

Basic and advanced considerations in CROS and BiCROS fitting: streaming control and counselling

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Abstract

The Problem

Management of unilateral hearing loss (UHL) continues to challenge hearing healthcare practitioners and individuals with hearing loss. For these patients, Starkey offers contralateral routing of signal (CROS) and bilateral CROS (BiCROS) solutions that are beneficial in the majority of listening situations. Some patients will continue to struggle with speech in noise and localization under certain circumstances. For instance, when noise is presented to the poorer ear or to the front of the listener, a unilateral hearing aid alone is better.

The Gap

Although we know that there are certain circumstances for which a unilateral hearing aid is more beneficial than CROS or BiCROS, hearing healthcare practitioners and CROS/BiCROS users may seek some direction as to when to use what. Therefore, it's time to shift gears and address this old problem in a new way.

The Opportunity

We offer this guide to hearing healthcare practitioners 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. Consider why we must continue striving for improvement in supporting the CROS/BiCROS population
5. Explain one current/emerging approach to improving our support of CROS/BiCROS users: manually switching transmission of contralateral signals, depending on the listening conditions
6. Review how to verify CROS and BiCROS systems
7. Describe Starkey's CROS/BiCROS implementation

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Who are we trying to help?

Approximately 60,000 new cases of unilateral hearing loss (UHL) arise in the United States each year (Williams, McArdle, & Chisolm, 2012). The asymmetry between the two ears resulting from UHL poses a unique and difficult problem for hearing healthcare practitioners and affects a patient's quality of life. Individuals with UHL 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 UHL, the head shadow effect can significantly reduce detection of sounds arriving on the side of the poorer-hearing ear and therefore traditional hearing aid solutions may be insufficient. The head shadow effect occurs when sound arriving on one side of the head is physically obstructed by the head itself, which causes attenuation and filtering of sounds before they reach the other side. (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 15-20dB, while frequencies below 1000 Hz are typically attenuated by less than 10dB (Taylor, 2010; Upfold, 1980). This frequency-dependent attenuation of sounds makes understanding speech particularly challenging for individuals with UHL when the speech signal originates from their poorer-hearing side. Valente, Valente, Enrietto, and Layton (2002) reported that individuals with UHL require up to an additional 13dB increase in signal-to-noise ratio (SNR) to achieve speech recognition in noise performance similar to that of individuals with normal hearing.

What are the current solutions?

CROS and BiCROS systems remain the current industry standard for the UHL population.

CROS systems

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 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 sound lets the patient hear sounds from their non-hearing side through their normal-hearing ear.

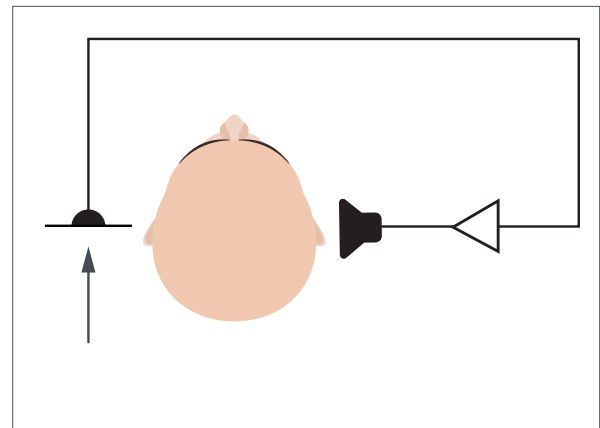


Figure 1. Schematic of CROS system

Candidacy

CROS devices benefit individuals with a unilateral hearing loss, where the loss is such that little to no benefit can be provided through amplification for the poorer-hearing ear. For CROS systems, the individual should have normal hearing or at most a mild high-frequency loss in their better-hearing ear (Dillon, 2001; Taylor, 2010). It is important to pay particular attention to the potential interaction between gain in the CROS system and the normal or near-normal hearing ear. If too much gain is applied, the user may perceive and be bothered by audible circuit noise from the CROS system. Too much gain in a CROS system may result in a reversal of the better and poorer hearing sides i.e., internal circuit noise may cause masking in the

ear with normal hearing (Dillon, 2001). 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 (described below) 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 to avoid occlusion. This risk of feedback is greatly reduced with use of a CROS system, which separates the microphone and receiver by positioning them on opposite sides of the individual's head (Dillon, 2001).

Expectations

Let's define successful CROS system fittings as those in which the candidate perceives benefit from their system and decides to continue using it (rather than returning it). Unfortunately, being a candidate for CROS also presents challenges to success. CROS candidates have normal or near-normal hearing in their better-hearing ear and thus may not perceive problems in many listening conditions (Hayes, 2006). For this reason, user motivation is a key aspect of success with CROS systems. 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 either in the form of increased performance or decreased frustration (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. Several questionnaires have been used to assess user benefit from CROS systems: 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 UHL using a CROS system, a transcranial CROS system consisting of a unilateral Completely-In-the-Canal (CIC) hearing aid, and a bone-anchored hearing aid (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 was 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.

The CROS candidacy requirement of normal or near-normal hearing in the better-hearing ear presents a unique challenge for individuals with UHL and hearing healthcare practitioners. Because individuals with normal hearing in one ear can hear relatively well in many listening conditions, the success rate of CROS system fittings is limited to approximately 50-60 percent. However, individuals who are successfully identified and fit with CROS systems can experience significant benefit across multiple domains of hearing as measured by a number of common self-report questionnaires.

BiCROS systems

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 always combine the signals from both sides of the head through the single amplifier. This combination of signals can degrade listening when one side of the user faces mostly noise or a poorer SNR than the other side. However, the net result will still provide

greater benefit than if the user had only a single hearing aid on the side with the poorer SNR (Dillon, 2001).

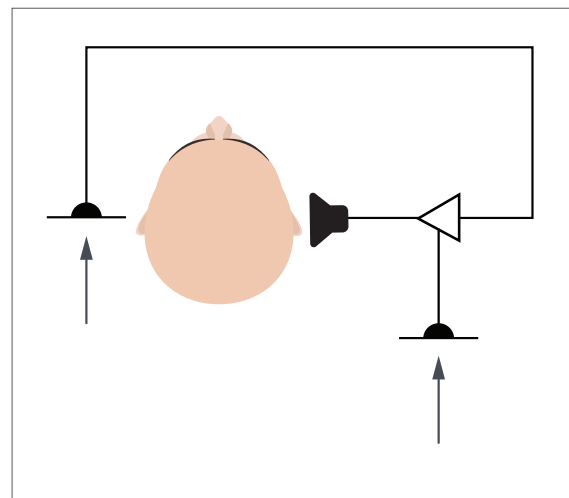


Figure 2. Schematic of BiCROS system

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 (poorer-hearing ear) and the other ear is aidable (better-hearing ear) (Dillon, 2001; Taylor, 2010).

BiCROS systems can yield an advantage in overcoming feedback oscillation, due to the separation between the microphone on the poorer-hearing ear and the amplifier and receiver on the better-hearing ear. However, the amount of additional stable gain afforded by a BiCROS system is much less than that afforded by a CROS system due to the proximity of the microphone and receiver on the better-hearing ear (Dillon, 2001).

Expectations

Let's consider a successful BiCROS fitting to be like that of a successful CROS fitting, meaning the user perceives benefit from their BiCROS system and wishes to continue using it. In contrast to CROS candidates, BiCROS candidates are more likely to notice their hearing challenges across a

range of listening conditions, because they have hearing loss in both ears. Thus, they are also more likely to perceive benefit from their BiCROS systems. 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). Since BiCROS system users are likely to perceive benefit across a broader range of listening conditions, the success rate of BiCROS systems is typically higher than that of CROS systems, at approximately 70-80 percent (Hill et al., 2006). Impressively, one study of experienced BiCROS users reported a success rate of 95 percent using modern digital systems (Williams et al., 2012).

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. We will review some recent research evidence of self-assessed subjective benefit from BiCROS systems in this section.

Williams et. al. (2012) conducted a study to compare user performance, benefits, and satisfaction with modern BiCROS systems versus previous-generation BiCROS systems. Participants reported significantly better performance and quality with the modern 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 modern versus their previous BiCROS systems. Study participants reported being significantly more satisfied with the modern 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; the authors did not include results from AV domain.

A good hearing aid fitting for the better-hearing ear is the foundation of a successful BiCROS fitting. 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. Successful users of BiCROS systems report significant benefits across multiple domains as assessed by self-report measures.

What's coming down the line to fix this longstanding problem?

Although CROS and BiCROS systems have evolved and improved over the last several decades, listeners continue to face challenges when using these systems. 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 conditions 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). While users have been able to start and stop transmission from their CROS/BiCROS systems for quite some time, the methods for doing so have historically been cumbersome and indiscreet. Historically, users would have to open the battery door of the transmitting device or remove the receiving device from their ear in order

to stop CROS/BiCROS transmission. Recently, advancements in CROS/BiCROS system technologies have afforded additional benefit to BiCROS users through manual control of transmission (Kuk, Seper, Lau, Crose, & Korhonen, 2015). Modern approaches to manual control of CROS/BiCROS transmission include switching through wirelessly controlled device memories and single-purpose, device-level switches. These new approaches to manual control are more discreet, efficient and user friendly than previous options.

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).

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 – Transmission on

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 4). 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.

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 authors presented speech to each listener's poorer-hearing ear and noise to the front, back, and the side of the better-hearing ear as shown in Figure 1. They performed these tests under several hearing aid conditions: i) unilaterally aided, in either omnidirectional or directional mode; ii) BiCROS with omnidirectional microphones on both the transmitting side and receiving side; iii) BiCROS with the transmitting side in directional mode and the receiving side in omnidirectional mode; iv) BiCROS with the transmitting side in omnidirectional mode and the receiving side in directional mode; and v) BiCROS with both the transmitting and receiving sides in directional mode. All BiCROS conditions yielded better speech understanding in noise, relative to the unaided and unilaterally aided conditions. The best performance was observed when both the transmitting side and receiving side were in directional mode. Using either the transmitting or receiving side in directional mode resulted in better performance than using both sides in omnidirectional mode. However, using only the receiving side in directional mode resulted in better performance than using only the transmitting side in directional mode.

This study lends further evidence to the use of BiCROS systems when speech is presented to the poorer-hearing ear. Active CROS/BiCROS transmission provides the most benefit when speech is coming from the poorer-hearing side; using directional microphones provides even more benefit.

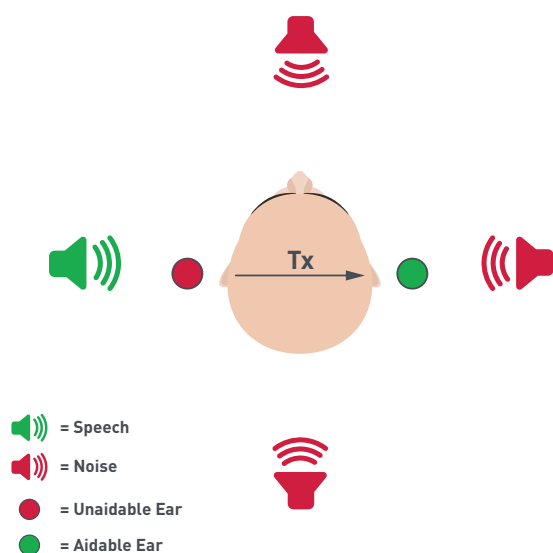


Figure 3. CROS/BiCROS is favorable when speech is presented to the poorer-hearing side.

CROS/BiCROS – Transmission off

On the one hand, evidence supports the use of CROS/BiCROS systems when speech is presented to the poorer-hearing ear. On the other hand, some evidence suggests CROS/BiCROS systems may cause difficulty in other listening conditions.

Speech understanding in noise is poorer with a CROS system than with unaided listening when speech is presented from the front and noise is presented from the poorer-hearing side as shown in Figure 5 (Hol et al., 2005; Ryu et al., 2014); and when noise is presented from the front and speech presented from the better-hearing side as shown in Figure 6 (Hol et al., 2005). Speech understanding in noise is poorer with a CROS system than with a unilateral Completely-In-the-Canal (CIC) hearing aid when noise is presented from the front and speech presented from the better-hearing side as shown in Figure 6 (Hol et al., 2010). Furthermore, speech understanding in noise is poorer with a BiCROS device than with unilaterally aided listening when speech is presented from the better-hearing side and noise is presented from the front, back, and the poorer-hearing side as shown in Figure 6 (Kuk et al., 2015). A summary of these results is provided in Table 1.

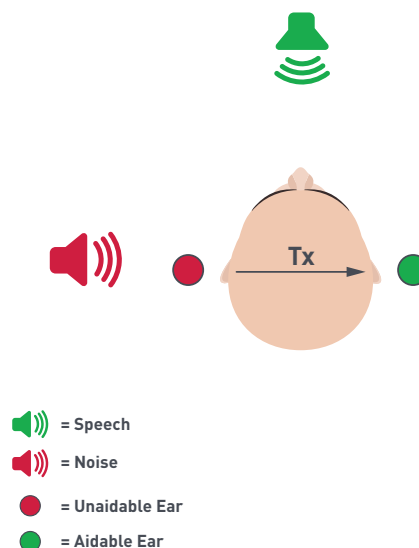


Figure 4. CROS/BiCROS is unfavorable when speech is presented from the front and noise is presented from the poorer-hearing side.

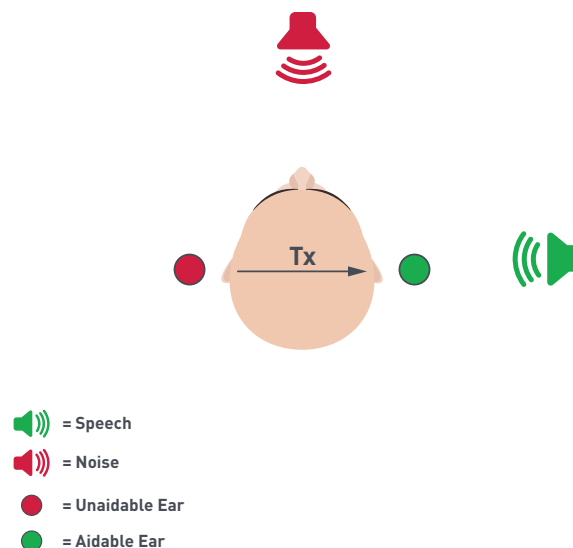


Figure 5. CROS/BiCROS is unfavorable when noise is presented from the front and speech is presented from the better-hearing side.

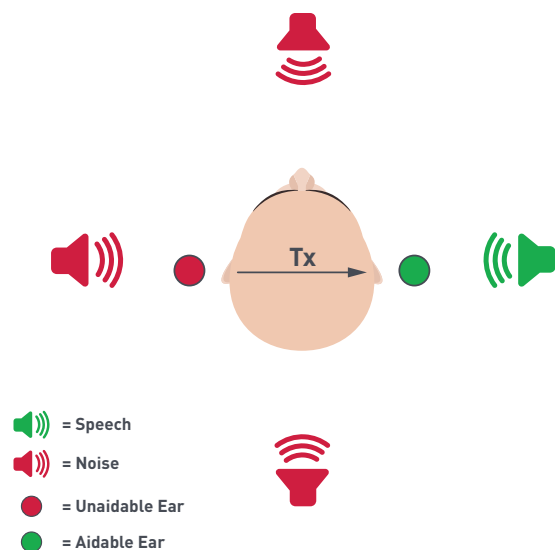


Figure 6. CROS/BiCROS is unfavorable when speech is presented from the better-hearing side and noise is presented from the front, back and poorer-hearing side.

So what does this all mean?

Starkey CROS/BiCROS products allow manual control of transmission of sound from the poorer-hearing side in listening conditions that are unfavorable for CROS/BiCROS systems (i.e., when noise is presented to the poorer-hearing side). Users can achieve better speech understanding in noise with a manually controlled CROS/BiCROS system than with a conventional CROS/BiCROS system when speech is presented to either ear, and noise is presented from the front, back and side contralateral to the speech.

Counseling CROS/BiCROS users to manually switch transmission

We should ask patients to turn their CROS/BiCROS transmitter off and back on while listening for any

perceptual difference in speech clarity or amount of noise interference (when the transmitter is on versus off). If turning their CROS/BiCROS transmitter off makes understanding speech more difficult (or noisier), then speech is likely coming from their poorer-hearing side. If that happens, the user should turn the transmitter microphone back on for that situation. If the user finds that turning their transmitter off makes understanding speech easier, improves sound quality, or reduces noise, then the noise is likely coming from their poorer-hearing side. If that happens, the user should leave their transmitter microphone off in that situation.

It's simple! In summary:

Turn CROS/BiCROS transmitter (Tx) OFF. Is speech understanding better?

NO → turn CROS/BiCROS Tx back ON

YES → leave CROS/BiCROS Tx OFF

Comparison	Speech Location	Noise Location	Figure	Outcome
CROS vs. unaided	Front	Poorer side	Figure 2	CROS
CROS vs. unaided	Better side	Front	Figure 3	CROS
CROS vs. unilateral CIC	Better side	Front	Figure 3	CROS
BiCROS vs. unilateral hearing aid	Better side	Front and back and poor side	Figure 4	BiCROS

Table 1. Summary of conditions unfavorable for CROS/BiCROS transmission

Verification of CROS and BiCROS hearing aids

Recommended process for measuring the head-shadow effect:

Step 1

Measure the real-ear unaided response (REUR) for the better ear (Figure 7a):

- Position the speaker at 45° to the ear.
- Position the reference microphone at the better ear (i.e. same side as speaker).
- Insert the probe tube into the better ear.
- Measure the better ear only

Step 1. "Better Ear" Measurement

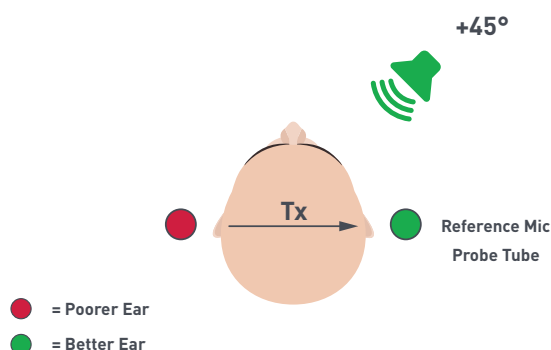


Figure 7a

Step 2

Measure the REUR with sound directed towards the poorer ear (Figure 7b):

- Position the speaker at 45° to the poorer ear.
- Position the reference microphone at the poorer ear (i.e. same side as speaker).
- The probe tube remains in the better ear (i.e. opposite side as speaker).

- Activate the cROS real ear measurement setting.

Step 2. "Poorer Ear" Measurement

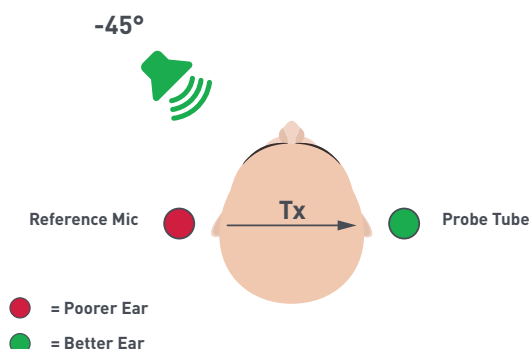


Figure 7b.

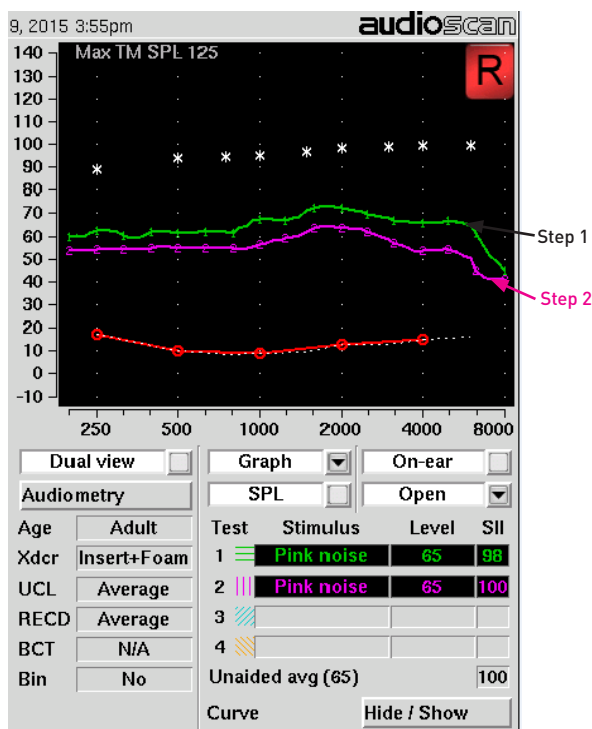


Figure 8. The difference between the two measurements (for the same input level) obtained in steps 1 and 2 represents an estimate of the head shadow effect for that patient.

Recommended steps for verifying CROS hearing aids:

Step 1

Measure the real-ear aided response (REAR) response for the better ear (Figure 9a):

- Position the speaker at 45° azimuth to the better ear.
- Position the reference microphone and probe tube at the better ear (i.e. same side as speaker).
- Position the CROS instruments (receiver/transmitter) in the ears and turn them on.

(Starkey CROS has to be in Demo mode to stream)

Step 1. “Better Ear” Measurement

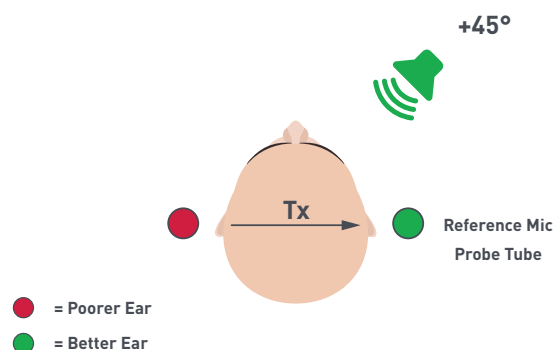


Figure 9a.

Step 2

Measure the response for the poorer ear (REAR) (Figure 9b):

- Position the speaker at 45° azimuth to the poorer ear.
- Position the reference microphone at the poorer ear (i.e. same side as speaker)
- The probe tube remains in the better ear.

- The response measured in step 2 should match that obtained in step 2 for the same input level.

(For this step the Verifit should be in CROS setting)

Step 2. “Poorer Ear” Measurement

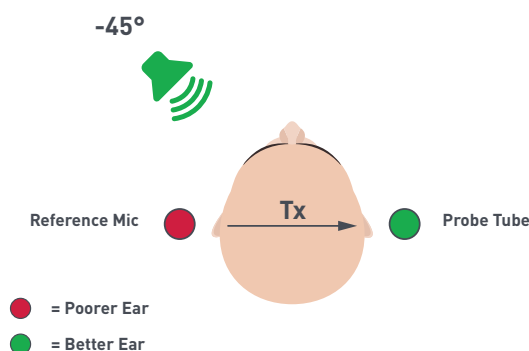


Figure 9b.

Step 3

Measure the REAR at 0° azimuth (Figure 9c):

- Position the speaker at 45° azimuth
- Position the reference microphone at the poorer ear or at the better ear.
- The probe tube remains in the better ear.

Step 3. REAR Measurement

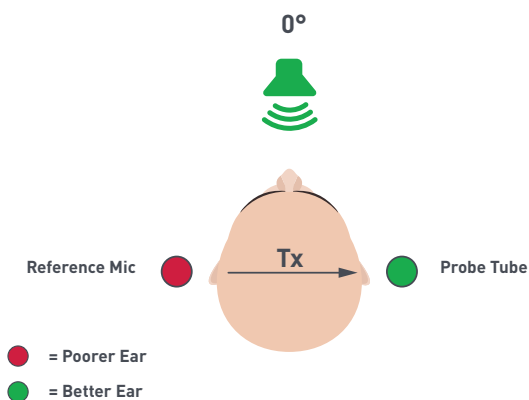


Figure 9c.

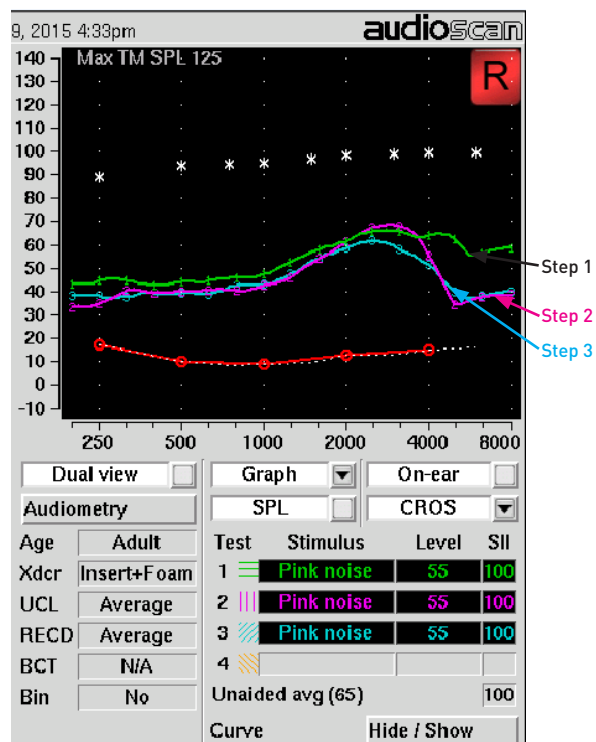


Figure 10. All measurements should be conducted with the same stimulus at the same level. Step 1 and step 2 curved should be close. If they are not, adjust the CROS response and repeat step 2 until the poorer side REAR matched the better-side REAR. Step 3 should display a smooth curve. An irregular response may indicate phasing problems with the hearing instrument or may be the result of reflections from nearby objects.

Recommended steps for verifying BiCROS hearing aids:

Step 1

Measure the REAR response for the better ear (Figure 12a):

- Position the speaker at 45° azimuth to the better ear.
- Position the reference microphone at the better ear (i.e. same side as speaker).
- Insert the probe tube into the better ear.
- Position the BiCROS instruments (both receiver and transmitter) on the ears and turn them on.

(Starkey CROS has to be in Demo mode to stream)

Step 1. “Better Ear” Measurement

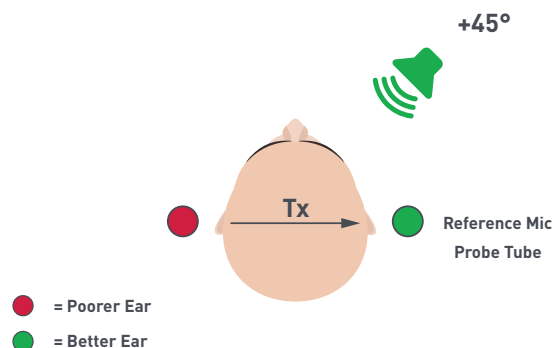


Figure 11a.

Step 2

Measure the response for the poorer ear (Figure 11b):

- Position the speaker at 45° azimuth to the poorer ear.
- Position the reference microphone at the poorer ear.
- The probe tube remains in the better ear.

(For this step the Verifit should be in CROS setting)

Step 2. “Poorer Ear” Measurement

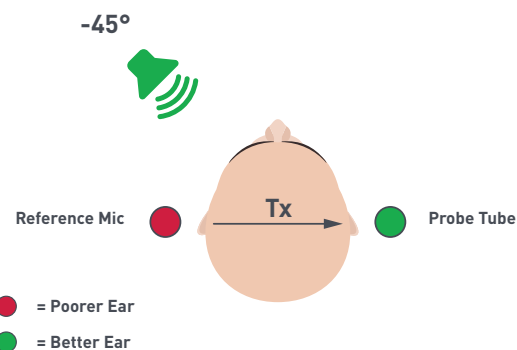


Figure 11b.

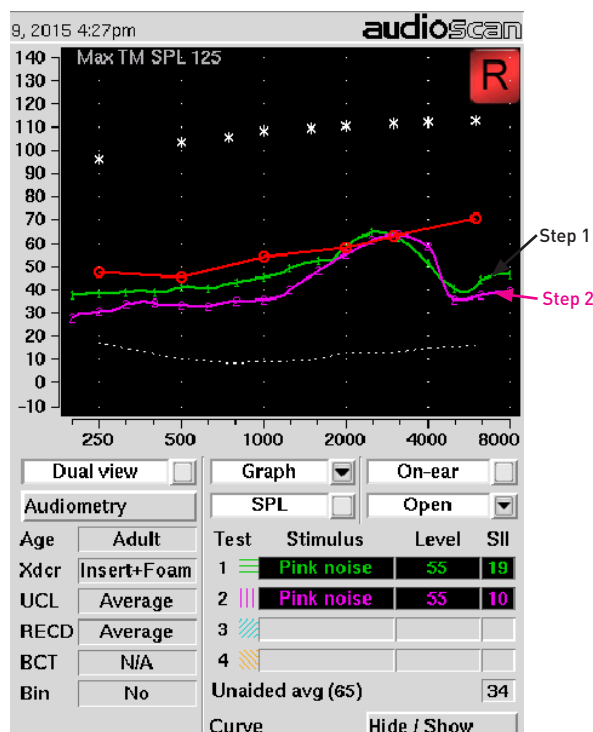


Figure 12. The measured response on Step 1 should be adjusted to approximate the real-ear targets prescribed by the fitting formula using the better side. The measured REAR on Step 2 should approximate that achieved in Step 1 for the same input level.

Starkey CROS and BiCROS Systems

Starkey's wireless CROS and BiCROS hearing aids use the 900sync wireless platform to allow for broadband audio streaming required for all CROS and BiCROS functionality.

Receivers

900sync Receiver-In-Canal (RIC) and mini Behind-The-Ear (mini-BTE) hearing aids can be used as CROS receivers. These can be activated as a receiver once the clinician pairs them with a transmitter during the fitting session and selects the CROS or BiCROS functionality; the transmitting instrument must be branded as a transmitter.

It is important to point out that even though the patient can choose a RIC or mini-BTE style of hearing aid to use as a CROS/BiCROS system, the receiver and the transmitter must be the same style and have the same microphone configuration.

CROS and BiCROS Hearing Aids



Transmitters

The transmitters appear identical to other hearing aids in the same product family; however, they are labeled CROS so the clinician can differentiate them from regular hearing aids. They do not have telecoil or autophone functionality.

Ear Retention for RIC Transmitter



The RIC transmitter will be placed on the poorer ear and will be connected to the Ear Retention (shown in the picture above), which will be placed inside 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 of standard earbuds. It is also labeled CROS to help the clinician differentiate it from traditional receivers.

Ear Retention for BTE Transmitter



For the BTE transmitter a thin tube should be used with an open earbud in the size that is the most comfortable for the patient.

Features

- **Accessories** - CROS/BiCROS devices will be compatible with all SurfLink accessories, including SurfLink Remote Control and SurfLink Media. The ability to control the hearing aids remotely should help patients with dexterity concerns that need to adjust the volume or turn off the transmission.
- **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 both omnidirectional and directional microphones on both the transmitter and receiver.
- **Memories** - The audiologist 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 13 and 14).
- **900sync ear-to-ear** - Ear-to-ear wireless connectivity allows for the patient to change memories in one device and the opposite device will switch to the same memory (Figure 15). Note that the default on Inspire is active.

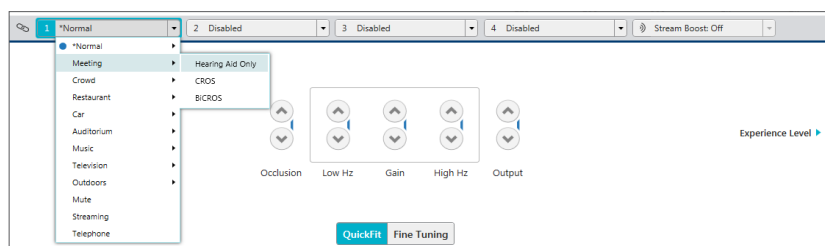


Figure 13

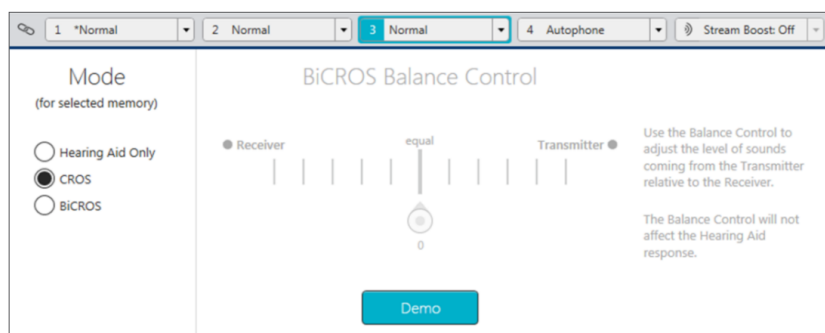


Figure 14

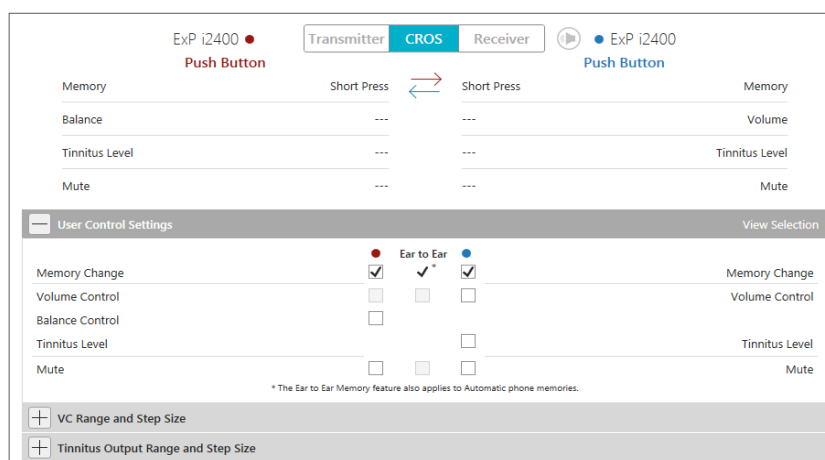


Figure 15

The importance of Manual Controls for CROS/BiCROS users

As we discussed previously there are some situations in which the patient will benefit from the CROS/BiCROS transmission, normally when speech is directed at the poorer ear and noise is around the better ear (see Figure 3). However, there are also times when the patient might benefit from stopping the transmission, for example when speech is directed at the better ear and the device is mostly transmitting the noise coming from the poorer side (see Table 1). One of the benefits of Starkey's new CROS/BiCROS system is that it allows the clinician to add a Hearing Aid Only memory. It will allow patients to decide when to stream information between ears and when to stop. Included are some examples showcasing how the features in the Starkey CROS/BiCROS system can help alleviate this problem.

Case 1: The BiCROS patient

Case History: Barbara is a 79-year-old woman who came to see her audiologist 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 audiologist 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 audiologist 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 audiologist also recommended the use of the SurfLink Remote Control to change memories and adjust the volume.

The fitting: Based on case history, the audiologist 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 audiologist 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 audiologist scheduled another follow-up visit to discuss which memories are being used the most, and which ones are not working as they should.

Case 2: The CROS patient

Case History: John is a busy 55-year-old man who has been through an acoustic neuroma surgery and consequently lost all the hearing in his left ear. His right ear has normal hearing. He reported not having any problems in quiet situations or when the speaker is on his right. John gets very frustrated in noisy restaurants when trying to understand people sitting on his left. He is very active and is often 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 audiologist recommended Starkey's CROS hearing aid with the memory change and volume control set up to be controlled by the hearing aid push button.

The fitting: The audiologist sets up the hearing aid with 2 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 audiologist counsels John regarding 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.

References

- Baguley, D., Bird, J., Humphriss, R., & Prevost, A. (2006). The evidence base for the application of contralateral bone anchored hearing aids in acquired unilateral sensorineural hearing loss in adults. *Clinical Otolaryngology*, 31(1), 6-14.
- Cox, R., Hyde, M., Gatehouse, S., Noble, W., Dillon, H., Bentler, R., . . . Wilkerson, D. (2000). Optimal outcome measures, research priorities, and international cooperation. *Ear and Hearing*, 21(4), 106S-115S.
- Cox, R. M., & Alexander, G. C. (1995). The abbreviated profile of hearing aid benefit. *Ear & Hearing*, 16(2), 176-186.
- Cox, R. M., & Alexander, G. C. (2002). The International Outcome Inventory for Hearing Aids (IOI-HA): psychometric properties of the English version: El Inventario Internacional de Resultados para Auxiliares Auditivos (IOI-HA): propiedades psicometricas de la version en ingles. *International Journal of Audiology*, 41(1), 30-35.
- Cox, R. M., Alexander, G. C., & Beyer, C. M. (2003). Norms for the international outcome inventory for hearing aids. *Journal of the American Academy of Audiology*, 14(8), 403-413.
- Dillon, H. (2001). CROS, Bone-conduction, and Implanted Hearing Aids Hearing Aids (pp. 434-450). New York, NY: Thieme.
- Ericson, H., Svård, I., Högset, O., Devert, G., & Ekström, L. (1988). Contralateral Routing of Signals in Unilateral Hearing Impairment A Better Method of Fitting. *Scandinavian Audiology*, 17(2), 111-116.
- Fletcher, H. (1953). Speech and hearing in communication.
- Gatehouse, S. (1999). Glasgow Hearing Aid Benefit Profile: Derivation and Validation of. *J Am Acad Audiol*, 10, 80-103.
- Gatehouse, S., & Noble, W. (2004). The Speech, Spatial and Qualities of Hearing Scale (SSQ). *International Journal of Audiology*, 43(2), 85-99.
- Harford, E., & Barry, J. (1965). A rehabilitative approach to the problem of unilateral hearing impairment: The contralateral routing of signals (CROS). *Journal of Speech & Hearing Disorders*.
- Harford, E., & Dodds, E. (1966). The clinical application of CROS: a hearing aid for unilateral deafness. *Archives of Otolaryngology*, 83(5), 455-464.
- Hayes, D. (2006). A practical guide to CROS/BiCROS Fittings. Audiology Online. Retrieved from <http://www.audiologyonline.com/articles/practical-guide-to-cros-bicross-977>
- Hill, S. L., III, Avron, M., Digges, E. N. B., Gillman, N., & Silverstein, H. (2006). Assessment of patient satisfaction with various configurations of digital CROS and BiCROS hearing aids. *Ear, Nose & Throat Journal*, 85(7), 427.
- Hol, M. K., Bosman, A. J., Snik, A. F., Mylanus, E. A., & Cremers, C. W. J. (2005). Bone-anchored hearing aids in unilateral inner ear deafness: an evaluation of audiometric and patient outcome measurements. *Otology & Neurotology*, 26(5), 999-1006.
- Hol, M. K., Kunst, S. J., Snik, A. F., & Cremers, C. W. (2010). Pilot study on the effectiveness of the conventional CROS, the transcranial CROS and the BAHA transcranial CROS in adults with unilateral inner ear deafness. *European archives of oto-rhino-laryngology*, 267(6), 889-896.
- Kochkin, S. (1990). Introducing MarkeTrak: A consumer tracking survey of the hearing instrument market. *Hearing Journal*, 43(5), 17-27.
- Kuk, F., Korhonen, P., Crose, B., & Lau, C. (2014). CROS your heart: renewed hope for people with asymmetric hearing losses. *Hearing Review*, 21(6), 24-29.
- Kuk, F., Seper, E., Lau, C., Crose, B., & Korhonen, P. (2015). Effects of Training on the Use of a Manual Microphone Shutoff on a BiCROS Device. *Journal of the American Academy of Audiology*, 26(5), 478-493.
- Lin, L.-M., Bowditch, S., Anderson, M. J., May, B., Cox, K. M., & Niparko, J. K. (2006). Amplification in the rehabilitation of unilateral deafness: speech in noise and directional hearing effects with bone-anchored hearing and contralateral routing of signal amplification. *Otology & Neurotology*, 27(2), 172-182.
- Nilsson, M., Soli, S. D., & Sullivan, J. A. (1994). Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. *Journal of the Acoustical Society of America*, 95(2), 1085-1099.
- Oeding, K., & Valente, M. (2013). Sentence recognition in noise and perceived benefit of noise reduction on the receiver and transmitter sides of a BiCROS hearing aid. *Journal of the American Academy of Audiology*, 24(10), 980-991.
- Olsen, S. Ø., Hernvig, L. H., & Nielsen, L. H. (2012). Self-reported hearing performance among subjects with unilateral sensorineural hearing loss. *Audiological Medicine*, 10(2), 83-92.
- Ryu, N.-G., Moon, I. J., Byun, H., Jin, S. H., Park, H., Jang, K.-S., & Cho, Y.-S. (2014). Clinical effectiveness of wireless CROS (contralateral routing of offside signals) hearing aids. *European Archives of Oto-Rhino-Laryngology*. doi: 10.1007/s00405-014-3133-0
- Shaw, W., Newman, E., & Hirsh, I. (1947). The difference between monaural and binaural thresholds. *The Journal of the Acoustical Society of America*, 19(4), 734-734.
- Taylor, B. (2010). Contralateral routing of the signal amplification strategies. *Seminars in Hearing*, 31(4), 378-392.
- Tillman, T., Kasten, R., & Horner, I. (1963). Effect of head shadow on reception of speech. *Asha*, 5(10), 778-779.
- Upfold, L. J. (1980). The evaluation of CROS aids with the unilateral listener. *Scandinavian Audiology*, 9(2), 85-88.
- Valente, M., Valente, M., Enrietto, J., & Layton, K. (2002). Fitting strategies for patients with unilateral hearing loss. In M. Valente (Ed.), *Strategies for selecting and verifying hearing aid fittings* (2nd ed., pp. 253-271). New York: Thieme.
- Valente, M., Valente, M., & Mispagel, K. (2006). Fitting options for adult patients with single sided deafness (SSD). Audiology Online. Retrieved from <http://www.audiologyonline.com/articles/fitting-options-for-adult-patients-980>
- Ventry, I. M., & Weinstein, B. E. (1982). The hearing handicap inventory for the elderly: a new tool. *Ear and Hearing*, 3(3), 128-134.
- Williams, V. A., McArdle, R. A., & Chisolm, T. H. (2012). Subjective and objective outcomes from new BiCROS technology in a veteran sample. *Journal of the American Academy of Audiology*, 23(10), 789-806.
- Wilson, R. H. (2003). Development of a speech-in-multitalker-babble paradigm to assess word-recognition performance. *Journal of the American Academy of Audiology*, 14(9), 453-470.



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