COMPARISON OF BAHA AND CROS HEARING AID IN SINGLE-SIDED DEAFNESS

by

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ABSTRACT

Nine adults with single-sided deafness previously implanted with a Baha were given a two-week trial with a CROS hearing aid and tested in unaided and aided conditions. Both devices were compared on head shadow effect reduction, speech perception measures, self-assessment questionnaires, and daily diaries. The CROS reduced the head shadow effect for more frequencies than the Baha. Participants performed well across all conditions with speech to the poor ear in quiet. The QuickSIN showed both devices adversely affected speech perception with noise to the poor ear; the CROS was more disadvantageous. Neither device improved speech perception with noise to the better ear. The BBSS and SSQ demonstrated subjective benefit and the diaries indicated frequent use of both devices. Five participants preferred the CROS for sound quality; three preferred the Baha for comfort. As both devices seem comparable, a CROS should be the first intervention option recommended before considering Baha surgery.

Key Words: Baha, CROS, single-sided deafness, speech perception

LIST OF ABBREVIATONS USED

SSD	single-sided deafness
Hz	Hertz
dB	decibel
SNR	signal-to-noise ratio
CROS	contralateral routing of signals hearing aid
Baha	bone-anchored hearing aid
AM	amplitude modulation
FM	frequency modulation
RF	radio frequency
APHAB	Abbreviated Profile of Hearing Aid Benefit
GHABP	Glasgow Hearing Aid Benefit Profile
IOI-HA	International Outcome Inventory for Hearing Aids
SSDQ	Single-Sided Deafness Questionnaire
GBI	Glasgow Benefit Inventory
HHIE-S	Hearing Handicap Inventory for the Elderly – screening version
BBSS	Bern Benefit in Single-Sided Deafness Questionnaire
SPIN-R	Revised Speech Perception in Noise Test
HL	hearing level
HINT	Hearing in Noise Test
SPL	sound pressure level
SAINT	Source Azimuth Identification in Noise Test
SRT	sentence reception threshold
BTE	behind-the-ear hearing aid
SSQ	Speech, Spatial Qualities Questionnaire
RCT	randomized controlled trial
QuickSIN	Quick Speech-in-Noise Test
ANOVA	Analysis of Variance
LSD	Least Significant Difference

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CHAPTER 1 - INTRODUCTION

Single-Sided Deafness

People with single-sided deafness (unilateral hearing) have significant hearing loss in one ear and normal or near normal hearing in the other ear. The hearing loss is usually sensorineural, affecting the cochlea on the side of the poor ear, and generally cannot be aided with conventional means of amplification (Berenholz, Burkey, & Lippy, 2007; Niparko, Cox, & Lustig, 2003; Williams, McArdle, & Chisolm, 2012). Single-sided deafness (SSD) can result from many etiologies, including congenital causes, sudden sensorineural hearing loss, Meniere's disease, trauma (such as temporal bone fractures), acoustic neuroma, infection, autoimmune inner ear disease, ototoxicity, meningitis, noise exposure and unknown causes (Hol, Kunst, Snik, & Cremers, 2010b; Williams et al., 2012).

Due to the head shadow effect, a sound arriving at the poorer side is reduced in intensity by the time it reaches the better ear due to obstruction of the head. Not only is sound energy diffracted by reflection from the head, outer ear and upper torso, but it is also absorbed within the 'shadow' region of the head, making transmission of sound from the poor ear to the better ear difficult (Bosman, Hol, Snik, Mylanus, & Cremers, 2003; Hol, Bosman, Snik, Mylanus, & Cremers, 2004; Lin et al., 2006). This effect is frequency-dependent, mostly attenuating sounds above 1000 Hz by 10-16 dB (Hill, Marcus, Digges, Gillman, & Silverstein, 2006; Wazen et al., 2003). High frequencies that are short in wavelength cannot compensate for the head shadow effect in bending around the head the way low frequencies can. Therefore, high frequency sounds from the side of the poor ear will encounter more intensity reduction while travelling to the side of the better ear compared to low frequency sounds (Flynn, Sammeth, Sadeghi, Cire, & Halvarsson, 2010).

Those living with SSD experience several communication difficulties, such as speech perception in the presence of noise (Taylor, 2010; Yuen, Bodmer, Smilsky, Nedzelski, & Chen, 2009). Due to the head shadow effect, high frequency cues (which are critical for good speech intelligibility), are reduced by the time they reach the opposite normal ear, while ambient background noise is not reduced (Hill et al., 2006). This causes an unfavourable signal-to-noise ratio (SNR) that can adversely affect communication (Lin et al., 2006). This is particularly problematic in situations where the noise is on the side of the better ear and the speech is on the side of the poor ear (Taylor, 2010; Yuen et al., 2009). However, speech perception can be improved when the speaker is directly facing the participant and in quiet situations because in the absence of background noise, the better ear can be used to compensate for hearing loss in the poor ear (Flynn et al., 2010).

For people with SSD, difficulty with speech understanding in noise also arises from a lack of access to the binaural auditory processing system (Bosman et al., 2003; Lin et al., 2006; Niparko et al., 2003; Taylor, 2010; Wazen et al., 2003; Williams et al., 2012). For example, they do not experience the benefit of loudness summation, an additive effect that would typically improve audibility by 3 dB (Hol et al., 2004; Taylor, 2010; Wazen et al., 2003; Williams et al., 2012). Moreover, background noise cannot be effectively squelched to help improve perception of the auditory signal (Hol et al., 2004; Taylor, 2010). Sound localization remains a challenge for individuals with SSD because binaural hearing cannot be re-established (Hol et al., 2004; Hol et al., 2010a; Lin et al., 2006; Niparko et al., 2003; Wazen et al., 2003; Williams et al., 2012). Binaural hearing is required for individuals to be able to compare the interaural level differences and interaural time differences between the two ears to assist with sound localization. These cues allow individuals to locate a sound source in the horizontal plane (Bosman et al., 2003; Hol et al., 2004; Hol et al., 2010a; Taylor, 2010; Wazen et al., 2003; Williams et al., 2012).

CROS Hearing Aids and Bone Conduction Implants

To help alleviate the negative effect of head shadow and difficulty with speech perception in noise that present with SSD, two intervention methods have been introduced: the Contralateral Routing of Signals (CROS) hearing aid and the bone-anchored hearing device (such as the Baha by Cochlear or Bone-Bridge by MED-EL). The CROS, which uses two hearing aids that fit behind each ear, has been a viable method for alleviating the effects of SSD for more than four decades (Williams et al., 2012). The hearing aid fit on the poor side houses a microphone and a transmitter. The hearing aid fit on the better ear houses a receiver that is connected to an open ear mold. The CROS does not amplify sound but rather transmits sound from the side of the unaidable ear to the contralateral ear, overcoming the head shadow effect (Hayes, Pumford, & Dorscher, 2005; Taylor, 2010).

Older CROS models consisted of two analog hearing aids connected together by a wire along the neck of the patient. Sounds from the poor ear were transmitted to the better ear through this means of hardwiring (Taylor, 2010; Williams et al., 2012). There was less universal acceptance of the older CROS models, with patients citing poor cosmetics, discomfort with occlusion of the better ear, poor sound quality related to distortion, social stigma concerns, ineffective reduction of high ambient noise, electromagnetic interference with other devices and possible interference with sounds heard in the better ear as reasons for being dissatisfied with the CROS (Bishop & Eby, 2009; Hill et al., 2006; Taylor, 2010; Wazen et al., 2003).

In recent years, CROS hearing aids have undergone substantial improvement with newer models now using radio frequency wireless transmission and digital sound processing strategies that allow for a wide range of adjustment (Hayes et al., 2005; Taylor, 2010). Amplitude modulation (AM) and frequency modulation (FM) have made wireless connectivity between the poor and better ear possible (Williams et al., 2012). The new wireless version of the CROS (such as the Unitron Tandem, Phonak CROS, or Widex CROS models) is regarded as more cosmetically appealing since there is no longer a wire around the neck but an unoccluding ear mold in the better ear that minimizes transfer of low frequency sound from the poor to better ear (Hol et al., 2005; Hol et al., 2010b). Signals from the microphone situated on the poor ear are transmitted to the receiver on the better ear through radio frequency (RF) activity. The distance between the transmitter and receiver is critical with CROS wireless transmission; there seems to be less efficiency with larger head sizes (Hayes et al., 2005; Taylor, 2010). The new models of the CROS not only use digital signal processing, but also offer a variety of additional features that attempt to rectify the limitations imposed by the older CROS models. For example, the newer versions of the CROS offer improved cosmetics, a stronger means of transmission, and also reduce interference (Williams et al., 2012). In addition, digital noise reduction and adaptive directional microphone technologies are now common on CROS hearing aids.

The term “Baha” is being used to refer to the general product type of bone-anchored hearing devices, not a specific product name. The Baha is another intervention method which may be used to help overcome the head shadow effect in people with SSD. It was originally developed over 30 years ago for patients with ear canal or chronic middle ear problems who could not be fitted with conventional hearing aids, and was approved by Health Canada as an amplification option for those with SSD in 2003 (Yuen et al., 2009). Also known as an osseointegrated aural prosthesis, the Baha is implanted in individuals with SSD to stimulate the ear with the normal cochlea (Bishop & Eby, 2009; Williams et al., 2012). The Baha requires that a titanium screw be surgically implanted in the temporal bone on the side of the poor ear. This titanium screw is connected to a percutaneous abutment. An electromechanical sound processor (external transducer) is coupled onto the abutment and can be removed when necessary. A period of osseointegration must follow surgery, in which the abutment must fuse with bone before the sound processor can be fit and the device activated. A microphone located on the sound processor picks up sounds originating from the side of the poor ear and transmits them to the contralateral inner ear by means of bone conduction or skull vibrations that directly stimulate the cochlear fluids (Flynn et al., 2010; Niparko et al., 2003). The Baha's direct transmission of sound by bone is highly effective at transmitting a high amount of gain and power output as no energy is lost through subcutaneous skin tissue (Bosman et al., 2003; Wazen et al., 2003). Over the years, the external sound processor has seen improvements in digital signal processing and now includes technologies such as digital noise reduction and directional microphone.

CROS hearing aids were the traditional intervention method for SSD before Baha surgery existed. Being less expensive with no commitment to surgery, CROS continues to be a viable amplification option for SSD participants. Since the fitting of this device is non-invasive, it is generally recommended as a first-step approach before the Baha is considered (Bishop & Eby, 2009).

Subjective and Objective Benefits of Baha and CROS

Many researchers have attempted to examine the subjective benefit and satisfaction with the Baha and CROS using self-assessment questionnaires (Faber, de Wolf, Cremers, Snik & Hol., 2013; Hill et al., 2006; Hol, Bosman, Snik, Mylanus, & Cremers, 2005; Hol et al., 2010a; Lin et al., 2006; Yuen et al., 2009). In the study by Yuen et al. (2009), twenty-one adults with severe to profound SSD who received Baha implantation completed the Abbreviated Profile of Hearing Aid Benefit (APHAB) pre- and post-fitting and the Glasgow Hearing Aid Benefit Profile (GHABP) post-fitting. The APHAB examines four domains of listening: ease of communication, listening in reverberant conditions, listening in background noise and aversiveness to sounds. Higher scores translate to greater difficulty. The GHABP takes in account initial hearing disability, residual disability, handicap, participant use, benefit and satisfaction with hearing aids. A higher score in the first three domains of the GHABP indicate greater difficulty, while higher scores in the latter three domains indicate less difficulty (Hol et al., 2010a). Yuen et al. (2009) administered these questionnaires 3 months following Baha fitting. Scores on three of the four APHAB domains (ease of communication, reverberation and background noise) were significantly lower for the aided condition compared to the unaided condition. The GHABP scores were rescaled so that levels of benefit could be demonstrated from 0 to 100. There was large variation in the scores with the Baha, with the residual disability domain showing a mean score of 33.8, the benefit domain showing a mean score of 48.5 and the satisfaction domain showing a mean score of 58.9. In a similar study by Hol et al. (2010a), Dutch versions of the APHAB and GHABP were administered to 56 participants with SSD both unaided and 6 weeks following Baha experience. In addition, the International Outcome Inventory for Hearing Aids (IOI-HA) and the Single-Sided Deafness Questionnaire (SSDQ) were given post-fitting of the Baha. The IOI-HA measures benefit, use, satisfaction, residual activity limitations, impact on others and quality of life. The SSDQ assesses use, satisfaction, manipulation of the Baha, cosmetics and hearing aid benefit. Results showed improvement with the Baha (especially with background noise) and suggested that quality of life, benefit and satisfaction with the device were substantially higher than the unaided condition.

Faber and colleagues (2013) assessed the subjective benefit of the Baha in a group of 11 elderly adults with SSD. The APHAB, Glasgow Benefit Inventory (GBI) and Hearing Handicap Inventory for the Elderly – screening version (HHIE-S) were administered to participants between the ages of 62 to 86 years. The GBI measures quality of life in three domains: social, general and physical. The HHIE-S examines the emotional and social consequences of hearing loss in the elderly. Results showed that 82% of the elderly participants continued to use their Baha 2 to 6 years post-implantation and were quite satisfied with its performance, feeling that it enhanced their quality of life. The APHAB showed that self-perceived disability from 49% to 42% after having worn the Baha. Ease of communication and background noise were the two domains that showed the greatest improvement. The majority of participants most likely used the device in listening situations that were highly demanding, which could explain their limited daily use. The GBI results showed improvement quality of life on a general and social level having used the Baha, while the HHIE-S showed that 46% of participants classified their handicap as mild to moderate compared to 18% who felt that their handicap was non-existent (Faber et al., 2013).

Very few studies have examined subjective benefits of CROS hearing aids for people with SSD. As part of a larger study on the benefits of CROS and BiCROS, Hill and colleagues (2006) examined 9 participants with severe to profound SSD who wore a corded CROS with digital signal processing. The researchers based acceptance of the device on whether the participants chose to keep the device at the end of their free 30-day trial period. The acceptance rate for the CROS was 66.7% (Hill et al., 2006). It should be pointed out that the CROS hearing aid used by Hill et al. (2006) was an older model with a wire around the neck. Device satisfaction may have been greater had a wireless version of the CROS been worn.

Other researchers have also examined acceptance rates as a means of quantifying the benefits obtained with the Baha. Kompis, Pfiffner, Krebs and Caversaccio (2011) further examined the factors that influence patients' decision to proceed with Baha surgery. All 46 Baha candidates wore a Baha headband for 7-10 days, with 29 deciding to pursue Baha surgery and 17 declining further use of the Baha. They all completed the Bern Benefit in Single-Sided Deafness Questionnaire (BBSS) during their trial period. The BBSS is a 10-item questionnaire that measures participants' perceived benefit from their hearing device. The researchers examined correlations between age, etiology, duration of deafness, transcranial attenuation, hearing thresholds and BBSS ratings with the decision for or against a permanent Baha to determine which factors had the strongest influence. They found that responses on the 10 questions of the BBSS were strongly correlated with the decision to pursue Baha surgery or not, with total values below 10 a strong predictor of Baha rejection. None of the other factors had a strong influence on the decision to choose or decline a permanent Baha.

Benefits of the CROS and Baha for people with SSD have been quantified also using objective measures, such as speech perception performance in quiet and in noise. Several studies showing some benefits of the CROS were conducted many years ago shortly after the concept of CROS amplification was introduced (e.g., Gelfand, 1979; Upfold, 1980). More recent studies using speech perception measures have tended to focus on the Baha. For example, Zeitler, Snapp, Telischi and Angeli (2012) used the Quick Speech-in-Noise Test (QuickSIN) with adults who had undergone Baha surgery after having been offered a trial with the CROS. With the QuickSIN, speech was presented at 90 degrees to the poor ear while noise was presented at 90 degrees to the better ear. Results showed improvement with the Baha compared to the unaided condition. Overall, participants obtained an unaided QuickSIN score of 12 dB (suggesting a moderate SNR loss) compared to an aided score between 2-4 dB (suggesting a normal to mild SNR loss). Therefore, a smaller SNR was needed for speech perception in noise with the Baha. Similarly, Yuen et al. (2009) observed an improvement with the Baha, compared to unaided, when the Hearing in Noise Test (HINT) sentences were presented to the side of the poor ear and noise to the side of the better ear.

Long-Term Effects

Some researchers have examined the long-term benefits of the Baha; however, research on the long-term benefits of the CROS is sparse. Hol and colleagues (2005) measured the long-term effects of the Baha with the APHAB, GHABP, IOI-HA and SSDQ after a 1-year interval. The APHAB did not show a significant deterioration compared to measurements obtained after 6 weeks of Baha usage even though the participants reported using the Baha less often after one year. Subjective benefit for the Baha remained equally as strong after 1 year as it had been after 6 weeks, suggesting that the Baha is highly valued on a long-term basis by those with SSD (Hol et al., 2005).

Newman, Sandridge and Wodzisz (2008) also examined the Baha on a longitudinal basis using speech perception measures and subjective outcome measures. Eight participants with acquired profound SSD underwent testing on a short (1 and 3 months), medium (6 and 9 months) and long-term (12 and 18 months) basis. Speech perception measures were obtained using the Revised Speech Perception in Noise (SPIN-R) test, where sentences were delivered at 50 dB HL to the poor ear, while multitalker babble was delivered to the better ear at +4 dB SNR in soundfield. The HINT was also used, with sentences delivered in front of participants and masking noise at a constant 65 dB(A) from 4 loudspeakers that surrounded the participants. The APHAB, HHIA and SSDQ were all administered to the participants at each time interval. The SPIN-R demonstrated consistent improvement over time at each time interval compared to unaided testing but the HINT showed a high degree of variability in performance as some participants had poorer speech perception at 12 and 18 months post-fitting. The different testing protocols for the SPIN-R and HINT could have explained the discrepancy in results, as the SPIN-R spatially separates the signal and noise to a greater degree than the HINT, in which the noise is diffuse with the speech held constant from the front. The Baha may be more advantageous with a listening situation in which the speech and noise are spatially separated, a scenario that most people with SSD would describe as their most challenging. Although the subjective measures showed a slight decline in daily use over time, long-term satisfaction with the Baha remained strong (Newman et al., 2008).

Comparison of Performance with Baha and CROS

The studies reviewed thus far were conducted with either the Baha or the CROS (e.g., Hill et al., 2006; Yuen et al., 2009; Zeitler et al., 2012). Other researchers have examined the performance of the Baha and CROS within the same study, thus allowing direct comparison between the two devices in the same sample of participants. These studies have compared CROS and Baha on localization abilities (e.g., Hol et al., 2005; Lin et al., 2006; Niparko et al., 2003), speech perception in noise (e.g., Hol et al., 2005; Lin et al., 2006), and self-perceived benefits (e.g., Hol et al., 2005; Hol et al., 2010b; Lin et al., 2006).

Several studies have found that both the CROS and the Baha show no improvement in localizing sound (Baguley, Bird, Humphriss, & Prevost, 2006; Flynn et al., 2010; Hol et al., 2010b, Niparko et al., 2003). To assess sound localization, most researchers used a 9-speaker array positioned at intervals of 30 degrees azimuth to participants with SSD. The stimuli consist of low centre frequency (500 Hz) and high centre frequency (3000 Hz) narrow-band noise that is held constant at 65 dB SPL. Each noise burst is emitted for 1 second. Participants are asked not to turn their head in the direction of the sound. They are scored on the basis of correct identification of the target loudspeaker and judged on lateralization ability (Bosman et al., 2003; Hol et al., 2004; Hol et al., 2005; Hol et al., 2010a; Hol et al., 2010b). Hol and colleagues (2005) tested 29 participants with SSD in 3 conditions: unaided (baseline), after 1 month of CROS use and 4-6 weeks after using their implanted Baha device. Sound localization ability was poor regardless of the condition in which participants were tested. Hol and colleagues (2010a) attempted to expand upon the previous study by adding 27 more participants. Sound localization was assessed at baseline and again after having used the Baha for 6 weeks. However, there was no improvement in sound localization with Baha usage. Similar results for sound localization were found with 10 adults, even though their testing conditions were randomized and they wore a Baha on a steel headband that involved no surgical implantation in the skull (Hol et al., 2010b).

Another method of assessing sound localization involves using the Source Azimuth Identification in Noise Test (SAINT). The SAINT measures sound localization in quiet and noisy conditions. The test utilizes four different stimuli: a pistol shot in quiet, a pistol shot with helicopter background noise, a female voice in quiet and a female voice in crowd noise. Five speakers are situated behind participants as they are asked to identify the location of the sound using a picture of the speaker arrangement (Lin et al., 2006; Niparko et al., 2003). For 10 adults with SSD, sound localization did not improve when wearing the CROS or after Baha implantation (Niparko et al., 2003).

Using the SAINT, Lin and colleagues (2006) investigated the effect of directional microphones on sound localization by having 14 participants with SSD try a directional microphone with their Baha after first using an omnidirectional microphone. Participants only used the CROS with an omnidirectional microphone. Although localization performance was not improved with neither the CROS nor Baha compared to the unaided condition, performance with the Baha, in both the omnidirectional and directional microphone conditions, was better than that with the CROS. Moreover, the Baha with a directional microphone was more helpful than the Baha with an omnidirectional microphone in conditions with background noise (Lin et al., 2006).

There are several advantages and disadvantages that both the CROS and Baha demonstrate with speech perception in noise compared to unaided performance. Although both devices cannot restore binaural hearing, they are effective in reducing the head shadow effect and both can improve speech perception, particularly when speech originates from the poor side (Flynn et al., 2010; Taylor, 2010). However, the devices can actually hinder performance in instances where speech is on the side of the better ear, and noise from the side of the poor ear is transmitted to the better ear (Flynn et al., 2010; Lin et al., 2006; Taylor, 2010).

Hol and colleagues (2005) assessed sentence reception thresholds (SRTs) for 29 participants with SSD who had worn the CROS for 1 month and had experienced 4-6 weeks of habituation with the Baha following surgery. Lateral noise was defined as the testing condition in which speech was presented to the front of participants and noise was presented to the poor or better ear at 90 degrees. Lateral speech was defined as the testing condition in which noise was presented to the front of participants and speech was presented to the poor or better ear at 90 degrees (Hol et al., 2004). Hol and colleagues (2005) found that when lateral speech consisting of short everyday sentences was presented to the poor ear, both the Baha and CROS were superior to the unaided testing condition. The CROS was not as successful as the Baha in overcoming the head shadow effect, most likely due to the open ear mold in the participants' better ear. However, with lateral noise presented at 65 dB(A) to the poor ear, performance was actually better when neither device was worn. Noise near the poor ear does not present a problem for those with SSD until it is amplified. This noise is best left unaided since its intensity will attenuate as it travels around the head to the better ear (Lin et al., 2006; Yuen et al., 2009). Moreover, Hol and colleagues (2005) found that speech perception performance was worse with the CROS than the Baha: using the CROS with lateral noise presented to the poor ear actually posed a disadvantage to participants. The CROS seems to transmit noise from the poor to the better ear more efficiently than the Baha, thus interfering with the speech signal. Perhaps the Baha is more effective with the noise reduction from the poor side, leading to less transmission of noise to the better ear. This would maintain the natural effect of the acoustic head shadow (Lin et al., 2006). However, Hol and colleagues (2010a) found that when noise was presented to the poor ear of 56 participants with speech presented to the front, the head shadow effect worsened with the Baha compared to the unaided condition.

Both the Baha and CROS are now equipped with circuitry for noise reduction and directional microphones. This technology has the potential to show improvement in managing noise on the side of the poor ear (Flynn et al., 2010). Researchers have investigated the benefits of directional microphones in Baha devices, but little attention has been placed on investigating CROS with directional microphones. Lin and colleagues (2006) examined the influence of a directional microphone on the performance of the Baha. Twenty-three SSD participants were originally fit with the

Telex CROS ACT II BTE for 1 month and completed the HINT, with SRTs measured in and with constant white noise at 65 dB(A). The noise was presented in front of participants, to the poor ear at 90 degrees and to the better ear at 90 degrees. It was not clearly stated whether the test conditions were counterbalanced and at what azimuth speech was presented. None of the participants showed preference for the CROS but instead, chose to undergo surgery with the Baha Compact model. They completed the HINT with the Baha in omnidirectional mode. Fourteen participants chose to pursue the option of wearing the Baha with a directional microphone for further testing one month later. There was no significant advantage to using the CROS or Baha with noise presented to the front of participants. Even though the aided SRTs were inflated for both devices with noise presented to the poor ear, the Baha presented less of a disadvantage than the CROS. Since the head shadow effect does not attenuate the level of noise reaching the better ear, the benefit seen with the Baha is presumably due to the directional microphone. SRTs with noise to the poor ear were lower than SRTs with noise to the better ear, presumably because the head shadow effect present with the former condition attenuated the noise to a greater degree before it merged with the speech signal (Lin et al., 2006). It is important to note that this study compared an older CROS model with an omnidirectional microphone to a relatively newer Baha model in both omni- and directional mode. These results should be viewed with caution because directional microphones (which are also available with the CROS) were not considered in this study.

In comparing the Baha to the CROS on subjective outcome measures, Lin and colleagues (2006) administered the APHAB to 23 SSD participants who wore the CROS for 1 month and then underwent Baha implantation with the option of wearing a directional microphone. They all demonstrated a strong preference for the Baha across 3 of the APHAB's communication subscales. Hol and colleagues (2005) also evaluated subjective measures for 29 participants with SSD who had worn the CROS for 1 month and the Baha for 4-6 weeks following surgery. They administered Dutch versions of the APHAB, GHABP, IOI-HA and SSDQ. The APHAB results showed that the Baha was subjectively rated better than the CROS in the domains ease of communication, background noise and reverberation. The CROS was rated negatively on the aversiveness to sounds subscale, possibly because the Baha presents a lower limit in maximum output. The GHABP revealed that participants used the Baha more often on a daily basis than the CROS, rated CROS benefit and satisfaction lower and reported greater residual disability with the CROS. The IOI-HA showed that the Baha was strongly recommended for others with the same hearing loss and the SSDQ demonstrated greater improvement with quality of life using the Baha (Hol et al., 2005).

Baguley and colleagues (2006) conducted a systematic review of four studies that compared the Baha and CROS aid using speech perception testing and subjective questionnaires in unaided, CROS and Baha conditions. All of these studies found that the Baha exceeded the CROS in demonstrating improved speech perception in noise abilities and subjective preference (Bosman et al., 2003; Hol et al., 2004; Niparko et al., 2003; Wazen et al., 2003). Bosman and colleagues (2003) found that for 9 participants with SSD who were tested 4 weeks after wearing the CROS and 4 weeks after undergoing Baha surgery, both the Baha and CROS reduced the head shadow effect for Dutch sentences that were presented to the poor and better ear with noise presented to the front of participants. However, the APHAB results showed stronger preference for the Baha. Niparko and colleagues (2003) measured speech perception with the HINT and subjective benefit with the APHAB and GHABP in 10 participants with SSD. The researchers used four HINT conditions: quiet, noise presented to the front of participants, noise presented to the left and noise presented to the right. They found that the Baha resulted in better speech perception than the CROS for half of the HINT conditions. The CROS offered little subjective benefit compared to the Baha according to the APHAB, while the GHABP showed that levels of benefit, satisfaction and residual disability were more favourable for the Baha (although the differences between the Baha and CROS were not as significant). Wazen and colleagues (2003) conducted a multisite prospective study. After wearing the CROS for 1 month, 30 participants with SSD received Baha surgery, with 18 of these participants from 3 U.S. sites. They were tested 4-8 weeks following CROS wear and again 4-8 weeks following Baha usage. The HINT revealed that speech perception in noise improved more with the Baha and it was subjectively preferred more than the CROS in terms of perceived benefit (APHAB) and satisfaction (SSDQ). Finally, Hol and colleagues (2004) verified the subjective preference for Baha over CROS with the APHAB results from their 20 participants but found that speech perception was equally as good with the Baha and CROS when noise was presented to the better ear.

In the studies reviewed by Baguley et al. (2006), as well as in the study by Lin et al. (2006), the CROS was always fit before the Baha. Hol and colleagues (2010b) attempted to address the limitation of non-randomization by comparing a wired CROS hearing aid to a Baha that was worn on a headband. For 10 participants who wore each device for 8 weeks in randomized order, performance with the CROS was found to be greater than that of the Baha on some measures. The Speech Spatial Qualities Questionnaire (SSQ) assessed listening ability in 49 communication scenarios. Although both the Baha and CROS were rated favourably according to the results of the SSQ, the APHAB and SSDQ showed that the CROS was favoured more and the SNRs with speech presented to the poor ear were better with the CROS than for the Baha (Hol et al., 2010b). It is possible that these favourable results for the CROS might simply be because the CROS was compared to the Baha headband. Perhaps the results would have been different had the CROS been compared to a surgically implanted Baha, since this device is more powerful.

Limitations of Previous Research

There were several methodological flaws that could have potentially skewed the results of the studies included in Baguley and colleagues' systematic review (2006). The CROS was always fit before the BAHA; the order of fitting was not randomized across participants and therefore did not account for order effects. The researchers did not adequately describe how the CROS aids were fit to allow for replication in future studies. All of the studies included in the systematic review were statistically underpowered and there was a double reporting of participants across the four studies. A prospective, randomized controlled trial (RCT) with greater number of participants and statistical power is needed in future to determine if these results can be replicated (Baguley et al., 2006; Bishop & Eby, 2009).

Although greater support has generally been found for the Baha than for the CROS, it should be noted that the majority of the previous studies have used older CROS models with basic analog technology or single-channel digital circuitry and a wire around the neck to transmit sounds from the poor ear to the better ear (Bishop & Eby, 2009; Hill et al., 2006; Hol et al., 2010b; Taylor, 2010). Studies that used a Baha with a directional microphone compared the device to the CROS in omnidirectional mode only (Lin et al., 2006). The sound quality of older CROS models was considered to be very poor, as the better ear was typically occluded with an ear mold, blocking sound from naturally entering the ear canal on that side (Bishop & Eby, 2009; Hol et al., 2005; Wazen et al., 2003). There is a lack of research comparing the newer wireless CROS hearing aid with directional microphones to current Baha models with directional microphones. In particular, it is imperative that studies use randomized test conditions when comparing the Baha to unoccluding digital wireless CROS devices that are currently on the market today (Bishop & Eby, 2009).

The present research study will build upon pre-existing studies that have compared the CROS hearing aid and Baha to determine if a new digital wireless CROS device can demonstrate at least equivalent benefit as the Baha in improving speech perception and participant benefit. If the CROS is found to be at least equally as beneficial as the Baha in maximizing hearing performance and participant satisfaction, this could have implications for participants currently on a waiting list for Baha surgery as they should first be counselled about the CROS hearing aid before considering surgical intervention. The overall research question asks whether the newer model of CROS hearing aid offers equivalent or greater benefit than the Baha for people with single-sided deafness. More specifically, the research questions are: How does the reduction of the head shadow effect compare for the Baha and the CROS? How does speech perception in quiet environments compare for the Baha and the CROS when speech originates from the side of the poor ear? How does speech perception in noise compare for the Baha and the CROS when speech is from the front and noise is on the side of the poor ear and on the side of the better ear? How do self-perceived benefits during daily activities compare for the Baha and CROS?

CHAPTER 2 - METHODS

Participants

Ten individuals diagnosed with single-sided deafness who were fit with Baha participated in the study. One participant dropped out of the study before completing the final visit. The remaining nine participants ranged from 44 to 66 years of age, with the average age being 54 years. One participant was male while eight participants were female. All participants had undergone Baha implantation within the last three years. Four participants were fit with a Cochlear BP100, four participants were fit with an Oticon Medical Ponto Pro and one participant was fit with a Cochlear Intenso. A review of their audiological files revealed that none of the participants had tried CROS hearing aids prior to Baha implantation. Table 1 provides descriptions of each participant, outlining the age at participation in this study, gender, Baha model worn and length of implantation.

All participants exhibited unaided pure tone air conduction thresholds within normal limits between 250 and 4000 Hz for the better ear except Participant 4 who showed a mild low frequency hearing loss; moreover, four participants exhibited a mild hearing loss at 6000 and/or 8000 Hz only. Unaided pure tone air conduction thresholds for the poor ear typically ranged from moderate to profound hearing loss. Table 2 outlines participants' unaided pure tone thresholds for the better ear, while Table 3 specifies the unaided pure tone thresholds for the poor ear.

Table 1
Participant descriptions

Participant	Age	Gender	Baha Model	Length of Implantation
1	49	Female	Cochlear BP100	~1 year
2	56	Female	Cochlear BP100	~2.5 years
3	44	Female	Oticon Medical Ponto Pro	~1 year
4	66	Female	Oticon Medical Ponto Pro	<1 year
5	46	Male	Oticon Medical Ponto Pro	~1 year
6	55	Female	Cochlear Intenso	~1.5 years
7	65	Female	Oticon Medical Ponto Pro	<1 year
8	57	Female	Cochlear BP100	~2.5 years
9	54	Female	Cochlear BP100	~2.5 years

Procedure

Participants' performance was compared between their own Baha and the Unitron Tandem 4 CROS hearing aid fitted with open domes. A within-subject, repeated measures design was utilized, in which all participants completed every condition of the research study. Data collection for each participant occurred over three visits, with each session lasting approximately an hour and a half. The total duration of the study for each participant occurred over a period of at least six weeks.

Baseline measures. On the first visit, participants reviewed and signed the consent form. During their initial visit, baseline unaided audiological testing was conducted. To quantify each participant's degree of hearing loss, pure tone air conduction thresholds were obtained with inserts for frequencies ranging from 250-8000 Hz (see Table 2 and Table 3). Warble tone thresholds were then obtained in soundfield at 2000, 3000, 4000 and 6000 Hz. Thresholds were obtained with warble tones presented at 90 degrees to the poor ear and with warble tones presented at 90 degrees to the better ear, with the difference in threshold between the two conditions providing the amount of head shadow. The two conditions were counterbalanced across participants to account for order effects.

Speech perception measures. Unaided testing continued with the administration of two speech perception measures in soundfield: word recognition testing and the QuickSIN. The order of word recognition testing and the QuickSIN was also counterbalanced across participants. Word recognition was tested with the recorded version of the CID W-22 (Auditec of St. Louis), with three different lists each consisting of twenty-five monosyllabic words presented at 50 dB HL across three different listening

Table 2
Unaided hearing thresholds for participants' better ear

Participant	Frequency (Hz)							
	250	500	1000	2000	3000	4000	6000	8000
1	10	5	5	5	10	5	10	25
2	5	5	5	5	10	20	20	20
3	5	5	5	0	0	-5	5	5
4	45	30	10	5	10	5	5	35
5	10	15	5	5	15	15	35	45
6	10	10	0	15	10	5	15	5
7	0	10	15	5	20	20	25	40
8	20	20	0	10	25	20	25	40
9	10	15	20	10	5	5	5	15

Table 3
Unaided hearing thresholds for participants' poor ear

Participant	Frequency (Hz)							
	250	500	1000	2000	3000	4000	6000	8000
1	100	95	70	65	80	80	65	85
2	75 VT	85 VT	100 VT	NR	NR	NR	DNT	DNT
3	NR	NR	NR	NR	NR	NR	NR	NR
4	100 VT	100 VT	95	100	85	NR	NR	NR
5	NR	NR	NR	NR	NR	NR	NR	NR
6	85	90	80	90	95	100	NR	NR
7	65 VT	NR	NR	NR	NR	NR	NR	NR
8	30	75 VT	NR	NR	NR	NR	NR	NR
9	55	50	50	60	60	60	70	70

*VT = Vibrotactile response, *DNT = Did not test, *NR = No response conditions. In the first condition, one list was presented at 50 dB HL at 90 degrees to the poor ear in quiet. In the second condition, the words were presented at 50 dB HL at 0 degrees while multitalker noise was presented at 45 dB HL at 90 degrees to the poor ear. This condition presented a speech-to-noise ratio of +5 dB. In the final condition, the words were presented at 50 dB HL at 0 degrees while multitalker noise was delivered at 45 dB HL at 90 degrees to the better ear, presenting a speech-to-noise ratio of +5 dB. The order of the three listening conditions was randomized both across participants and across visits for the same individual participant.

The QuickSIN, consisting of four lists of six short sentences spoken by the recorded voice of a female speaker, was administered at 50 dB HL in soundfield. Multitalker noise was presented in conjunction with the target sentence and increased at a fixed number of dB with the completion of each sentence, with the SNR varying with each adjustment. Participants were asked to ignore the multitalker noise and repeat each sentence. The multitalker noise was initially presented at 25 dB HL (signal-to-noise ratio of 25 dB), and increased by 5 dB after each sentence until the multitalker noise was of equal intensity with the final sentence (signal-to-noise ratio of 0 dB). The lists with the speech and multitalker noise recorded on separate channels were used to allow for a different presentation azimuth for the speech and noise. Two different conditions were assessed with the QuickSIN and counterbalanced both across participants and across visits for the same individual participant. In one condition, two lists of sentences were presented to the participant at 0 degrees with the multitalker noise delivered at 90 degrees to the poor ear. In the other condition, two different lists of sentences were presented to the participant at 0 degrees with the multitalker noise delivered at 90 degrees to the better ear. Two different lists of sentences were presented within each condition and the two scores were averaged. If the score was found to differ by 4 dB or more for two lists of the same condition, a third list was administered and the two scores that were most similar were averaged.

At the end of the first visit, participants were either instructed to continue wearing their Baha for the next two weeks or were fit with the CROS hearing aids to be worn for the next two weeks. Five participants wore their Baha first and were subsequently tested with this device on their second visit, while the other four participants were fit with the CROS first and subsequently tested with this device on their second visit. Order of device fitting and usage was randomized across participants.

Those fit with the CROS following unaided testing had the device programmed to their hearing loss with Unitron's software, UFit. All were fit with a slim tube and open dome, since hearing was relatively normal for all participants in the better ear. Real-ear measures were performed using the Audioscan Verifit system. A probe module was first placed on each ear and a probe tube was inserted into the better ear only. The CROS aids were set at maximum volume as recommended by the manufacturer and the participant was positioned with the better ear facing the speaker at 45 degrees, with "BTE" selected on the Verifit. The "carrot story" was played at 65 dB SPL and a curve was recorded. Then the participant was positioned with the poor ear facing the speaker at 45 degrees and "CROS" selected on the Verifit, a second curve was recorded while the participant listened to the carrot story again. If the two curves did not match at frequencies above 1000 Hz, the graduate student researcher fine-tuned the CROS hearing aid and repeated the verification procedure. The low frequencies were not modified as the CROS was fit with open domes, thus providing minimal low frequency gain. Participants were counselled on the insertion and removal of the CROS, battery replacement, volume control, removal of domes for cleaning and the difference between left and right aids. At the end of the first visit, participants were given a diary form (Appendix A) and instructed to indicate the date the device was worn, hours of device use per day and situations in which the device was worn (e.g., during a meeting at work, walking on the street in traffic, during a dinner party, etc.). The diary form was given to all participants regardless of the device that was to be worn for the next two weeks.

Aided measures. The second visit began with collection of the diary form from participants and proceeded with aided measurements, where each participant was tested with the device that had been worn the previous two weeks. Similar to the baseline measures, soundfield thresholds were obtained with warble tones delivered 90 degrees to the better ear in one condition and 90 degrees to the poor ear in the other condition. The speech perception measures of word recognition testing and the QuickSIN were administered in a counterbalanced fashion. Finally, two self-assessment questionnaires, the Bern Benefit in Single-Sided Deafness Questionnaire (BBSS) and the Speech Spatial Qualities Questionnaire (SSQ) were given to assess the self-perceived benefits provided by the device that was worn the previous two weeks (Gatehouse & Noble, 2004; Kompis et al., 2011). The BBSS (Appendix B) is a 10-item questionnaire that measures participants' perceived benefit from their CROS or Baha device. The 10 items examine different situations in which participants rate the benefit derived from their device with ratings that range from -5 ("Much Easier Without the Aid") to +5 ("Much Easier With the Aid"). A higher score indicated that participants felt the device offered more benefit in challenging listening situations compared to no device. The SSQ (Appendix C) describes 49 scenarios in which participants may experience difficulty hearing. Participants rated their perceived hearing ability for all scenarios using a 10-point scale, ranging from "Not at all" to "Perfectly". A higher score indicated greater self-perceived benefit from the device. The self-assessment questionnaires took approximately fifteen minutes to complete. After completion of the SSQ and BBSS, participants were given another diary form and left the second visit wearing the device that had not been worn the previous two weeks. Therefore, those who had initially worn the Baha between their first and second visits were now fit with the CROS and those who wore the CROS between their first and second visits left the second visit wearing their Baha for the remaining two weeks of the research study.

At the beginning of the third visit, the graduate student researcher collected the diary form concerning the hearing device worn the previous two weeks. Participants wore this device while aided measures were once again completed with warble tones presented in soundfield and speech perception testing. Participants completed the SSQ and BBSS once again on the device worn during the past two weeks. Finally, the graduate student researcher verbally asked participants whether the Baha or CROS hearing aid was preferred and questioned them on the specific reasons for their choice.

CHAPTER 3 - RESULTS

Head Shadow Effect

To measure the head shadow effect, participants' soundfield thresholds were measured between 2000 and 6000 Hz using warble tones presented at 90 degrees to the poor ear and at 90 degrees to the better ear. The head shadow effect was calculated as the difference between the two hearing thresholds at each frequency. The head shadow effect was calculated for each listening condition: unaided, Baha and CROS. Figure 1 shows the average difference between thresholds with sounds to the poor ear and better ear for each listening condition. Lower threshold differences between the two ears represent a greater reduction in the head shadow effect.

A one-way ANOVA for repeated measures was conducted for each frequency to determine whether the amount of head shadow effect differed for each of the 3 listening conditions. At 2000 Hz, there was a significant effect of listening condition on the head shadow effect ($F(2,16)=4.52$, $p=.028$). Post-hoc Least Significant Difference (LSD) tests revealed that the CROS significantly reduced the head shadow effect ($p=.009$) compared to the unaided condition but the Baha did not significantly reduce the head shadow effect ($p=.081$). However, there was no significant difference between the CROS and the Baha ($p=.512$).

Similar to the results for 2000 Hz, there was a significant effect of listening condition on head shadow effect at 3000 Hz ($F(2,16)=3.682$, $p = .048$). Post-hoc LSD tests showed that the CROS significantly reduced the head shadow effect compared to the unaided condition ($p=.026$); however the Baha did not significantly reduce the head shadow effect ($p=.073$). Comparison of the Baha to the CROS showed no significant difference ($p=.594$).

At 4000 Hz, there was no significant effect of listening condition on head shadow effect (F(2,16)=1.725, p=.21).

At 6000 Hz, there was a significant effect of listening condition on head shadow effect (F(2,16)=7.685, p=.005). Post-hoc LSD tests revealed that the CROS significantly reduced the head shadow effect compared to the unaided condition (p=.002) and so did the Baha (p=.017). There was no significant difference between the CROS and the Baha, however (p=.889).

Speech Perception Measures

The percentage of correctly repeated words from the recorded version of the W-22 word lists was calculated for the quiet and noise listening conditions. Figure 2 displays the word recognition score percentages for the unaided, Baha and CROS conditions.

A one-way ANOVA for repeated measures was conducted for each word recognition measure to determine if there were any significant differences between the unaided, CROS and Baha conditions. Results showed that when speech was presented in quiet at 90 degrees to the poor ear, there was no significant effect of listening condition on word recognition scores (F(2,16)=.707, p=.508). Similarly, when speech was presented at 0 degrees and multitalker noise was presented at 90 degrees to the poor ear, there was no significant effect of listening condition on word recognition scores (F(2,16)=3.312, p=.063). When speech was presented at 0 degrees and multitalker noise presented at 90 degrees to the better ear, there was also no significant effect of listening condition on speech recognition scores (F(2,16)=2.774, p=.092).

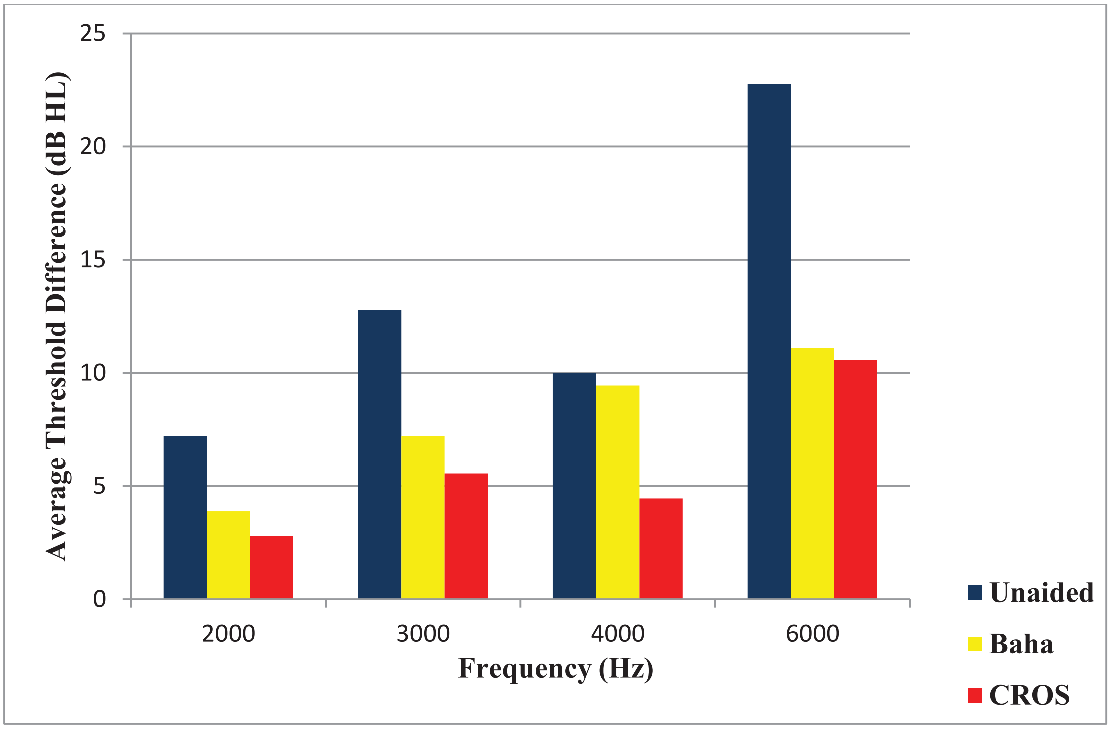

Figure 1. Head shadow effect: Difference in thresholds with warble tones presented to good and poor sides.

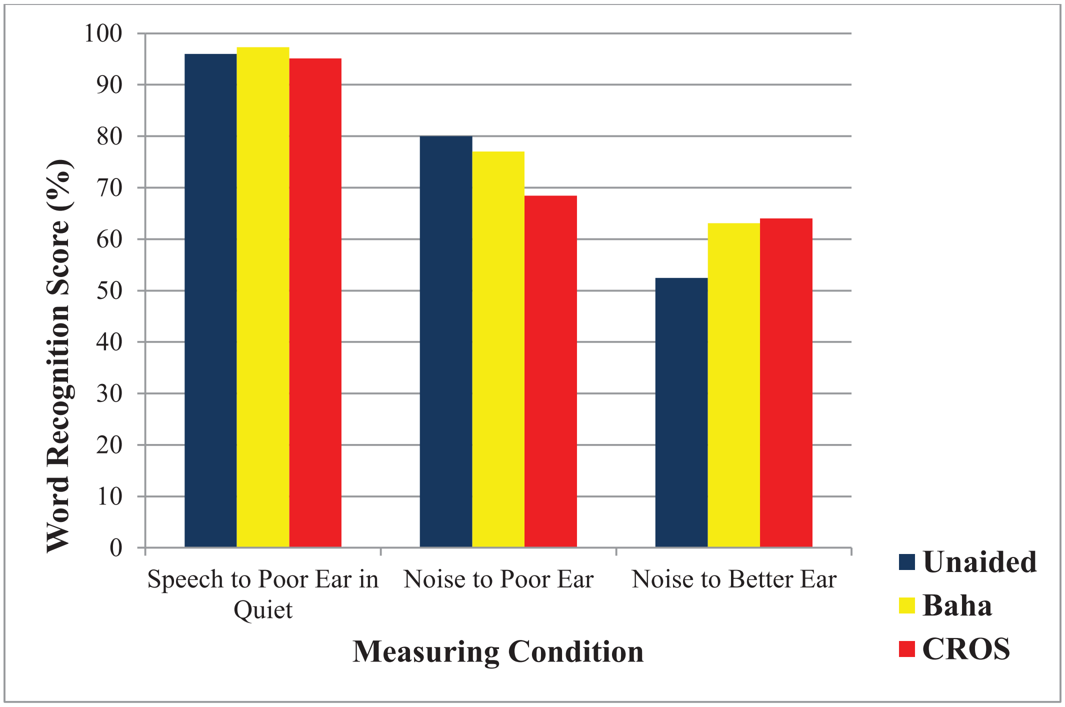

Figure 2. Word recognition scores in quiet and noise for unaided, Baha and CROS conditions.

The QuickSIN was scored using standard test procedures. Five key words for each of the 6 sentences of every list are scored, with one point awarded for each correct word. The total number of correct words for each sentence is summed across the list for all 6 sentences. This total sum is then subtracted from 25.5, resulting in the score. The score is defined as the increase in signal-to-noise ratio required by a hearing-impaired listener to identify 50% of key words in the sentence lists compared to normal-hearing peers. A low QuickSIN score indicates better performance. Figure 3 outlines participants' average scores for the QuickSIN sentences presented in unaided, Baha and CROS conditions.

A one-way ANOVA for repeated measures was conducted for the QuickSIN for each azimuth testing condition. With multitalker noise presented at 90 degrees to the poor ear, there was a significant effect of listening condition on the ability to perceive sentences in noise ($F(2,16)=16.632$, $p=.000$). Post-hoc LSD tests revealed that the CROS significantly reduced the ability to perceive sentences when noise was presented to the poor ear ($p=.000$) and so did the Baha ($p=.017$) compared to the unaided condition. There was also a statistically significant difference between the CROS and the Baha ($p=.042$). The Baha did not reduce the ability to perceive sentences, when noise was presented to the poor ear, as much as the CROS did.

With multitalker noise presented at 90 degrees to the better ear, there was no significant effect of listening condition on the ability to perceive sentences in noise ($F(2,16)=.730$, $p=.497$). Compared to the unaided condition, neither the Baha nor the CROS improved the ability to perceive sentences when noise was presented to the better ear.

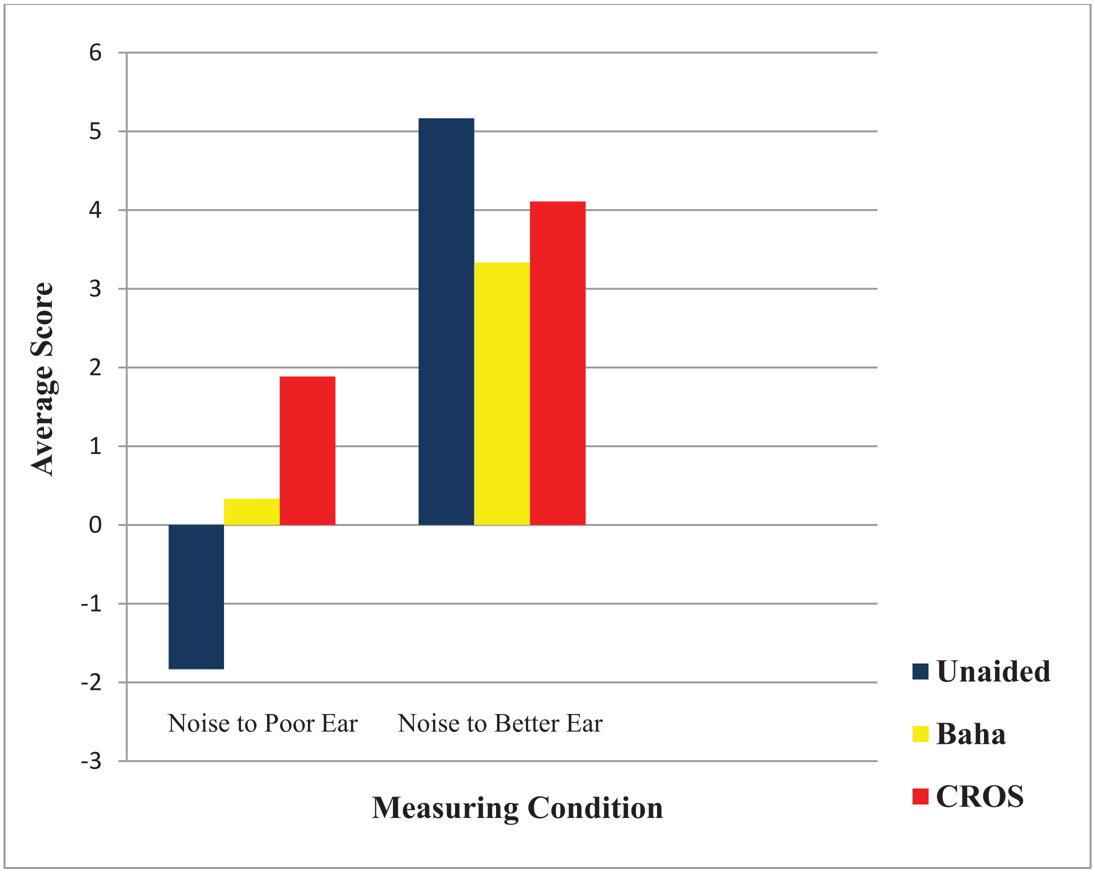

Figure 3. QuickSIN scores for unaided, Baha and CROS conditions.

Self-Assessment Measures

The BBSS and SSQ questionnaires were scored using the standard test procedures. Similar to Kompis et al. (2011), individual scores for the BBSS were obtained by adding the ratings for each listening scenario. The total score, averaged across participants, was 23.6 (range = 3 to 39) for the Baha and 26.4 (range = 11 to 40) for the CROS.

Figure 4 depicts the BBSS mean, minimum and maximum scores for each communication scenario across all participants. For each scenario, a score higher than 0 shows benefit of the device. As seen in Figure 4, the mean score for each scenario was greater than 0 for the Baha and CROS conditions. Thus, the CROS and Baha were both subjectively rated as beneficial in the communication situations outlined by the BBSS.

The Wilcoxon Signed Ranks test was used to investigate whether there was a significant difference between the CROS and Baha on the BBSS total scores. Results showed that there was no significant effect of listening condition on the BBSS scores ($Z = -.356$, $p = .722$).

To obtain individual scores for the SSQ questionnaire, the ratings for each listening scenario were summed. The total score, averaged across participants, was 269.5 (range = 193 to 337) for the Baha and 286.1 (range = 216 to 399) for the CROS.

Figure 5 illustrates the mean, minimum and maximum scores for each subscale of the SSQ across all participants. A score of 0 on any given listening scenario indicates that the device was not at all helpful. A score higher than 0 for each listening scenario shows some benefit of the device, while a score of 10 indicates the device was extremely beneficial. As seen in Figure 5, the mean score for each scenario was greater than 0 for

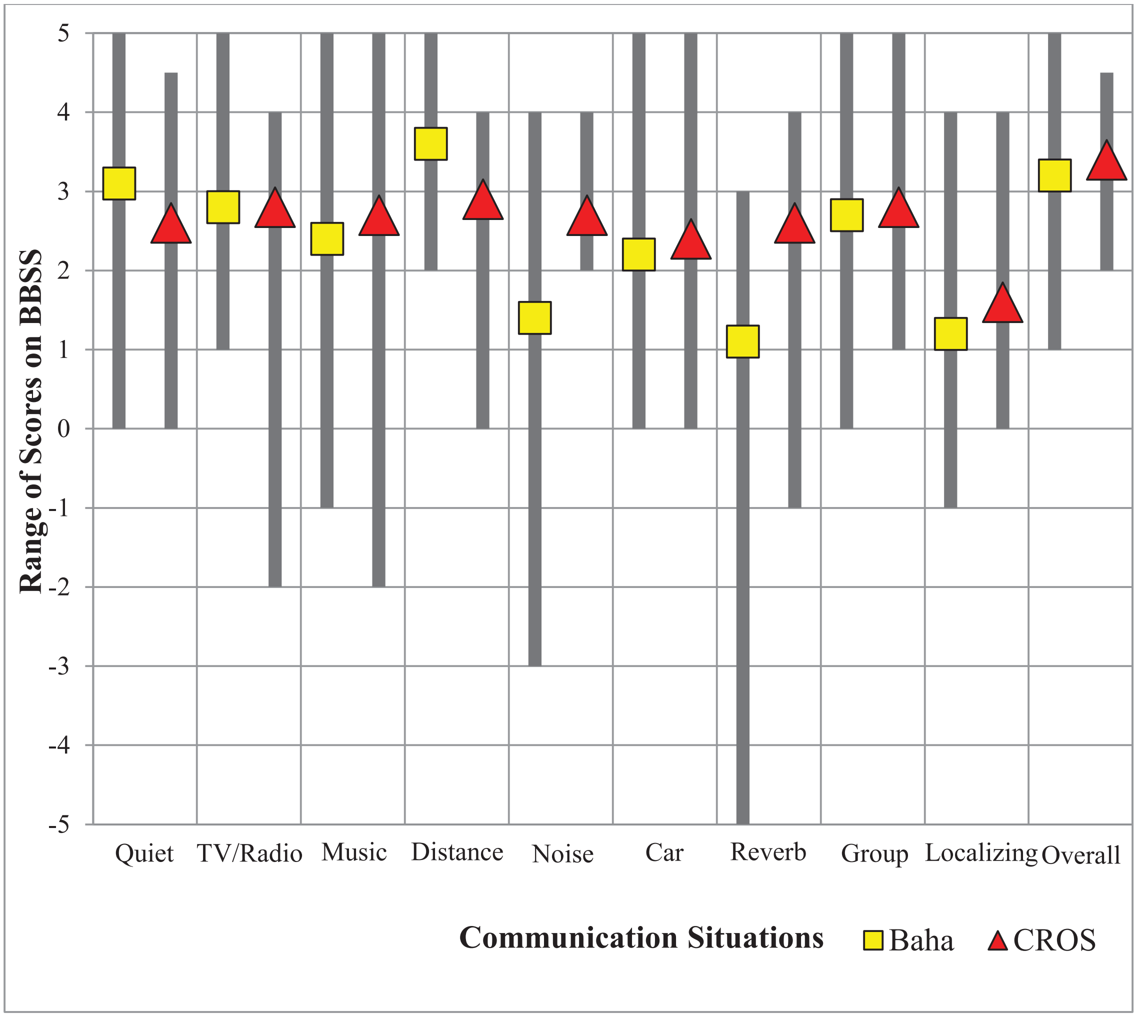

Figure 4. BBSS mean, minimum and maximum scores for each communication scenario (Baha and CROS).

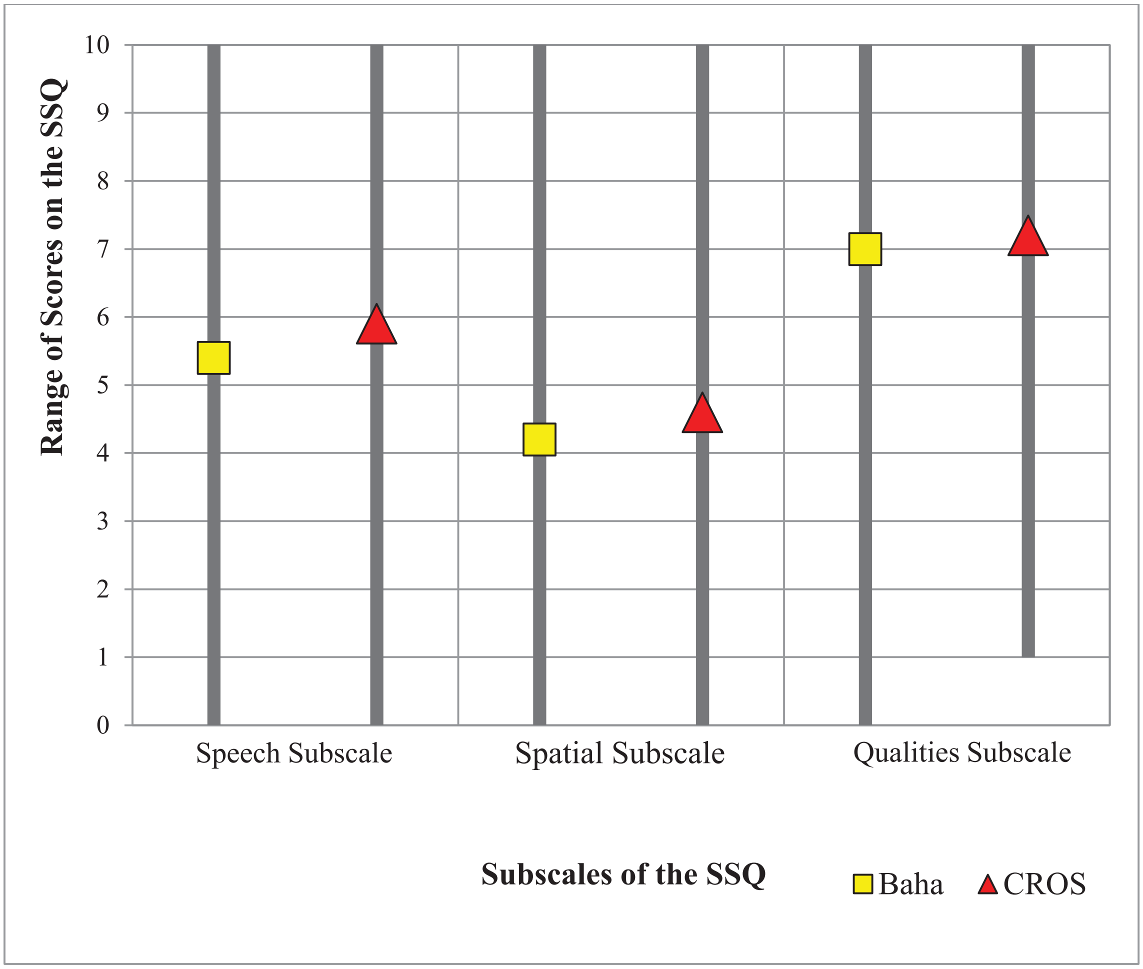

Figure 5. Mean, minimum and maximum scores on SSQ subscales (Baha and CROS).

the Baha and CROS conditions. Therefore, both the CROS and Baha were subjectively rated as beneficial in the listening scenarios outlined by the SSQ.

The Wilcoxon Signed Ranks test was used to determine if the CROS was significantly different from the Baha on the SSQ questionnaire. The overall results, with all SSQ subscales combined, showed that self-perceived benefit was not significantly influenced by the type of hearing device ($Z=-.830$, $p=.407$). There were also non-significant differences for the three individual subscales.

Data obtained from the Baha and CROS diaries were analyzed descriptively. Depending on the time that elapsed between visits, some participants wore their hearing device a few days more or less than the two-week trial period. As outlined in Table 4, participants used either device between 10 and 18 days. The average number of hours of use per day varied among participants, and ranged from 5 to 15 hours.

Participants were also asked to tally in which situations they used the Baha or CROS daily. The number of times that participants used the Baha for each communication situation is displayed in Table 5.

Overall, the Baha was used more often in the car and in one-on-one communication situations at home. The device was worn less often during outdoor activities, in group communication situations at home, and in other situations specified by the participants such as church and theatre.   All nine participants wore the Baha while in a restaurant or coffee shop, travelling by car and walking. The Baha was only worn by five participants in group communication situations at home.

Table 4
Diary data for Baha and CROS hearing aid usage

	Days of Usage		**Average # of Hours/Day**	
Participant	**Baha**	**CROS**	**Baha**	**CROS**
1	12	10	8	10.5
2	11	14	9	8
3	14	12	7	7
4	14	14	9	9.5
5	13	12	12	14
6	14	14	5	9
7	18	14*	12	14*
8	15	11	15	12
9	14	16	9	5

*Participant wore both Baha and CROS for 4 days during CROS trial period

Table 5
Number of times that the Baha was used in the communication situations outlined in the diary

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Tota l**
One-on-one (Work)	10	x	6	x	13	7	10	12	10	68
Group (Work)	10	x	6	x	13	8	10	12	10	69
One-on-one (Home)	8	11	x	14	13	7	12	11	14	90
Group (Home)	x	5	x	7	13	1	x	x	14	40
Restaurant/ Coffee Shop	1	3	2	3	13	7	6	3	10	48
Car	12	5	7	13	13	13	13	2	14	92
Walking	10	8	6	8	13	6	4	3	14	72
Outdoor	x	3	5	1	x	2	x	4	14	29
Other	5	5	6	10	x	7	3	4	x	40

x – Participant did not use device in this situation

Table 6 displays the number of times that the CROS was used in each communication situation outlined in the diary. Similar to the Baha results, the CROS was worn more often in one-on-one communication situations in the home and in the car, and it was used less often outdoors. All nine participants wore the CROS in one-on-one communication situations and restaurants or coffee shops. Only five participants wore the CROS outdoors.

When questioned about their preferred hearing device overall, five out of nine participants preferred the CROS hearing aid to the Baha, citing sound quality as the main reason for their choice. Three participants preferred the Baha compared to the CROS for convenience of wear as they did not like having to wear two hearing aids and struggled with retention of the CROS domes. One participant remained undecided, as she liked the comfort offered by the Baha but preferred the sound quality of the CROS.

In terms of whether the Baha model influenced the choice of device, two out of four Cochlear BP100 users preferred the Baha, one preferred the CROS and the other participant was the one who remained undecided. With the Oticon Medical Ponto Pro, three out of four preferred the CROS while the other person preferred the Baha. The participant who wore the Cochlear Intenso preferred the CROS. These findings were not statistically analyzed but the general trends suggest that the Baha model did not influence participants' choice of device.

Table 6
Number of times that the CROS was used in the communication situations outlined in the diary

	1	2	3	4	5	6	7	8	9	Total
One-on-one (Work)	4	x	6	x	12	7	8	10	13	60
Group (Work)	4	1	5	x	12	7	3	9	12	53
One-on-one (Home)	10	2	4	14	12	13	14	11	16	96
Group (Home)	4	12	1	3	12	13	7	x	16	68
Restaurant/ Coffee Shop	5	5	3	2	12	9	8	3	14	61
Car	10	5	3	10	10P	17	16	x	16	87
Walking	10	14	8	6	12	6	5	x	16	77
Outdoor	x	3	3	x	x	1	1	x	16	24
Other	6	6	3	10	1	2	10	2	16	56

x – Participant did not use device in this situation

CHAPTER 4 - DISCUSSION

Using objective and subjective outcome measures, the present study was conducted to determine if a new digital wireless model of CROS hearing aid offers equivalent or greater benefit than the Baha for 9 participants with single-sided deafness. The two devices were compared on the reduction of head shadow effect, speech perception in quiet with words originating from the side of the poor ear, speech perception in noise with speech delivered at the front of the participants and noise on the side of the poor ear and the side of the better ear, and self-perceived benefits during daily activities.

For each unaided and aided conditions, the head shadow effect was calculated as the difference between thresholds obtained with warble tones presented in soundfield to the poor and better ear; and a significant difference between a device and the unaided condition suggested that the device was able to overcome the head shadow effect. The CROS was successful in overcoming the head shadow effect at 2000, 3000 and 6000 Hz, while the Baha only helped to overcome the head shadow effect at 6000 Hz compared to the unaided condition. Although there was no significant difference between the CROS and Baha for any frequency tested, the CROS helped reduce the head shadow effect at a greater number of frequencies than the Baha.

When monosyllabic words were presented in quiet on the side of the poor ear, participants performed very well in all listening conditions, with scores over 95% for the unaided, Baha and CROS conditions. There was no significant difference between the listening conditions; thus the CROS and Baha did not provide benefits with speech directed to the poor ear at an average conversational level in quiet. This result was not surprising. As pointed out by Flynn (2010), in quiet situations people with single-sided deafness can use their better ear to compensate for the hearing loss in their poor ear. Moreover, participants of the current study already performed so well in the unaided condition that the devices were not able to demonstrate much additional benefit. With speech presented at a conversational level in quiet, the audibility of high frequency speech cues is not significantly affected by the head shadow; that is, although speech delivered to the poor ear may arrive at the good ear with less intensity, it remains sufficiently audible for accurate perception. The unaided condition may have been more challenging had the speech stimuli been delivered at a level softer than 50 dB HL.

Trends in the speech perception results with noise at 90 degrees to the poor ear differed for the word recognition scores and the QuickSIN. Word recognition scores were not significantly influenced by the listening condition when multitalker noise was presented to the poor ear, however, QuickSIN scores were. It is possible that measuring speech recognition using monosyllabic words was not a sensitive enough test to assess differences between conditions. Previous research that has used sentences in noise (e.g., Hol et al., 2005; Lin et al., 2006) suggests that the unaided condition is better than wearing the CROS or Baha when noise originates from the poor side, because both devices transmit the noise to the better ear. Similar results were found in this study with the QuickSIN. With noise presented at 90 degrees to the poor ear, participants performed very well in the unaided condition, with an average score close to -2; however performance was negatively affected when the Baha and CROS were worn, with the CROS having more of an adverse effect on speech perception than the Baha. These results agree with other studies demonstrating better unaided performance with noise presented to the poor ear and a greater disadvantage with the CROS compared to the

Baha (Hol et al., 2005; Lin et al., 2006). The results may be explained by the fact that the CROS overcame the head shadow effect at more frequencies than the Baha. That is, the CROS may have transmitted noise to the better ear "more successfully" than the Baha, thus interfering with speech perception to a greater degree.

Trends in the speech perception results with noise presented at 90 degrees to the better ear were similar between the word recognition scores and QuickSIN results. Both measures showed that speech perception did not significantly improve when wearing the Baha or CROS compared to the unaided condition. Performance was comparable across all 3 listening conditions; neither the Baha nor the CROS offered additional benefit with speech perception. These results are in disagreement with Hol et al. (2004) and Hol et al. (2005) who found that, with short everyday sentences presented at 0 degrees and noise presented to the better ear, both devices resulted in lower SNRs than the unaided condition. Similarly, Yuen et al. (2009) found better performance with the Baha than without when HINT sentences were presented to the side of the poor ear with noise to the side of the better ear. Zeitler et al. (2012) also found significant Baha benefits using the QuickSIN with speech to the side of the poor ear and noise to the side of the better ear. It is unclear why the current results are in disagreement with the above studies. There was a small number of participants in the current study, and they performed fairly well unaided thus not leaving substantial room to measure improvement.

Although speech perception in noise benefits were not measured with either the CROS or Baha, in terms of self-perceived benefits during daily activities, participants rated both hearing devices to be beneficial to their daily living activities. It was important to assess participants' self-perceived satisfaction with these devices because the tests that are performed in the audio booth are generally not representative of everyday listening situations. The results of the BBSS and SSQ show that the Baha and CROS were rated equally as effective in alleviating hearing difficulties. These results support the notion that the CROS can offer subjective benefit similar to those offered by the Baha.

The Baha and CROS diaries indicated that the majority of participants wore each hearing device for the two-week trial period in a variety of communication situations. A few participants wore their device a few days more or less than two weeks. Participants' average total use of either device ranged from 10 to 18 days, while their average hours of use per day ranged from 5 to 15 hours. Both the Baha and CROS were used more often in one-on-one communication situations at home. The Baha was not worn very often in group communication situations at home and in other situations as specified by the participants. The CROS and Baha diaries indicated that the devices were worn less often outdoors. It is likely that these results were influenced by participants' lifestyle; the number of times in which the devices were worn in each communication situation depended on how often participants encountered those situations in their daily lives. This study explored the various listening scenarios in which participants wore each device, not the proportion of time that they used the device in each situation.

More than half of the participants preferred the CROS hearing aid over the Baha. Better sound quality for the CROS was reported by 6 participants. However, the Baha was still favoured by those who felt comfort was their top priority compared to sound quality. It should be pointed out that the CROS was fitted with disposable domes instead of custom fit ear tips. One may argue that if participants had received custom fit ear tips, discomfort and retention issues with the CROS might have been less frequently reported.

Because the performance of both devices was similar, it is recommended that people with SSD try CROS hearing aids, a non-invasive intervention, prior to considering Baha surgery. Although this approach has been suggested by Bishop and Eby (2009), it appears that it is not always followed. Most studies on Baha do not mention whether participants tried a CROS first (one exception is the study by Zeitler et al., 2012). Likewise, participants in the current study had not tried a CROS prior to Baha surgery; indeed a number of participants volunteered that they had never heard of CROS before and wished that they had been informed about this option. However, it should be noted that in reaction to new wireless CROS models that have arrived on the market recently, there is now an increased tendency for patients with SSD to receive counselling on CROS usage prior to considering Baha implantation (Janine Verge and Mark Gulliver, personal communication).

Limitations and Future Directions

Although the CROS demonstrated at least equivalent performance to the Baha on several measures, there are some limitations in the current study. The sample size was quite small and only one male was included, limiting the generalizability of the results. The trial period of two weeks was quite short and may not have provided enough time for participants to adjust to the new CROS. Participants only had approximately two weeks to adjust to the CROS compared to one to two years of experience with the Baha. This could have inadvertently skewed the results in favour of the Baha. All of these factors could have confounded the results of the study. It is recommended that future studies use a longer trial period in comparing the new digital wireless CROS to the Baha. Using a CROS hearing aid with custom ear tips would also address the issues of retention and discomfort. The long-term benefit of both hearing devices also needs to be assessed.

Conclusion

Previous studies comparing the Baha to the CROS hearing aid for those with single-sided deafness typically showed better performance for the Baha than the CROS but older CROS models with analog technologies were used. The current study attempted to build upon these pre-existing studies to determine if a new digital wireless CROS device could demonstrate at least equal benefit as the Baha in improving speech perception and subjective benefit. Overall, the CROS showed equal benefit compared to the Baha, supporting the argument that patients with single-sided deafness should first be counselled about the CROS before considering a surgical intervention such as the Baha. The findings have implications for healthcare professionals hoping to reduce the waitlist for surgery and offer more device options to those with single-sided deafness.

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APPENDIX A

PERSONAL DIARY FORM

CROS Usage

Please indicate the date and number of hours per day in which the CROS device was worn. Please also indicate the environments in which the CROS was worn by placing a check mark beneath the appropriate heading. As much as possible, you should stop using your Baha during the 2 weeks when you are trying the CROS; however, if you must wear your Baha in some situations because it helps you more, you can wear it instead of the CROS but please make note of this in the form below beside the corresponding date.

		Environmental situations in which the CROS was worn								
Date Worn (dd/mm/yyyy)	Number of Hours Worn Today	One-on-one conversation at work	Group conversation at work	One-on one conversation at home	Group conversation at home	At a restaurant, coffee shop, etc.	In a car. Note if you were a passenger ("P") or driver ("D")	Walking on the street	Other outdoor activities	Other – Please describe the situation

Baha Usage

Please indicate the date and number of hours per day in which the Baha was worn. Please also indicate the environments in which the Baha was worn by placing a check mark beneath the appropriate heading.

		Environmental situations in which the Baha was worn								
Date Worn (dd/mm/ yyyy)	Number of Hours Worn Today	One-on-one conversation at work	Group conversation at work	One-on one conversation at home	Group conversation at home	At a restaurant, coffee shop, etc.	In a car. Note if you were a passenger ("P") or driver ("D")	Walking on the street	Other outdoor activities	Other – Please describe the situation

APPENDIX B

BERN BENEFIT IN SINGLE-SIDED DEAFNESS QUESTIONNAIRE (BBSS)

Participant Code: ....

BAHA ________ or CROS __________ Date: ....

Please rate your perceived benefit from your aid in the following situations by a vertical line. Example:

Much easier without the aid	... somewhat easier	Similar with and without	... somewhat easier	Much easier with the aid

-5 -4 -3 -2 -1 0 1 2 3 4 5

1. To hold a conversation with one person in a quiet environment. For me, this is:

Much easier without the aid	... somewhat easier	Similar with and without	... somewhat easier	Much easier with the aid

-5 -4 -3 -2 -1 0 1 2 3 4 5

2. To understand a TV or a radio speaker. For me, this is:

Much easier without the aid	... somewhat easier	Similar with and without	... somewhat easier	Much easier with the aid

-5 -4 -3 -2 -1 0 1 2 3 4 5

3. To listen to music. For me, this is:

Much more pleasant without the aid	... somewhat more pleasant	Similar with and without	... somewhat more pleasant	Much more pleasant with the aid

-5 -4 -3 -2 -1 0 1 2 3 4 5

4. To follow a conversation from some distance (5 m / 15 ft or more). For me, this is:

Much easier without the aid	... somewhat easier	Similar with and without	... somewhat easier	Much easier with the aid

-5 -4 -3 -2 -1 0 1 2 3 4 5

5. To follow a conversation with background noise. For me, this is:

Much easier without the aid	... somewhat easier	Similar with and without	... somewhat easier	Much easier with the aid

-5 -4 -3 -2 -1 0 1 2 3 4 5

6. To hold a conversation while driving in a car. For me, this is:

Much easier without the aid			... somewhat easier		Similar with and without		... somewhat easier		Much easier with the aid	
-5	-4	-3	-2	-1	0	1	2	3	4	5

7. To understand speech in a reverberant room, such as a large entrance hall or a church. For me, this is:

Much easier without the aid			... somewhat easier		Similar with and without		... somewhat easier		Much easier with the aid	
-5	-4	-3	-2	-1	0	1	2	3	4	5

8. To participate in a group conversation with 3 or more participants. For me, this is:

Much easier without the aid			... somewhat easier		Similar with and without		... somewhat easier		Much easier with the aid	
-5	-4	-3	-2	-1	0	1	2	3	4	5

9. To localize a sound source, such as a honking car. For me, this is:

Much easier without the aid			... somewhat easier		Similar with and without		... somewhat easier		Much easier with the aid	
-5	-4	-3	-2	-1	0	1	2	3	4	5

10. Over all, for me hearing is:

Much better without the aid			... somewhat better		Similar with and without		... somewhat better		Much better with the aid	
-5	-4	-3	-2	-1	0	1	2	3	4	5

APPENDIX C

SPEECH SPATIAL QUALITIES QUESTIONNAIRE (SSQ)

Appendix C

Speech Spatial Qualities

Advice about answering the questions

The following questions inquire about aspects of your ability and experience hearing and listening in different situations.

For each question, put a mark, such as a cross (x), anywhere on the scale shown against each question that runs from 0 through to 10. Putting a mark at 10 means that you would be perfectly able to do or experience what is described in the question. Putting a mark at 0 means you would be quite unable to do or experience what is described.

As an example, question 1 asks about having a conversation with someone while the TV is on at the same time. If you are well able to do this then put a mark up toward the right-hand end of the scale. If you could follow about half the conversation in this situation put the mark around the mid-point, and so on.

We expect that all the questions are relevant to your everyday experience, but if a question describes a situation that does not apply to you, put a cross in the "not applicable" box. Please also write a note next to that question explaining why it does not apply in your case.

Please answer the following questions, then go on to the questions about your hearing

Participant Code:

BAHA ______ or CROS ______

Date:

Speech Spatial Qualities (Part 1: Speech hearing)

1. You are talking with one other person and there is a TV on in the same room. Without turning the TV down, can you follow what the person you're talking to says?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
2. You are talking with one other person in a quiet, carpeted lounge-room. Can you follow what the other person says?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
3. You are in a group of about five people, sitting round a table. It is an otherwise quiet place. You can see everyone else in the group. Can you follow the conversation?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
4. You are in a group of about five people in a busy restaurant. You can see everyone else in the group. Can you follow the conversation?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
5. You are talking with one other person. There is continuous background noise, such as a fan or running water. Can you follow what the person says?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐

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Speech Spatial Qualities (Part 1: Speech hearing, continued)

6. You are in a group of about five people in a busy restaurant. You CANNOT see everyone else in the group. Can you follow the conversation?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
7. You are talking to someone in a place where there are a lot of echoes, such as a church or railway terminus building. Can you follow what the other person says?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
8. Can you have a conversation with someone when another person is speaking whose voice is the same pitch as the person you're talking to?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
9. Can you have a conversation with someone when another person is speaking whose voice is different in pitch from the person you're talking to?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
10. You are listening to someone talking to you, while at the same time trying to follow the news on TV. Can you follow what both people are saying?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐

11. You are in conversation with one person in a room where there are many other people talking. Can you follow what the person you are talking to is saying?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
12. You are with a group and the conversation switches from one person to another. Can you easily follow the conversation without missing the start of what each new speaker is saying?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
13. Can you easily have a conversation on the telephone?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
14. You are listening to someone on the telephone and someone next to you starts talking. Can you follow what's being said by both speakers?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐

Speech Spatial Qualities (Part 2: Spatial hearing)

1. You are outdoors in an unfamiliar place. You hear someone using a lawnmower. You can't see where they are. Can you tell right away where the sound is coming from?	*Not at all* … *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
2. You are sitting around a table or at a meeting with several people. You can't see everyone. Can you tell where any person is as soon as they start speaking?	*Not at all* … *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
3. You are sitting in between two people. One of them starts to speak. Can you tell right away whether it is the person on your left or your right, without having to look?	*Not at all* … *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
4. You are in an unfamiliar house. It is quiet. You hear a door slam. Can you tell right away where that sound came from?	*Not at all* … *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
5. You are in the stairwell of a building with floors above and below you. You can hear sounds from another floor. Can you readily tell where the sound is coming from?	*Not at all* … *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐

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Speech Spatial Qualities (Part 2: Spatial hearing, continued)

6. You are outside. A dog barks loudly. Can you tell immediately where it is, without having to look?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
7. You are standing on the footpath of a busy street. Can you hear right away which direction a bus or truck is coming from before you see it?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
8. In the street, can you tell how far away someone is, from the sound of their voice or footsteps?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
9. Can you tell how far away a bus or a truck is, from the sound?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
10. Can you tell from the sound which direction a bus or truck is moving, for example, from your left to your right or right to left?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐

SSQ 5.6 page 6

Speech Spatial Qualities (Part 2: Spatial hearing, continued)

11. Can you tell from the sound of their voice or footsteps which direction a person is moving, for example, from your left to your right or right to left?	*Not at all* — *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
12. Can you tell from their voice or footsteps whether the person is coming towards you or going away?	*Not at all* — *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
13. Can you tell from the sound whether a bus or truck is coming towards you or going away?	*Not at all* — *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
14. Do the sounds of things you are able to hear seem to be inside your head rather than out there in the world?	*Inside my head* — *Out there* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
15. Do the sounds of people or things you hear, but cannot see at first, turn out to be closer than expected when you do see them?	*Much closer* — *Not closer* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐

Speech Spatial Qualities (Part 2: Spatial hearing, continued)

16. Do the sounds of people or things you hear, but cannot see at first, turn out to be further away than expected when you do see them?	*Much further* ... *Not further* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
17. Do you have the impression of sounds being exactly where you would expect them to be?	*Not at all* ... *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐

Speech Spatial Qualities (Part 3: Qualities of hearing)

1. Think of when you hear two things at once, for example, water running into a basin and, at the same time, a radio playing. Do you have the impression of these as sounding separate from each other?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
2. When you hear more than one sound at a time, do you have the impression that it seems like a single jumbled sound?	*Jumbled* 0 1 2 3 4 5 6 7 8 9 10 *Not jumbled*	Not applicable ☐
3. You are in a room and there is music on the radio. Someone else in the room is talking. Can you hear the voice as something separate from the music?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
4. Do you find it easy to recognise different people you know by the sound of each one's voice?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
5. Do you find it easy to distinguish different pieces of music that you are familiar with?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐

SSQ 5.6 page 9

6. **Can you tell the difference between different sounds, for example, a car versus a bus; water boiling in a pot versus food cooking in a frypan?**	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
7. **When you listen to music, can you make out which instruments are playing?**	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
8. **When you listen to music, does it sound clear and natural?**	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
9. **Do everyday sounds that you can hear easily seem clear to you (not blurred)?**	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
10. **Do other people's voices sound clear and natural?**	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐

Speech Spatial Qualities (Part 3: Qualities of hearing, continued)

11. Do everyday sounds that you hear seem to have an artificial or unnatural quality?	*Unnatural* 0 1 2 3 4 5 6 7 8 9 10 *Natural*	Not applicable ☐
12. Does your own voice sound natural to you?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
13. Can you easily judge another person's mood from the sound of their voice?	*Not at all* 0 1 2 3 4 5 6 7 8 9 10 *Perfectly*	Not applicable ☐
14. Do you have to concentrate very much when listening to someone or something?	*Concentrate hard* 0 1 2 3 4 5 6 7 8 9 10 *Not need to concentrate*	Not applicable ☐
15. Do you have to put in a lot of effort to hear what is being said in conversation with others?	*Lots of effort* 0 1 2 3 4 5 6 7 8 9 10 *No effort*	Not applicable ☐

Speech Spatial Qualities (Part 3: Qualities of hearing, continued)

16. When you are the driver in a car can you easily hear what someone is saying who is sitting alongside you?	*Not at all* … *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
17. When you are a passenger can you easily hear what the driver is saying sitting alongside you?	*Not at all* … *Perfectly* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐
18. Can you easily ignore other sounds when trying to listen to something?	*Not easily ignore* … *Easily ignore* 0 1 2 3 4 5 6 7 8 9 10	Not applicable ☐