and gain characteristics being modified throughout the study the authors introduce confounding factors that may affect the results, and were not considered in the research design or data analysis.

Several methodological issues with respect to the acclimatization outcome measure of auditory brainstem electrophysiology are also of concern. Two replications of the ABR were performed within each recording session, to ensure consistency within subjects. However, ABR measures can vary across different sessions even for the same subject, as well between subjects of different sex (Watson, 1996). Another critical issue was the intensity at which the clicks were presented through the TDH earphones. The intensity level they presented the stimulus at was 110dB SPL, which is well above threshold for all subjects in the study. Acclimatization effects on the auditory brainstem, induced by amplified sound, may be specific to a range of sound intensities. Presenting multiple intensity levels would have allowed the authors to see the relative effects each intensity level had on acclimatization.

This study also lacked a control group, which prevented the authors from determining the relative impact the hearing instruments had on the ABR.

In summary, with no significant correlation between perceptual and physiological measures, along with no modification in ABR for the left ear, this study provides only suggestive evidence for the existence of an acclimatization effect using electrophysiological measures after amplification has been introduced.

Retrospective Studies

Study #2: Munro, Pisareva, Parker, and Purdy conducted a retrospective non-randomized between and within group study that looked at the impact of long-term monaural hearing instrument experience on the auditory brainstem response (ABR). Another objective was to determine if there was a relationship between the duration of daily hearing instrument use and the magnitude of ABR asymmetry. Their study consisted of two groups. One had yet to be fitted with a hearing instrument (n=9; mean age 69 years). The second group consisted of long-term hearing instrument users (n=8; mean age 64 years). There was a minimum of 2 years of hearing instrument use and self-reported daily use of at least 5 hours per day, as an inclusion criterion for the study. Hearing thresholds for both groups were sloping in nature, with thresholds close to 20dB at 0.5 kHz and 60dB at 4 kHz. Differences in thresholds between the two groups were non-significant.

The effect of monaural hearing instrument experience was analyzed using a within and between repeated measure of analysis. A two way RM ANOVA was performed for the electrophysiological data with ear and presentation level as the factors. When comparing the two groups the authors found no difference between the left and right ears of either group, nor was there any significant interaction between ear and presentation level. The authors did find statistically significant interaction between the mean difference in wave V to SN10 peak-to-peak amplitude between the fitted and non-fitted ears for those monaurally aided group at 70dB and 80dB HL. No statistically significant interaction was found for wave V to SN10 peak-to-peak amplitude between the fitted and non-fitted ear at 90dB HL, nor were there any effect on wave III and wave V latency. The authors also found no strong relationship between the amount of time an individual wore their hearing instruments to the magnitude of ABR asymmetry in the fitted vs. non-fitted ear. However, the authors did not employ a datalogging strategy to monitor daily use, opting for a self-report response. As mentioned previously the amount of time one is exposed to amplified sound may have a large impact on the acclimatization effect, specific details of durational use was not outlined in the current study.

As this study is a retrospective non-randomized mixed clinical trial it is assigned a 2A level of evidence. Since the study design was retrospective the authors were not able to follow the changes in the ABR as a result of amplification and were therefore unable to determine when and over what period acclimatization occurred.

Methodological strengths of the study included the averaging of three waveforms into one grand waveform at each of the three intensity levels to minimize the impact of the individual variability seen in the ABR within the hearing impaired subject in the study. As they presented multiple intensity levels, they were able to determine the relative effects of acclimatization at each of these levels. The statistically significant difference of wave V to SN10 peak-to-peak amplitude at 70dB HL and 80dB HL in the aided ear suggests the amplified sound provided by the hearing instrument is providing acoustic cues that may not have been previously audible to the subject, and in turn is causing the morphology of the ABR waveform to be altered. Whereas no significant change in the ABR at 90dB HL suggests that this level is audible to the subjects even without the use of amplification. With no significant changes to wave V to SN10 peak-to-peak amplitude in the control group we can be reasonably confident that these modifications are the result of amplification.

A methodological flaw of this study involves the lack of control for hearing instrument experience. The authors used a minimum experience of 2 years as a cut-off for inclusion into the study, but do not provide any more details in regards to hearing instrument experience. As the time that one has been exposed to an amplified sound can have a large impact on the amount of acclimatization that has already occurred, not taking into account individual differences in hearing instrument experience introduces a confounding factor.

In summary, with the only change in the ABR morphology being the wave V to SN10 peak-to-peak amplitude, and the limited information on hearing instrument experience, the evidence of acclimatization using electrophysiological measures is suggestive.

Study #3: Bertoli, Probst, and Bodmer performed a retrospective study looking at the effects of hearing instrument use on late auditory evoked potentials. The authors had three groups, one normal hearing control group (n=10; 6 men; mean age 70.1 years), one unilaterally fitted group (n=10; 7 men; mean age 77.1 years), and one bilaterally fitted group (n=10; 8 men; mean age 69.5 years). Hearing instrument experience varied between the two hearing instrument groups with the unilateral group having 6.3 years of experience and the bilateral group having 12.4 years of experience. The author's noted this discrepancy reflected the different reimbursement criteria when prescribing hearing aids in Switzerland, for retired and working population.

The author's initially analyzed the data using a within-subject and between-subject RM ANOVA. The P1, N1, and P2 amplitudes and latencies were analyzed at electrode sites Cz and Pz with subject group as the between-subject factor (unilateral, bilateral, and normal) and ear (left, right), frequency (0.5, 1, 2 kHz) and level (55, 70, 85 dB SPL) as within-subject factors. Due to the large number of total conditions (18) in the study whenever significant effects were found for the RM ANOVA, a Bonferroni's post-hoc measure was performed. This was used to offset the increased potential for type I errors. With respect to amplitude the authors found a significant effect of level on amplitude of all components (P1, N1, P2), as well a significantly larger P2 amplitude in the unilateral vs. bilateral hearing instrument group. When comparing between the groups; hearing instrument users had longer P1 and N1 latencies at Cz, compared to the normal hearing group, but no significant interaction of within-subject group with ear, frequency, and level were observed for any of the AEP components.

To further investigate the effect of hearing instrument use on cortically evoked potentials, the authors subtracted the difference of the P1, N1, P2 amplitude and latencies for both the bilateral group (right ear subtracted from left) and the unilateral group (aided ear subtracted from unaided ear). RM ANOVAs were then calculated for the difference values with factors being subject group (unilateral, bilateral), frequency, and level. Bonferroni's post-hoc measurements were performed when significant main effect differences were found.

No significant results between subject group could be found for P1, N1, P2 latency and amplitudes; however, upon visual inspection the authors did discover a trend for the P2 amplitude in the fitted vs. non-fitted ears of the unilateral group, with P2 amplitude increasing with frequency in the ear receiving amplified sound. The authors subsequently performed an additional ANOVA and found a significant interaction between ear and frequency for P2 peak amplitude, with amplitudes being significantly larger in the aided vs. unaided ear at 2 kHz. Post-hoc analysis also revealed this difference to be statistically significant.

As this study is a retrospective non-randomized mixed clinical trial it is assigned a 2A level of evidence. Since the study design was retrospective the authors were not able to follow the changes in the cortically evoked potentials as a result of amplification and were therefore unable to determine when and over what period acclimatization occurred.

A methodological strength of this study was the inclusion of both types of hearing instruments wearers. This allowed the authors to have a relative comparison on the effect that bilateral and unilateral amplification have on acclimatization. However, the wide discrepancy in the hearing instrument experience between the two groups (unilateral=6.3 years, bilateral=12.4 years) introduced a confounding variable, as the amount of acclimatization may be dependent on the duration of amplification to which an individual has received. While the authors did have a control group, they were not matched in terms of their hearing thresholds. As the control group had not yet experience any amount of auditory deprivation the impact amplification had on the cortically evoked responses, in a system experiencing some level of auditory deprivation, could not be properly determined. Another confounding variable was the large difference in mean age between those in the unilateral and bilateral hearing instrument groups. The literature is inconsistent on the impact aging has on cortically evoked responses (Ceponiene et at., 2008).

The main finding of this study was the increase in P2 amplitude in the unilateral group only. As most studies in the literature tend to focus on the N1 or the composite N1-P2 amplitude, there is little known about the significance of P2. The authors speculated that P2 reflects a preattentive alerting system, and those in the unilateral hearing instrument group direct more resources to listening than their bilaterally fitted counterparts. However, this may not be a direct reflection of the impact of amplification, but a consequence of how the unilaterally fitted individuals adapted to their listening situation.

As it is not fully clear that the increase in P2 amplitude for those in the unilateral hearing instrument group is the direct result of amplification, the evidence for acclimatization using cortically evoked potentials is suggestive.

Two of the three studies reviewed in this critical appraisal measured acclimatization to hearing instruments using the auditory brainstem response (ABR). Overall, Philibert et al. found improved latency morphology of the ABR on the right side only, concluding that the right ear was more sensitive to amplification compared to the left. While Munro et al. and colleagues found an increase in the peak-to-peak amplitude of wave V to SN10 in the ear receiving amplification. However, Munro did not specify which ear (left or right) was the one fitted with the hearing instrument. This makes comparing with Philibert et al., difficult, as we do not how many of the fitted ears were on the right ear compared to the left. As Munro and his colleagues did not specify which ears were fitted, we cannot rule out the right ear advantage as a confounding variable in their study.

Philibert found a significant improvement in wave V latency, while Munro found an increase in wave V to SN10 peak-peak amplitude may be attributed to the different recording parameters the two studies used. Future studies should strive to keep recording parameters as uniform as possible. Different electrode montages, click rates, and intensity levels all can impact the morphology of the ABR waveform. Minimizing the differences in recording parameters between studies can reduce related confounding factors.

The stimulus used to evoke the ABR was a click for both studies. As the click is a predominately high frequency stimulus, the corresponding ABR activity stems from the more basal regions of the cochlea. Employing a tone burst would provide additional information about acclimatization towards the apical end of the cochlea. This would allow the authors to use multiple frequencies and compare the relative effect that different amounts of gain across frequency, provided by the hearing instrument, has on acclimatization.

Bertoli et al. measured cortically evoked potentials to follow acclimatization in a group of experienced hearing instrument users. As this is the only study in the literature that assessed unaided cortical responses to measure acclimatization, comparisons across studies measuring a similar auditory evoked response cannot be made. A methodological limitation of the study was the electrode montage the authors used to measure the P1-N1-P2 response. The Fz, Cz, Pz setup used in this study is recommended when measuring a mismatched negativity paradigm (Roeser, Valente, & Hosford-Dunn, 2007). Future studies need to be aware of the paradigm they employ when obtaining the P1-N1-P2 response. Different paradigms can produce different waveform morphology, which may introduce a confounding variable in the results obtained.

Comparisons between the study performed by Bertoli and the Philibert and Munro studies cannot be made as late auditory evoked potentials reflected a different part of the auditory pathway than the ABR. The ABR measures the synchrony from the peripheral portion of the auditory nerve up to the lateral lemniscus/inferior colliculus within in the brainstem. Late auditory evoked potentials reflect activity up to the level of the secondary auditory cortices. An advantage of recording cortically evoked responses is that more complex stimuli, such as speech, can be used. This may provide a closer approximation to objective real-world hearing instrument benefit compared with using pure-tone stimuli.

Conclusions and Future Directions

All of the studies reviewed in this critical appraisal show some type of statistically significant amplification-induced acclimatization effect, when electrophysiological measures were used. This indicates that older individuals within these studies, who had long-standing hearing impairment, have some amount of plasticity within their auditory nervous system. While current research suggests auditory system acclimatization with the introduction of hearing instruments through electrophysiological measures, further research is needed before implementation into a clinical setting can be achieved. When understanding how acclimatization occurs, factors such as hearing instrument experience, age, severity and configuration of hearing loss, and the recording parameters used all play a role in waveform morphology and need to be accounted for when interpreting any future results. More longitudinal prospective studies need to be performed as they give insight into the course of acclimatization from the initial hearing instrument fitting. This may be helpful from a clinical standpoint in determining an appropriate time frame for how long trial periods should be, when fitting first time hearing instrument users in the future. Studies should employ well established stimulus parameters for the appropriate auditory evoked potential being measured. The goal of these studies should not only be to identify if acclimatization is occurring, but where in the auditory system it occurs to provide a better understanding how the brain is adapting to the newly amplified sound. Future research will also need to look at how the magnitude of plasticity within the auditory system changes with age. Determining if there is a point at which acclimatization is minimal, with the introduction amplification, may provide clinicians with a directive on when to pursue hearing instruments in a time frame where objective benefit is still present for the patient.

Clinical Implications

Based on the suggestive evidence in this review, clinical practice procedures should not be modified at this time to include the use of electrophysiological measures in the monitoring for acclimatization with the introduction of amplification. A foundational knowledge base that includes large scale prospective clinical studies needs to be developed before implementation of electrophysiological monitoring of hearing instrument acclimatization can be effectively utilized.

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