Basic and Advanced Considerations in CROS and BiCROS Fitting: Streaming Control and Counseling

Dennis Van Vliet (Adapted from authors Jeff Crukley and Adriana Goyette)

Management of unilateral hearing loss (UHL), often referred to as Single Sided Deafness (SSD) where one ear has an unaidable hearing loss and the other ear has normal or aidable hearing, continues to challenge hearing professionals and individuals with hearing loss. For these patients, Starkey offers contralateral routing of signal (CROS) and bilateral CROS (BiCROS) solutions that are beneficial for many listening situations. In this discussion we will define CROS systems as transmitting the signal from one side of the head with a hearing loss that does not benefit from amplification over to the normal or better hearing ear. BiCROS systems will similarly transmit signal from an unaidable ear across the head to an ear that requires amplification, mixing the inputs as necessary.

We know that there are certain circumstances when activation of a CROS or BiCROS microphone and transmitter may interfere with speech, and other times when the CROS system notably improves communication. With careful counseling, programming and setup of options available in the CROS systems, users may easily enjoy the benefits that the technology offers.

This guide is offered to hearing professionals in order to: **1.** Review the rationale and candidacy for CROS and BiCROS; **2.** Consider success rates for CROS and BiCROS system fittings; **3.** Review the benefits and limitations of CROS and BiCROS systems; **4.** Explain an approach to improving our support of CROS/BiCROS users; **5.** Manually switch transmission of contralateral signals, depending on the listening conditions; **6.** Describe Starkey's CROS System for CROS and BiCROS users.

Fitting Considerations

In the U.S., the overall incidence of adults reporting hearing trouble resulting from moderate to severe unilateral hearing loss is about 1.5 percent or 1.7 million people. *(Golub, Lin, Lustig & Lalwani, 2018)*. The asymmetry between the two ears resulting from SSD poses a unique and difficult problem for hearing professionals and negatively affects a patient's quality of life. Individuals with SSD struggle with listening in noisy environments and localization of sounds *(Dillon, 2001; Ericson, Svärd, Högset, Devert, & Ekström, 1988; Olsen, Hernvig, & Nielsen, 2012; Taylor, 2010*).

In cases of SSD, the head shadow effect can significantly reduce detection of sounds arriving on the side of the poorer-hearing ear. The head shadow effect occurs when sound arriving on one side of the head is physically obstructed by the head itself as it travels to the opposite side, which causes attenuation and filtering of sounds. *(Fletcher, 1953; Shaw, Newman, & Hirsh, 1947; Taylor, 2010; Tillman, Kasten, & Horner, 1963)*. Sound attenuation caused by the head shadow effect is frequency dependent. Frequencies above 2000 Hz are attenuated by as much as 15-20 dB, while

frequencies below 1000 Hz are typically attenuated by less than 10 dB *(Taylor, 2010; Upfold, 1980)*. This frequency-dependent attenuation of sounds makes understanding speech particularly challenging for individuals with SSD when the speech signal originates from their poorer-hearing side. Valente, Valente, Enrietto, & Layton (2002) reported that individuals with SSD require up to an additional 13 dB increase in signal-to-noise ratio (SNR) to achieve speech recognition in noise performance similar to that of individuals with normal hearing.

Current Solutions

Recommendations for CROS and BiCROS systems remain a common current industry standard for assisting patients with hearing loss who have one ear that cannot benefit from amplification. Surgically implanted Bone Anchored Hearing Aids (BAHA) or Power Completely-in-the-Canal (CIC) aids that transfer sound to a normal hearing ear on the opposite side via bone conduction (Transcranial CROS) are sometimes recommended. Children identified with asymmetric hearing loss are often offered FM systems and preferential seating in classroom situations. In 2019 the FDA approved cochlear implants to be used in some cases of SSD. A cochlear implant is not a CROS but the surgical implantation of a device to provide electrical stimulation to the auditory nerve.

CROS Applications

Harford and Barry (1965) introduced the CROS system for patients with no functional hearing in one ear and normal hearing in the other ear. A CROS system consists of a single microphone and single receiver contained in two separate devices. The microphone-equipped device is fitted to the ear with no functional hearing and the receiver-equipped device is fitted to the ear with normal or near normal hearing. Sound arriving at the device on the ear with no functional hearing transmits, through a wired or wireless connection, to the device on the ear with normal hearing *(Dillon, 2001; Taylor, 2010)*. Figure 1 shows a schematic representation of a CROS system. Contralateral routing of the signal (sound) lets the patient hear sounds from their non-hearing side through their normal-hearing ear.

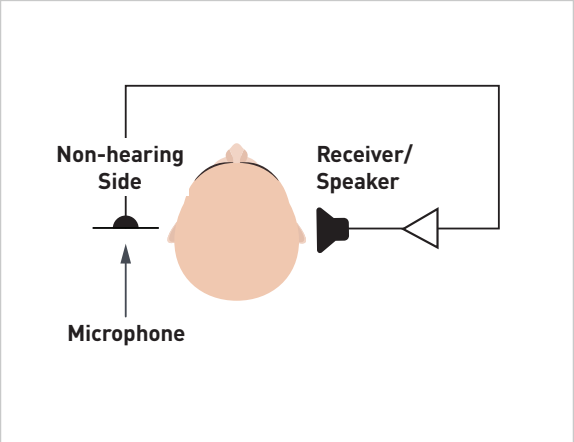

Figure 1: Schematic of CROS system.

Candidacy

CROS systems are considered when the individual has normal hearing or at worst a mild high-frequency loss in their better-hearing ear *(Dillon, 2001; Taylor, 2010)*. Proper fitting and verification of a CROS system should result in similar hearing sensitivity of sounds arriving at either ear *(Dillon, 2001)*.

An additional application of CROS systems is to increase gain — while avoiding oscillatory feedback — for individuals with aidable, steeply sloping hearing loss in one ear, and an unaidable loss in the other ear. A conventional hearing aid or BiCROS system would increase the risk of feedback due to the proximity of the hearing aid microphone and receiver because the individual requires significant high-frequency gain coupled with an open earmold. This application is sometimes referred to as a "Power CROS". The risk of feedback is reduced by separating the microphone and receiver on opposite sides of the head *(Dillon, 2001)*.

Expectations

At the most basic level, the CROS system candidate must understand that the system may help with audibility but will not restore the experience of localization that occurs with binaural hearing. It is appropriate to define successful CROS system fittings as those in which the candidate perceives benefit from their system and decides to continue using it. CROS candidates having normal or near normal hearing in their better-hearing ear and may not perceive problems in many listening conditions *(Hayes, 2006)*. For this reason, perceived need and user motivation are key aspects for success. A CROS system user must be able to recognize listening conditions in which their poorer-hearing ear gives them difficulty and in which the CROS system offers benefit. *(Hayes, 2006; Taylor, 2010)*. CROS systems tend to achieve a 50 percent success rate *(Harford & Barry, 1965; Harford & Dodds, 1966; Hayes, 2006; Taylor, 2010; Valente, Valente, & Mispagel, 2006)*. However, some claim success rates as high as 67 percent *(Hill, Avron, Digges, Gillman, & Silverstein, 2006)*.

Subjective Outcomes

Benefit provided by hearing aids can be measured objectively with speech recognition testing or subjectively with user ratings, which are typically gathered with questionnaires. Objective performance and benefit will be discussed in a later section of this paper. Here, we will discuss subjectively measured benefit from CROS systems. Individuals who are successfully identified and fit with CROS systems can experience significant benefit across multiple domains with self-report questionnaires. Questionnaires that have been used to assess user benefit from CROS systems include: The Hearing Handicap Inventory for the Elderly *(HHIE; Ventry & Weinstein, 1982)*, the Abbreviated Profile of Hearing Aid Benefit *(APHAB; Cox & Alexander, 1995)*, the Glasgow Hearing Aid Benefit Profile *(GHABP; Gatehouse, 1999)*, the International Outcome Inventory for Hearing Aids *(IOI-HA; Cox et al., 2000; Cox & Alexander, 2002; Cox, Alexander, & Beyer, 2003)*, and the Speech, Spatial, and Qualities of Hearing Scale *(SSQ; Gatehouse & Noble, 2004)*.

Hol and colleagues (2005) conducted a study to evaluate benefit from CROS systems and bone anchored hearing aids (BAHA) using the APHAB and GHABP. The APHAB results showed significant benefit from the CROS system relative to unaided performance in the domains of Ease of Communication (EC), Background Noise (BN), and Reverberation (RV). CROS system use resulted in Aversiveness (AV) subscale detriment. Relative to unaided listening, GHABP results for CROS system use showed a mean benefit of 39 percent, mean residual disability of 42 percent, and mean satisfaction of 32 percent.

Baguley and colleagues (2006) conducted a meta-analysis of CROS studies incorporating the APHAB as a measure of benefit. In each of the studies evaluated, CROS users reported more benefit with a CROS system than unaided in all four of the APHAB subscales *(EC, BN, RV, AV)*.

Hol and colleagues (2010) conducted a study to compare outcomes for a group of participants with unilateral hearing loss using a CROS system, a transcranial CROS system consisting of a unilateral CIC hearing aid, and BAHA on a headband. Participants completed Dutch versions of both the APHAB and SSQ for unaided listening and each of the aided conditions. Participants reported the most benefit from the CROS system in the EC, BN, and RV subscales of the APHAB. All aided conditions resulted in AV subscale detriment; however, CROS system use yielded the least detriment. SSQ data indicated that participants received more benefit from the CROS system than either the CIC or BAHA.

Ryu et. al. (2014) conducted a study to evaluate the clinical effectiveness of a wireless CROS system. Subjective satisfaction and benefit were measured using Korean versions of the HHIE and SSQ. All participants reported significant improvement in the emotional, situational, and total scores of the HHIE, and significant improvements in the speech, spatial, and quality subscales of the SSQ.

BiCROS Applications

A BiCROS system consists of a microphone equipped device fitted to the poorer-hearing ear and a hearing aid fitted to the better-hearing ear. Sound arriving at the device on the poorer-hearing side is transmitted, through a wired or wireless connection, to the hearing aid on the better hearing side *(Dillon, 2001; Taylor, 2010).* Figure 2 depicts a schematic representation of a BiCROS system. Traditional BiCROS systems combine the signals from both sides of the head through the single amplifier.

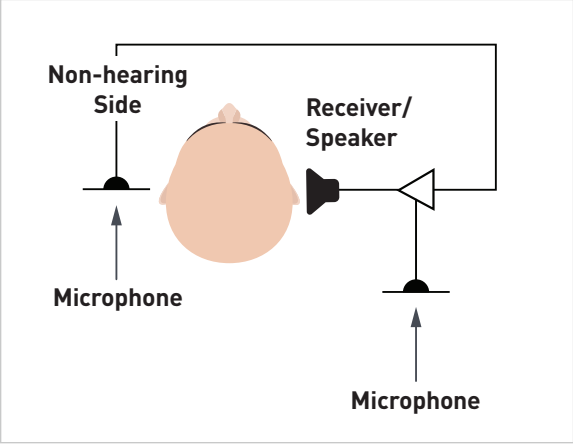

Figure 2: Schematic of BiCROS system

Candidacy

BiCROS systems serve individuals with an asymmetric bilateral hearing loss such that one ear has no functional hearing or a loss too great to benefit from amplification and the other ear is aidable. *(Dillon, 2001; Taylor, 2010).* Because BiCROS candidates have bilateral hearing loss, they are likely to perceive benefit from amplification across a broad range of listening conditions. As such, the success rate of BiCROS fittings is typically in the range of 70-80 percent *(Hill et al., 2006).* Impressively, one study of experienced BiCROS users reported a success rate of 95 percent using advanced digital systems *(Williams et al., 2012).*

Successful users of BiCROS systems report significant benefits across multiple domains as assessed by self-report measures. While motivation is an important component of a successful BiCROS fitting, achieving a good fitting with the hearing aid on the better-hearing ear is an essential first step *(Hayes, 2006)*. Perceptible improvements in audibility and awareness of sounds and clarity of speech from the user's poorer-hearing side are reasonable goals for a successful BiCROS fitting *(Hayes, 2006).*

Subjective Outcomes

As with CROS systems, benefit from BiCROS systems has been assessed with both objective and subjective measures such as the APHAB and SSQ. Williams et. al. (2012) conducted a study to compare user performance, benefits, and satisfaction with contemporary (for the time of the study) BiCROS systems versus previous-generation BiCROS systems. Participants reported significantly better performance and quality with the newer BiCROS systems than with their previous systems across all domains, subscales, and almost all individual items of the SSQ. The authors also included selected items from the MarkeTrak questionnaire *(Kochkin, 1990)* to assess participants' satisfaction with the contemporary versus their previous BiCROS systems. Study participants reported being significantly more satisfied with the contemporary BiCROS systems across all the items assessed by the MarkeTrak questionnaire.

Oeding and Valente (2013) conducted a study to examine real-world subjective benefit from a BiCROS system with the APHAB.

Participants completed the APHAB for unaided listening and then again after four weeks using a BiCROS system. Mean APHAB data indicated study participants perceived significant benefit from the BiCROS system across the EC, BN, and RV domains of the APHAB.

CROS and BiCROS systems have evolved and improved over the last several decades. We know that listeners prefer and hear better when using modern CROS and BiCROS systems relative to systems based on previous generation technology *(Hill et al., 2006; Williams et al., 2012)*. We also know that in many situations users benefit from and prefer listening with CROS/ BiCROS systems more than with unilateral or unaided listening *(Hill et al., 2006; Hol, Kunst, Snik, & Cremers 2010; Kuk, Korhonen, Crose, & Lau, 2014; Lin et al., 2006; Ryu et al., 2014)*. However, a number of listening complications such as the inability to restore true binaural function and directionality, intolerance of additional gain that may be necessary, and distortion in the better ear continue to trouble CROS/BiCROS users *(Hol, Bosman, Snik, Mylanus, & Cremers, 2005; Hol et al., 2010; Kuk et al., 2014; Lin et al., 2006; Ryu et al., 2014)*.

Objective benefit from CROS/BiCROS systems

In addition to assessing user benefit through subjective self-report measures as discussed previously, benefit from CROS and BiCROS systems can also be assessed using objective performance measures. Objective performance measures typically measure speech recognition in the presence of competing noise. Speech recognition in noise is often reported as the SNR required for 50 percent performance as with the Hearing in Noise Test *(HINT; Nilsson, Soli, & Sullivan, 1994)* or 50 percent correct word recognition performance as in the Words in Noise test *(WIN; Wilson, 2003)*. Alternatively, the SNR and presentation levels of the target and competing stimuli may be held constant in order to determine differences in percent correct word recognition performance as reported in the studies by Kuk and colleagues (2014; 2015).

CROS system performance

In this section, we will discuss benefits and detriments of CROS and BiCROS systems across a number of different experimental objective speech recognition conditions. Both CROS and BiCROS systems will be discussed together in this section because the listening conditions discussed have similar effects on objective performance for users with both types of systems.

CROS/BiCROS systems offer the largest amount of benefit, relative to unilateral fittings, when speech is presented on a user's poorer-hearing (transmitting) side *(Figure 3)*. The head shadow effect is eliminated by transmitting the speech signal directly to the better hearing ear and thus this system may improve the SNR.

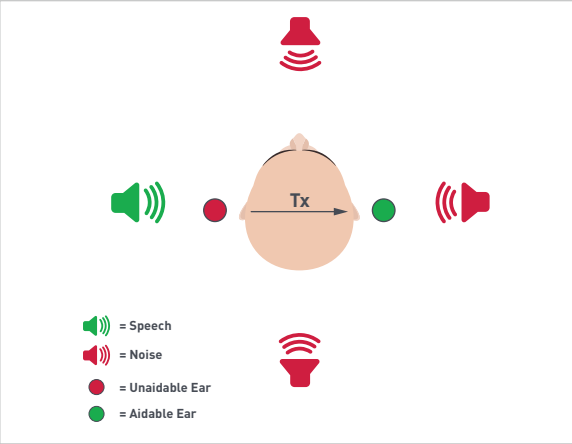

Figure 3: CROS/BiCROS is favorable when speech is presented to the poorer-hearing side.

Kuk et al. (2014) tested a group of six BiCROS users on speech understanding in noise using a modified version of the Hearing in Noise Test *(HINT; Nilsson et al., 1994)*. The best performance was observed when both the transmitting side and receiving side were in directional mode. Active CROS/BiCROS transmission provides the most benefit when speech is presented to the poorer-hearing side; using directional microphones provides even more benefit.

Speech understanding in noise may be poorer depending on the orientation of the noise and desired signal. See Figures 4 and 5 *(Hol et al., 2005; Ryu et al., 2014)*; Figure 6 *(Hol et al., 2005), (Hol et al., 2010)*, *(Kuk et al., 2015*).

The takeaway from the data in the collection of research for CROS and BiCROS is that the systems are helpful when desired sound is directed to the non-hearing ear equipped with a CROS mic, and detrimental when undesirable sound is similarly directed. The burden is on the user to manage head orientation and control of streaming from the CROS mic side to optimize performance.

Fitting and Counseling CROS/BiCROS Users

A reasonable fitting approach is to set up memories for BiCROS system users to easily switch between modes offering a choice between CROS, BiCROS and monaural function. CROS system users may only need transmission on or off. For optimum performance, patients should be counseled to orient themselves as best they can in the environment and toggle through the available programs, leaving the system where they hear the best.

Starkey CROS Systems

Starkey has a long history of providing custom hard-wired CROS and BiCROS systems to meet unique needs of patients. The introduction of the 900 MHz wireless capability in the Muse series of standard products allowed CROS and BiCROS hearing aids to be routinely offered for patients with unilateral and asymmetric hearing loss. As 2.4 GHz technology matured to the point that it was practical for routine hearing aid wireless technology, it was incorporated into the Thrive line of products for programming and connecting with accessories and smart phones. With this updated technology, Starkey utilized Near Field Magnetic Induction (NFMI) to carry the signal from the CROS microphone and transmitter to the device providing acoustic information to the better ear.

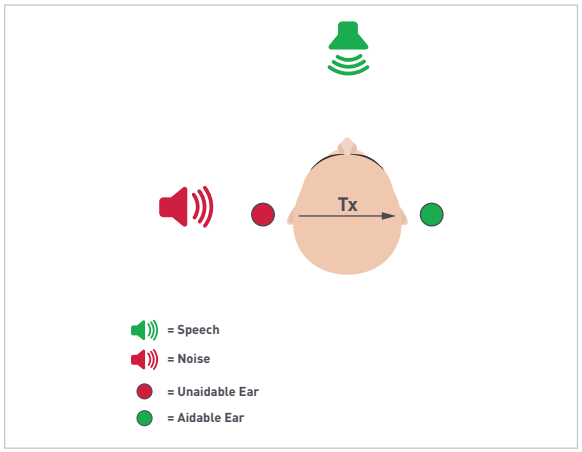

Figure 4: CROS/BiCROS is unfavorable when speech is presented from the front and noise is presented from the poorer-hearing side.

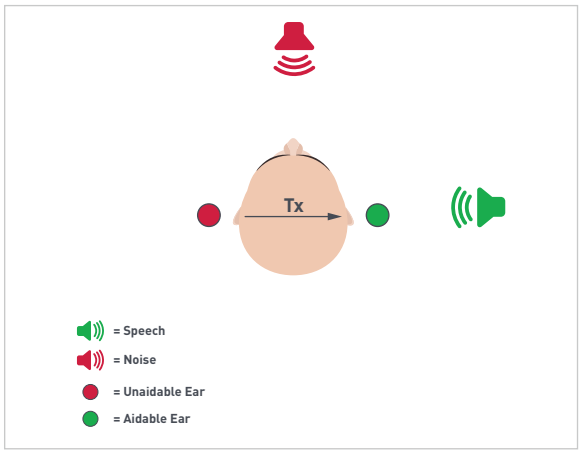

Figure 5: CROS/BiCROS is unfavorable when noise is presented from the front and speech is presented from the better-hearing side.

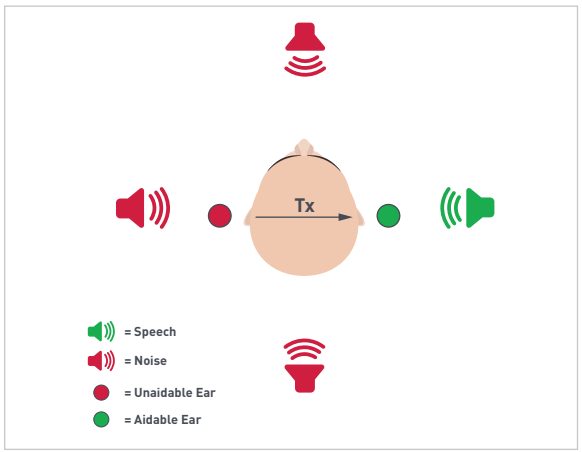

Figure 6: CROS/BiCROS is unfavorable when speech is presented from the better-hearing side and noise is presented from the front, back and poorer-hearing side.

Starkey CROS/BiCROS products allow convenient manual control of transmission of sound from the poorer hearing side in listening conditions that are unfavorable for CROS/BiCROS systems. The ability to control the hearing aids remotely via the smart phone app or an available remote control should help patients with dexterity concerns change memories, adjust the volume or turn on and off the transmission.

The receiving device is a standard production Receiver in Canal (RIC) 312 powered device, a 13-battery powered standard Behind the Ear (BTE), or a Rechargeable RIC. These products all support 2.4 GHz connectivity, and telecoil compatibility.

Today's Starkey systems are easily programmed to be either CROS, BiCROS or Hearing Aid only as is required by the patients' needs.

Figure 7: CROS and BiCROS hearing aids

The RIC transmitter is placed on the poorer ear and connected to the ear retention piece *(Fig. 8)*, which is placed in the ear canal. The ear retention piece looks very similar to a SnapFit receiver, but it does not have any electronic components or wires inside of it. It is low cost and can be used with any size standard earbuds or custom mold. It is also labeled CROS to help differentiate it from traditional receivers.

Figure 8: Ear Retention for RIC Transmitter

For the BTE transmitter retention a thin tube should be used with an open earbud in the size that is the most comfortable for the patient. *(Figure 9)*

Figure 9: BTE transmitter retention

Features

Flexibility for convenience and optimal utility of Starkey CROS and BiCROS systems:

- Accessories: CROS/BiCROS hearing aids are compatible with all 2.4 GHz accessories, including the Remote Control, Mini Remote Microphone, Remote Microphone +, Table Microphone and TV Streamer.
- Indicators: There are specific indicators (different from volume and battery alerts) to indicate to the user that the CROS/BiCROS transmission has started or stopped.
- Microphone Flexibility: Support for omnidirectional and directional microphones on both the transmitter and receiver.
- Memories: The hearing professional is able to enable or disable the CROS/BiCROS on a per memory basis. The patient also has the option of having a Hearing Aid Only memory in which the CROS/BiCROS feature is not active (no transmission). *(Figure 10 and 11)*
- Edge Mode: An on-demand analysis of the immediate acoustic environment and an artificial intelligenence-guided deployment of noise reduction, gain and output settings for optimum comfort and performance. *(Figure 12)*

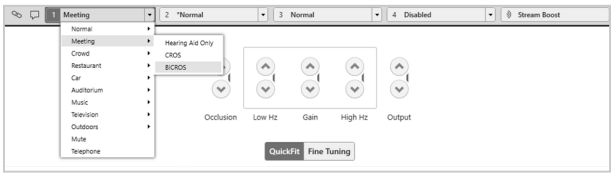

Figure 10: Independent memory configuration

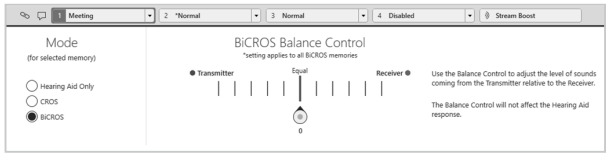

Figure 11: Balance control

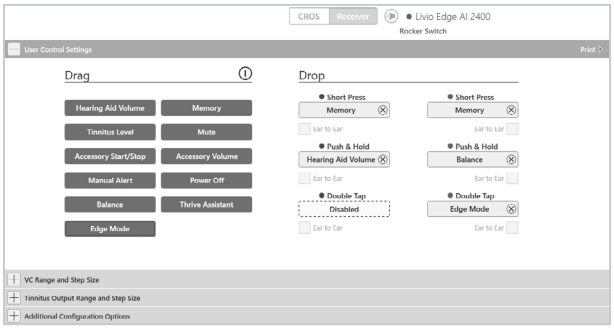

Figure 12: On-board control configuration

The Importance Of Manual Controls For CROS/BiCROS Users

As discussed above, patients will benefit from the CROS/BiCROS options depending on the environment. One of the benefits of Starkey's CROS/BiCROS system is that it allows the hearing professional to add a variety of options to access the advanced features the Thrive platform and to direct CROS transmission as needed.

Case Studies

The following case studies are offered to underscore the fitting strategies that may be used with CROS/BiCROS patients:

Case 1: The BiCROS Patient

Case History: Barbara is a 79-year-old woman who came to see her hearing professional due to a longstanding unilateral hearing loss that makes it increasingly difficult for her to communicate. During her case history, she explained that she is completely deaf in the right ear due to sudden hearing loss that happened 20 years ago. She learned to live with the unilateral hearing loss but now she is also starting to notice some difficulty hearing with her left ear. She is experiencing difficulty understanding conversations in noisy places, especially if the person is on her right side. Barbara also commented that she lives in a retirement home and is normally not in noisy situations. She does however have trouble understanding her friends when she goes to the cafeteria.

Recommendation: After conducting a complete audiological test battery, the hearing professional discovered that Barbara has a profound hearing loss in the right ear and a mild sloping to moderate hearing loss in the left ear. The hearing professional recommended a Starkey BiCROS system so she will be able to understand speech better from her left ear and decrease her problems understanding when the speaker is on the right. Since Barbara has dexterity problems the hearing professional also recommended the use of the 2.4 GHz Remote Control to change memories and adjust the volume.

The fitting: Based on case history, the hearing professional decided to set up Barbara's hearing aid with three memory options: **1.** Normal (BiCROS), **2.** Restaurant (BiCROS) and **3.** Normal (Hearing Aid Only). The hearing professional explained that the hearing aid-only memory might be more beneficial when the person she is talking to is on her left (better ear). The BiCROS will work better when she wants to hear somebody on her right (poorer ear) in a noisy environment. They practiced changing the memories using the remote control and the hearing professional scheduled another follow-up visit to discuss which memories are being used the most, and to address any adjustments needed.

CASE 2: THE CROS PATIENT

Case History: John is a busy 55-year-old man who recently underwent left acoustic neuroma surgery, consequently losing his hearing in that ear. His right ear has normal hearing. He reported frustration in understanding conservation on his left in noisy restaurants. He did not report having problems in quiet situations or when speakers sit to his right. John is very active and is frequently in noisy restaurants, meetings and lecture halls. He would like to be able to use the hearing aids without any accessories as he does not want to carry anything around.

Recommendation: John's hearing professional recommended Starkey's CROS hearing aid with the memory change and volume control set up to be controlled by the hearing aid push button. Since John carries a smart phone with him, the Thrive app will allow additional functionality without having extra hardware to carry.

The fitting: The hearing professional set up the hearing aid with two memory options: **1.** Normal (CROS) and **2.** Restaurant (CROS) memory (directional microphone active). She also gave him the option to stop the transmission and mute the microphone of the receiver by pressing and holding the push button for a few seconds. They practiced changing the memories and activating the mute function. The hearing professional counseled John on how he might benefit from each memory in different environments, and they scheduled a follow-up appointment to review the benefit of the different memories.

CASE 3: BiCROS PATIENT #2

Case history: Julie is a 74-year-old socially active woman with bilateral sensorineural hearing loss; mild in her left ear with excellent word recognition, and a moderate to severe loss on the right with fair word recognition ability. She was initially fit on the right ear monaurally in a team ENT/audiology practice without much success. As the team worked with her, a second hearing aid was recommended for the better ear, but her frustration continued. She eventually sought help in a hearing center closer to her home. There, additional testing and questioning yielded the recommendation for a BiCROS fitting since the fitting on the poorer ear yielded only discomfort and distraction. Julie is in her words "Technically challenged" and has difficulty managing anything much more than the very basics of her smart phone.

Recommendation: A BiCROS fitting with the ability to toggle through two or three programs that offer 1) monaural amplification on the left, 2) a CROS mode and 3) a BiCROS mode.

The fitting: A basic routine was set up on Julie's phone so that she could toggle through memories of her Starkey Premium level BiCROS system without having to think about which ear needed an active microphone. Her task is simply to try the memory options and use the one that is most effective for her in the situation where she needs help. A 2.4 GHz remote was offered as a simpler alternative for toggling, but she opted to use her phone. Subsequent follow-up appointments were very encouraging with the patient reporting excellent results and satisfaction with the fitting.

Summary

Unilateral and asymmetric hearing losses often present challenges for both patients and hearing professionals. Fortunately, CROS systems have dramatically improved since the hard-wired versions of the 1960s. CROS systems often need extra thought beyond a careful fitting to the better ear. A more tech savvy user may fully embrace a complicated solution that offers many choices and switching. Other patients may feel overwhelmed with the choices and prefer a more user-friendly solution. The good news is that choices are available that are practical, comfortable and cosmetically acceptable. Understanding the need for the patient to take an active role in mode selection along with the ability to easily switch through available options will improve the potential for success with CROS systems.

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