Comparison of Manufacturer Predicted and Measured REAR Values in Hearing Aid Fitting

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ABSTRACT

According to Audiology best practice guidelines, probe microphone verification measures should be performed to ensure that hearing aid gain and output characteristics meet prescribed targets for the individual hearing aid recipient. Past research has shown that the prescribed gain from a validated prescriptive method should be verified using a probe microphone approach that is referenced to ear canal SPL. However, majority of the hearing aid providers do not routinely conduct real-ear verification measures. The reasons most often cited for not performing probe microphone measures are based on financial, time, or space constraints. On the other hand, the manufacturer's "initial fit" approach requires no additional equipment, space, or time.

Past research has also demonstrated close relationship between optimal fitting of hearing aids and subjective outcomes. The current document provides a literature search on comparison of manufacturer's first fit and the fitting based on prescribed targets. We were also interested in examining if hearing aid fitting procedure has an effect on self-perceived benefit.

INTRODUCTION

Fitting of hearing aid is the process of setting hearing aid parameters to provide the maximum benefit to the patient. The process involves measurement of hearing aid recipients' pure tone hearing thresholds at standard frequencies, usually from 250 Hz to 8 kHz in octave steps. After taking the audiogram, the audiologist may take additional measurements, such as MCLs (most comfortable levels) or UCLs (uncomfortable levels, the sound pressure level at which discomfort first occurs as a function of frequency). Speech audiometry at various presentation levels is also performed. Once hearing aid prescription is made, audiologist then takes an impression of the concha and the outer portion of the canal for the ear being fitted.

In the past, hearing aids were not necessarily fitted based on the prescriptive procedures due to technological limitations. However, with development of Behind-The-Ear (BTE), In-The-Ear (ITE) hearing aids, and in the canal hearing aids, it became essential to perform fittings based on prescriptive techniques. The main aims of prescriptive approaches are i) to provide an appropriate gain to achieve normal hearing, ii) to present an average speech spectrum at a comfortable level to the ear, iii) to provide the maximum dynamic range, iv) to provide signals to restore equal loudness function, v) to provide aided speech signals at MCL in the speech frequencies, vi) to provide gain based on the size and shape of the dynamic range, and vii) to provide gain based upon the discomfort level (McCandless G., 1988). The approaches are available for linear instruments as well as for nonlinear hearing aids. These include National Acoustics Laboratory Nonlinear fitting procedures version 1 and 2 (NAL-NL1, NAL-NL2; Byrne et al., 2001;Keidser et al., 2011) or the Desired Sensation Level input/output formulas (DSL [I/O], DSL 5.0; Cornelisse et al., 1995; Scollie, 2005).

In recent years, hearing aid technology has advanced considerably fast. The parameters that have been introduced for some of the latest hearing aids are not prescribed by any of the generic prescription procedures discussed above. Hearing aid manufacturers, therefore, have introduced their own proprietary fitting algorithms (e.g., Oticon, Phonak, GN ReSound, and Widex) for the optimal fitting of their devices. These algorithms have been developed based on the research done by the respective manufacturers. On the other hand some manufacturers (e.g., Bernafon, Siemens, and Unitron); still recommend using established prescription procedures such as NALNL2 and DSL I/O for fitting of their devices.

Linear Prescriptive Procedures

NAL-R formula

Byrne and Tonnisson (1976) described the National Acoustics Laboratory (NAL) formula and was later revised as NAL-R by Byrne and Dillon (1986). The formula prescribes gain as a function of frequency having a slope of 0.31 times the audiogram slope, with frequency-specific offsets designed to maximize speech intelligibility. Although the calculation for the threshold is a third slope, the NAL-R procedure requires a calculation of the three frequency average, i.e., pure tone average.

NAL-R formula

Insertion Gain (IG) = X + 0.31 * HT + C

where, X= 0.15*PTA

Pure Tone Average (PTA) = (HT500+ HT1k+HT2k)/3

HT is the threshold of hearing for the respective frequencies C is the correction factor. It is different for each octave frequency as shown in table 1. HT500, HT1k, HT2k are measured hearing thresholds at 500Hz, 1 KHz and 2 KHz respectively.

NAL-RP (Revised. Profound) formula

The NAL-R formula is better suited for subjects with mild or moderate hearing loss; however, for people with steeply sloping losses in the high frequency region, it did not provide equal loudness. According to Byrne et al. (1991), people with severe to profound hearing losses require additional gain and less high frequency emphasis.

NAP-RP Modification 1 provides increase in the required gain. In cases where the PTA exceeds 60dB, it provides a gain of 66% instead of 46% of the hearing loss (Hawkins D., 1992). The additional low frequency emphasis is required to maximize the speech intelligibility based on the hearing threshold at 2 KHz.

NAL-RP modification 2 increases the gain in the low, and reduces the gain in the high frequencies, if the degree of hearing loss at 2000 Hz exceeds 90 dB. This adjustment is beneficial for a people with severe hearing impairment. More low frequency gain provides power and less high frequency gain helps dealing with feedback issues.

NAL –RP formula

Insertion Gain (IG) = X + 0.31 * Ht + A (2)

where X = 0.15*PTA for PTA < 60

X = 0.15*PTA + 0.2 (PTA-60) for PTA > 60

Non-Linear prescriptive procedures

Byrne (1990) summarizes four rationales on why non-linear gain or dynamic range compression is applied:

1- Noise reduction — Low frequency components dominate much noise. Simple noise reduction systems take advantage of this by cutting low frequency gain as overall signal level increases. A reduction in low-frequency amplification reduces the noise but also the low-frequency components of speech. A system in which compression affects mainly the low frequencies, an earlier example is the MultiFocus hearing aid (Brunved, 1994). This is a two-band hearing aid with wide range (low-level) compression in the low-frequency band only.

2- Improving audibility — a quiet but desired sound, such as a soft voice, is often below hearing-impaired thresholds. Dynamic range compression can amplify such a sound, making it audible to the hearing-impaired listener, while not making normal to loud sounds uncomfortably loud.

3- Loudness normalization (recruitment compensation) — Sensorineural hearing impairments lead to elevations in threshold, but is often associated with decreased threshold to discomfort from sound. Thus, the perceived loudness increases more rapidly with sound pressure level than for a subject with normal hearing. This is referred to as loudness recruitment. Compression may compensate for loudness recruitment by providing the hearing-impaired subject with the same loudness perceived by an unimpaired subject (Dillon, 1999).

Pluvinage (1989) recommended measuring loudness growth with 1/2-octave bands of

noise to select compression features to help restore normal loudness. Practically, this involved selecting hearing aid crossover frequency for a two-band compression system and prescribing the gain for 50 dB SPL and 80 dB SPL inputs for each band (Johnson et al., 1989). In cases with sloping high-frequency losses, greater compression is provided in the high frequencies than in the low band to restore normal loudness.

4- Automatic volume control— compression can be used to reduce the need for volume adjustments by the hearing aid user making the aid usability of the hearing aid easier and more comfortable. Dillon (1996) suggested that the compression reduces the long-term level variations of speech and thereby tends to maintain audibility for soft speech, together with comfort for loud sounds, without much need for volume control adjustments.

Non-linear prescriptive procedures involve calculating gains in consideration with the gain-frequency response of various input levels.

NAL-NL1

For years, the National Acoustics Laboratory's NAL-NL1 has been the benchmark for compressive, independently derived, prescriptive formulas (Dillon, 1999).NAL- NL1 tries to equalize loudness, rather than normalising it across speech frequencies. According to Dillon, et al. (1998), if all of the frequencies of speech are amplified so that they are heard equally loud, speech intelligibility is maximized. It is a threshold-based prescription that prescribes the gain-frequency responses for different input levels, or the compression ratios at different frequencies, in wide dynamic range compression hearing aids.

The primary goal of this prescription is to maximise speech intelligibility while not exceeding overall normal loudness at a range of input levels and the use of predictive models for speech intelligibility and loudness (Moore & Glasberg, 2004). The procedure includes specific considerations of NAL-RP, regarding amplification for those with severe-to-profound hearing loss. The NAL-NL1 fitting method provides insertion gain targets for 65 dB SPL inputs that are very similar to those given by NAL-RP.

To calculate NAL-NL1 gain targets, gain calculations were performed for 52 audiograms, for input levels from 30 to 90 dB SPL, in 10 dB increments. These audiograms represented all of the common variations in severity and configuration of hearing loss. For each input/audiogram combination, the program manipulated the gains in each 1/3-octave band until the speech intelligibility index was maximized. The loudness was restricted to be normal or to a lower loudness level if that achieved a higher speech intelligibility index. Three types of output were produced for each audiogram and input level.

A complex equation specifies the gain at each standard 1/3-octave frequency from125Hz to 8000Hz. The gain at each frequency depends on the threshold at that frequency, the PTA value, slope of the audiogram from 500Hz to 2 KHz, and the overall level of the broad band signal with long term speech spectrum. The gain at each frequency was systematically varied for various input levels, until the calculated speech intelligibility was maximized while maintaining the loudness level. For multi-channel hearing aids, the procedure recommends cross over frequencies, compression thresholds, compression ratios,

and gains for 50, 65 and 80 dB SPL input levels.

The evaluation of the NAL-NL1 showed that the prescribed overall gain was slightly too high for adults, particularly, for higher input levels, and slightly too low for lower input levels for children (Raj Kumar, et al., 2013).

NAL-NL2 Procedure

More recently, the NAL-NL2 hearing aid prescription has been developed. Extensive studies conducted by National Acoustic Laboratories indicated that different populations preferred different gain settings relative to that provided by NAL-NL1 (Keidser et al., 2012). A number of changes were implemented in NAL-NL2 to address this finding which included 3 dB less overall gain at the input level of 65 dB SPL for adults with a mild or moderate hearing loss, a 2 dB increase in the overall gain prescribed for children and in-built gain corrections for gender, aid configuration and prior experience with amplification. Adjustments were also made to compression ratios and compressor speeds for those with severe to profound hearing loss. With such changes, it is important to assess the applicability of the revised prescription to the bimodal population.

The developers of the NAL-NL2 formula determined that adults with mild to moderate hearing loss preferred less overall gain for 65dB inputs than would be prescribed by NAL-NL1 (Keidser et al., 2008). This is corroborated by other studies (Smeds et al., 2006; Zakis et al., 2007) in which hearing aid users with mild to moderate hearing loss preferred less gain for high and low level inputs. These reports indicate that participants generally preferred slightly less gain and higher compression ratios than those prescribed by NAL-NL1, a preference that was incorporated into the revised prescriptive procedure.

The optimization technique used in the NAL-NL2 procedure, as illustrated by Raj Kumar et al., (2012) one loop uses an intelligibility model to find the gain-frequency response to maximize speech intelligibility and the second loop uses a loudness model to calculate the perceived loudness by the hearing-impaired person. To achieve the optimal gain-frequency responses for 240 audiograms, covering a wide range of severity and slopes, each at seven speech input levels from 40 to 100 dB SPL an adaptive process was used.

Desired Sensation Level Input / Output (DSL/O) Procedure

The objective of this method is to achieve the desired sensation level of the amplified signal for multiple level inputs. DSL [I/O] can also be used as an effective method of achieving Loudness Equalization. Basically the DSL I/O prescription aims to fit the long-term average speech spectrum into the hearing-impaired user's dynamic range. This is done to ensure that the hearing aid will not amplify sounds so that they are uncomfortable for the user. Obtaining a desired sensation level for multiple level inputs is the main goal of this procedure. It provides maximum audibility while maintaining comfortable loudness across all input levels, by providing the user with an audible and comfortable signal in each frequency region. The procedure provides frequency-specific output targets for multiple input signal levels, based upon speech, not on tones.

Device-independent enhancement of the original DSL Method has provided

prescriptive targets for the fitting of wide-dynamic-range compression hearing aids. It applies loudness data and a curvilinear fit to map a wide range of input levels to target hearing instrument output levels across frequencies. It has been used in DSL software systems and in most hearing instrument and real-ear system manufacturers software implementations.

The input dynamic range is divided into three regions: 1) input levels below a compression threshold, or Imin; 2) input levels that will exceed the compression threshold when amplified, or Imax; and, 3) the area between these two limits. Comelisse et al. describe the DSL I/O prescription as a series of mathematical equations.

Proprietary fitting algorithms

Even though the probe-microphone technology has been available for more than 20 years, many audiologists do not verify their hearing aid fittings with these measures. It has been reported that less than half of audiologists routinely perform probe-microphone measurements (Kirkwood, 2006; Mueller and Picou, 2010). The reasons of not including them to verify hearing aids include lack of resources; space for the equipment; time to perform the measurements; and, confidence that verification using probe-microphone measurements will result in better outcomes as compared to the manufacturer's "initial fit" approach which does not require time or resources.

The real ear measurements are used to adjust the gain of the hearing aid until the measured hearing aid response matches the prescribed response. On the other hand, the initial-fit approach by different manufacturers usually involves an "approximation" of in situ hearing aid gain and output based on data such as the age of the patient, the earmold or shell type, venting size, and tubing characteristics. In other words, manufacturers' proprietary softwares used to program hearing aids provide estimations of real-ear hearing aid responses associated with a fitting algorithm.

Many hearing practitioners tend to believe that software simulations indicate the values that are directly reflective of a particular hearing instrument being programmed and the particular patient getting fitted. It is possible that for some patients, the simulations may be beneficial or work out quite well, but for others they may be significantly different from the required gain, particularly in high frequencies where important speech information is present.

Although manufacturers commonly explain the basic rationale behind the proprietary algorithms, there is still lack of clarity on the fitting targets, how they vary with hearing loss, and how they compare with the generic fitting prescriptions or the prescriptions by other manufacturers.

OBJECTIVES

Search Strategy

A review of literature was conducted using methods that followed the guidelines provided by Cox (2005). The initial electronic databases searched included PubMed and MEDLINE. The following key words were entered into the search fields: "hearing aid fitting", "hearing aids," "prescriptive," "fitting," "formula," "gain". Finally, a further electronic search of Google scholar, Web of Science (ISI), SCOPUS – V.4 (Elsevier) databases and the reference

lists of the relevant manuscripts were examined for articles that did not appear in prior searches. All searches were conducted during August and September, 2017.

Results and discussion

A total of nineteen articles were identified for detailed analysis and inclusion in this review. All articles were published between 2003 and 2017.The manuscript provides a review of literature on comparison of generic and proprietary fitting algorithms for their gains and subjective outcomes.

Comparison of manufacturer predicted and measured REAR values

Hawkins and Cook (2003) investigated the accuracy of hearing aid fittings predicted by the manufacturer's software, using 12 subjects. They tested hearing aids from several different major manufacturers as well as different styles of hearing aids. The results of the difference between the measured and simulated insertion gain values across frequencies for 12 patients tested in their study showed that at 4000 Hz, six of the 12 patients showed measured insertion gains that were >10dB less than the simulated values. At 3000 Hz and 4000 Hz, none of the patients' actual insertion gain exceeded the simulated insertion gain. Their results revealed that the fitting software overestimated actual real-ear gains, particularly at higher frequencies. Authors concluded that the audiologists should not expect the amount of high-frequency insertion gain that the simulations suggest. They suggested that the data reported in this study indicate that the simulated gain values from hearing aid fitting software should be used only as a starting point.

Another study by Bentler (2004) compared the measured $2cm^3$ coupler response from six different behind-the-ear hearing aids using speech input (65 dB SPL RMS). Each of the six hearings were programmed for the same hearing loss and with six different manufacturers' initial-fit algorithms. The measured responses from $2cm^3$ coupler were different for different manufacturers fitting algorithm and also differed from the generic NAL-NL1 prescription by as much as 15 dB from 1500 to 3000 kHz. The majority of the responses fell below the NAL-NL1 prescribed target.

Aarts and Caffee (2005) compared initial-fit approach of a hearing aid manufacturer's predicted real-ear aided responses, to the measured real-ear aided responses for a nine channel digital hearing aid, using seventy nine ears. Two different hearing loss configurations were evaluated- a flat mild loss and a sloping mild to moderately severe loss. The 50 and 90 dB SPL FFT speech-weighted stimuli used during real-ear measures were the same as those selected in the manufacturer's software when the predicted real-ear aided response values were provided. They found that the ability of the hearing aid fitting software to predict real-ear aided response values was poor. A criteria of 4 dB or more different from predicted at four or more frequencies was used. In all conditions, the measured values were significantly different from the predicted values. The results also suggested that differences between the predicted and measured responses were greater among males than females.

The authors concluded the use of average real-ear unaided gain (REUG) in the hearing aid fitting software is the attributing factor to the discrepancy between predicted and

measured real-ear aided response values. The real-ear unaided gain refers to the amount of open ear amplification resulting from the resonances of the concha and ear canal in the frequency range 0.25–4 kHz. The real-ear unaided gain varies significantly across individual ears, especially in terms of the location and magnitude of the primary resonance peak (Weiner and Ross, 1946).

Bretz (2006) compared three manufacturers' recommended paediatric first-fit approaches with the NALNL1 and DSL ([I/O]) prescription targets. Three different hearing aids were programmed using the same audiometric shape for five different degrees of hearing loss. Coupler measurements (2 cm3) were made to assess the output of each hearing aid at four different input levels (55, 60, 70, and 75 dB SPL). The average output of the hearing aids programmed via the initial-fit approach varied by about 20 dB across manufacturers. In addition, the manufacturers' initial-fit gain values tended to be below both the NAL-NL1 and DSL [I/O] prescribed targets.

The studies described above only assessed the discrepancy between gains predicted by the manufacturers' software and gains actually measured. They did not assess the extent to which fitting could be made more accurate by adjustment of the hearing aids. Also, they did not explore the influence of several factors that might affect the deviation from the target values. The studies discussed below assessed how the hearing aid parameters may have an effect on discrepancy in gains between generic and simulated gains.

Aazh and Moore (2007) examined whether routine real ear insertion gain (REIG) measurement is necessary in fitting digital hearing aids; and the extent to which modifying the frequency-gain response of an aid can lead to better matches to the target in cases where the target gain was not initially achieved. The differences between predicted and measured real-ear insertion gain were recorded among patients receiving a variety of digital hearing instruments. The target formula was selected as NAL-NL1 in the programming software of four types of digital hearing aids. When the manufacturer's initial-fit approach was compared to the measured response, only 36% of the forty two ears tested were found to be within ±10 dB of the NAL-NL1target at one or more frequencies between 0.25 and 4 kHz. After modifying the frequency-gain response of the aids, 17% (seven aids) still did not meet the target. It was also observed that the chance of meeting the prescription target was higher for hearing aids with more adjustable "handles"(more channels).Two of the aids that failed to meet the target were open fit hearing aids and it was not possible to increase the gain at the failed frequency of 3 kHz due to the risk of feedback. Similar to Hawkins et al. (2003) study, the proportion of mismatches and the magnitudes of the mismatches were both greatest at 3 and 4 kHz.

Kumar et al. (2017) compared hearing aids manufactures recommended first fitting methods to two generic prescriptive methods (NAL-NL1 and DSL I/O) for three digital programmable multichannel hearing aid fittings. Gradually sloping type, rising type and flat type audiogram configuration in terms of mild, moderate and moderately severe hearing loss were assessed. Three different hearing aids were assessed-4channel, 8 channel and 12 channel. Significant differences in electroacoustic parameters were observed in 4 channel, 8 channel, 12 channel digital programmable

hearing aids when using "first fit" formula, NAL-NL1 and DSL (I/O) with gradually sloping type, rising type and flat type audiogram configuration in mild to moderately severe hearing loss. The authors suggested high variability in manufacturer recommended "first fits". The large differences seen between manufacturers' hearing aid fittings also suggested that the audiologists must verify their hearing aid fittings. This is especially important for young paediatric patients who cannot give accurate reports on how well they are hearing and little information can be obtained through validation procedures (i.e. speech perception testing).

According to Dillon and Keidser (2003), first fit approach by hearing aid software may not adequately adjust the hearing aid to achieve a target if the average real ear unaided gain (REUG), microphone location effect, and vent and tubing effects incorporated in the hearing aid software are different from the individual values In addition to that unusual shapes or sizes of ear canals may result in especially large discrepancies between the target and measured real ear insertion gain values (Sanborn, 1998).

For open-fit hearing aids, sound is delivered to the ear canal via a thin tube or a receiver in the ear canal attached to an open dome. For open fits, the ear canal is left open, so the sound delivered by the hearing aid can leak out of the ear canal, which in turn can reduce the amount of gain or real ear insertion gain compared to the standard mould fitting, particularly at low frequencies (Dillon, 2001). If this effect is not taken into consideration, by the manufacturers' software, it can lead to differences between the programmed and achieved real ear insertion gain, leading to errors in the first fit. It can mainly affect the low frequencies. This has led some manufacturers to state that, for open fittings, the real ear insertion gain may be approximately 10 dB below the NAL–NL1target for frequencies up to 1.25 kHz (Oticon Ltd., 2010).

Aazh and Moore (2012) assessed the extent to which target real ear insertion gains were achieved for a specific model of open fit hearing aid by use of the manufacturer's first-fit program and following adjustment based on real ear measurements. It was observed that 71% of the initial fittings were not within±10 dB of the NAL–NL1 target real ear insertion gain at one or more frequencies between 0.25 and 4 kHz. Differences of as large as 22dB in real ear insertion gains were noticed between the first-fit and the target real ear insertion gains. Authors suggested that the hearing aid fittings based solely on the manufacturer's programming software may be inadequate, at least for the model of hearing aid they tested in their research.

Comparison of subjective outcomes- initial fit vs fitting based on real ear measuring

While it is evident from the above studies that the manufacturer's initial-fit approach fails to approximate the prescribed response as verified with a probe microphone, however, the question is does it matter? In other words, whether these differences in frequency response influence subjective outcomes of hearing aid benefit.

Byrne (1992) asked participants to judge the intelligibility and pleasantness of sound as processed through hearing aids in which the frequency response was systematically varied; in other words, how much variation in frequency response was required for it to be judged differently in terms of sound

quality for a hearing aid user. The results indicated that root mean square (RMS) differences of as little as 3–4 dB were judged to be significantly different more often than not.

Nerbonne et al. (1995) evaluated 51 adults and older adults fitted with linear amplification using the NAL-R prescription formula, to evaluate relationship between hearing aid benefit and the real ear data. Following four months post fitting, self-report of hearing aid benefit as measured through the Hearing Handicap Inventory for the Elderly (HHIE; Ventry and Weinstein, 1982) or the Hearing Handicap Inventory for Adults (HHIA; Newman et al., 1990). The amount of "fitting error" or deviation in real ear insertion gain (REIG) relative to NAL-R target values was computed. The authors reported that in majority of the cases, fitting errors resulted in less gain than prescribed by the NAL-Rformula. There was no significant correlation between real ear insertion gain fitting error values and scores on the Hearing Handicap Inventory for the Elderly or Hearing Handicap Inventory for the Adults. Similar results were reported by Weinstein et al. (1995).

On the other hand, a study by Polonenko et al. (2010) reported that DSL v5.0a targets could be closely approximated across frequency with commercial hearing aids, and that the fittings approximated closely to preferred listening levels (PLLs) of adults who wear hearing aids. The PLL was measured while participants listened to running speech at an overall level of 60 dBA in the sound field. After performing PLL procedure, the subjective ratings The Client Oriented Scale of Improvement (COSI; Dillon et al., 1997) was evaluated, where each situation previously identified at the initial visit by the participant was read and the participant was asked (1) if his/her hearing function had changed in each situation, and (2) to rate his/her final hearing ability in each situation with their hearing aids. The 95% confidence interval for closeness of fit to the DSL v5.0a prescriptive targeting this study ranged from 5.8 to 8.4 dB across the frequency range as verified by probe-microphone measures.

A study by Kochkin et al. (2010, 2011) evaluated use of verification and validation for 788 subjects fit with hearing aids between 2008 and early 2009. The authors reported that if the hearing aid recipients are fitted with a comprehensive fitting protocol, which includes real ear verification had greater levels of real-world success compared to those fitted with a protocol that did not include probe microphone verification. The success was defined by recipient's hearing aid usage, benefit and satisfaction. They also reported that the utilization of verification and validation during the hearing aid fitting process was shown to significantly reduce patient visits.

Given that the initial-fit approach often results in differences from the prescribed target, that even small differences from the prescribed target can have perceptual consequences, and that previous research is equivocal concerning the relationship between closeness of fit and subjective outcomes, we were interested in examining whether self-perceived benefit would differ as a function of the hearing aid fitting procedure utilized; specifically manufacturer's initial-fit approach versus a verified prescription. A study by Abrams et al. (2012) assessed specific research question of whether self-perception of hearing aid benefit, as measured through the

Abbreviated Profile of Hearing Aid Benefit (APHAB; Cox and Alexander, 1995), would differ as a function of hearing aid fitting procedure.. The comparison was made between manufacturer's initial-fit approach versus a verified prescription. As part of a counterbalanced, cross-over, repeated-measures study design, half of the participants were fit with new hearing aids via the manufacturer's initial fit while the second half were fit to a verified prescription using probe-microphone measurement during the first visit. After 4–6 week period, the participants' hearing aids were refit via the alternate method and an additional 4–6 week period of take home experience was provided. The APHAB was administered at baseline and at the end of each intervention. The mean scores obtained with the verified prescription were higher than those obtained with the initial-fit approach for the APHAB subscales of Ease of Communication, Reverberation, and Background Noise. The mean score for Aversiveness subscale in APHAB was also better (i.e., lower) for the verified prescription but was not statistically significant. Seven of the twenty two participants preferred initial-fit based settings and fifteen preferred verified prescription based setting for their hearing aid.

A study by Van Vliet (2006), stated that using a manufacturer's representation of the real-ear or 2cc coupler output is not much better than guesswork. He also commented that neglecting the use of probe microphone measures to verify the true hearing aid fitting is not a responsible behaviour as a hearing professional. He attributed the differences between measured and simulated results as anatomic differences, equipment calibration differences, different assumptions, and other factors. He also suggested that the audibility, which is the paramount goal of amplification, need to be verified by direct measurement. He stated that relying on subjective comments, clinical experience, or derived representations for a hearing aid fitting is not an acceptable standard of care.

Beck (2010) reviewed a total of 40 patients at one year post fitting. Of those, sixteen patients attended an additional follow-up appointment, and of those, six were fitted using real ear measures, 10 were fitted without real ear measures. The study results found a significant difference in the insertion gain between those fitted with real ear measures and those not fitted with real ear measures. Specifically, people fitted with real ear measures had more gain at 3 kHz and 4 kHz. In addition to that, patients fitted without real ear measures were indeed "under-fit" with respect to target gain at the same frequencies. The author reported that the Glasgow Hearing Aid Benefit Profile (GHABP, Gatehouse, 1999) showed people not fitted using real ear measures had a significantly greater decline of 18%, in their satisfaction ratings one year later. That was significantly different from the satisfaction ratings of the people fitted with real ear measures.

Another benefit of performing real ear measures is the improvement in amount of patient satisfaction. Kochkin et al. (2010), suggested that by using probe microphone verification measurements there was a reduction inpatient complaints, which led to reduced repeat appointments and return-for-credit aids. This was attributed to the patient's access to an audible signal. The authors commented that completing real-ear measurements can be seen as an opportunity to improve patient care and provider satisfaction.

Mueller (2005) suggested that manufacturers' fittings procedures are often quite different from the validated methods in terms of gains and outputs. The simulated real-ear gain differs significantly from what is present in the real ear. Therefore, if a dispenser is concerned about aided audibility, speech intelligibility, and listening comfort, there is no alternative to probe-microphone measures.

Comparison of Prescriptions over Time

To facilitate a comparison of generic and proprietary gain prescriptions over time (1998, 2008, and 2013), Smeds et al. (2015) calculated the average gain in 1/3-octave bands around 0.5, 1, 2, and 4 kHz for various modern hearing aids of the type classified as top-end products. The gain comparisons were made with NAL and DSL prescriptions. The study reported that from 1998 to 2013, the median gain at 2 and 4 kHz has not changed; however, the spread in the gain data has reduced. The largest change over time is observed for 1 kHz, with a significant reduction in the 2013 measurements. The prescribed gain for the proprietary methods when the hearing aids were programmed for an inexperienced hearing aid user are shown as white boxes. As shown in the figure, the median gain was reduced 5-6 dB both in the 2008 and the 2013 for this setting for all frequencies except a smaller reduction for 500 Hz.

DSL v4 prescribes higher gain values than DSL v5. Similarly, NAl-NL2 provides reduction in gain compared to NAL-NL1, particularly at 1 and 2 kHz but provides a higher gain at 4 kHz. The proprietary prescriptions' gain at 4 kHz is quite similar to the higher gain prescribed by NAL-NL2.

With the changes in the NAL and DSL prescriptions (for the audiogram and input levels used in the comparisons made by Smeds et al. (2005), NAL-NL2 and DSL v5 today prescribe very similar gain at 1, 2 and 4 kHz, whereas DSL v5 prescribes higher gain than NAL-NL2 at 500 Hz.

CONCLUSIONS

Hearing aid prescriptions are either generic, such as the NAL and DSL procedures, or proprietary and specific to a hearing aid manufacturer. The generic prescriptions are often based on an explicit research (empirical findings) and theory. The research on generic fitting procedures is usually conducted by professionals, not the hearing aid manufacturers. The data and results of these generic procedures are generally published in scientific domain. Manufacturers' proprietary prescriptions may also include device-specific considerations in their formulations; however, these fitting algorithms are based on the research conducted by the manufacturers.

Practitioners are generally not well prepared to critically evaluate the body of research that does exist. As a result hearing aid professionals sometimes do not have an accurate appreciation of the value of providing optimal fitting to hearing aid recipients.

Real-ear measurement is an efficient way to verify hearing aid amplification and should be included in every hearing aid fitting. In addition to that validation with a standardized outcome measure will improve the confidence of the recipient as well as professional fitting the hearing device. An objective pre-post measure is preferred;

however, if it is not feasible to measure objective outcome, subjective responses with a brief questionnaire can provide valuable insight into patient satisfaction and real-world benefit.

Past research has shown that verification using real ear measurements as part of routine clinical care can reduce the number of return visits, reduce the number of aids returned for credit, and increase patient satisfaction.

The NAL-NL2 and DSL v5 (adult version) prescriptions, provide less gain than their previous versions. The previous versions of these prescriptions differed greatly in prescribed gain. DSL v4 prescribed substantially more gain than NAL-NL1. Latest research has shown that the latest version of the two prescriptions have become more similar mainly because DSL v5 prescribes substantially less gain than DSL v4 for adult hearing aid users.

It has been observed that, both generic and proprietary prescriptions have decreased their prescribed gain over time. These changes are particularly made to accommodate first-time hearing aid users. However, the amount of gain reduction for first-time hearing aid users varies among manufacturers. However, there still is lack of evidence on non-inferiority of fittings using proprietary procedures over real ear measurements based fittings based on generic prescriptions.

The research so far supports that the clinical use of a verified prescription does matter as it will likely yield better self-perceived hearing aid fitting outcomes than currently available initial-fit approaches.

Even though hearing aid technology has clearly advanced, the percentage of hearing-impaired people owning hearing aids (about 22%) has not changed since 1991 (Kochkin, 2001). The reason is partly because the scientific basis of hearing aid fitting has fallen far behind the technological development of amplification devices (Medwetsky et al., 1999). There is relatively little high-quality research to provide effectiveness guidelines for the fitting process. Therefore, there is a need to promote the ability of practitioners to use the appropriate verification and validation tools when fitting hearing devices.

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