BINAURAL SPATIAL MAPPING OPTIMIZES REAL–WORLD HEARING AID BEHAVIOR

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For decades, researchers and clinicians have emphasized the importance of bilateral hearing aid fittings in minimizing disruptions to the exquisitely-tuned binaural auditory system. The availability of hearing aids with wireless features has renewed interest in the subject, and focused the discussion on signal processing. This paper describes the rationale, design and efficacy of Binaural Spatial Mapping, Starkey's wireless ear-to-ear communication protocol. Along the way, it debunks some popular notions about binaural hearing, hearing impairment, and listener preferences, arriving at a destination that optimizes real-world hearing aid behavior.

Survey Says…

Satisfaction with hearing aids is at an all-time high of 80 percent (Kochkin, 2010). Nonetheless, problems persist in adverse listening situations – such as in restaurants, cars and large groups (Kochkin, 2010). These situations are important to hearing aid wearers and typically involve communication or intentional listening (Wagener, et al., 2008).

The notion of multiple environment listening utility, proposed by Kochkin (2007), suggests a direct relationship between the number of satisfactory listening situations and overall satisfaction with hearing aids. It stands to reason, then, that improving performance in problematic listening situations would yield increased satisfaction with hearing aids. Indeed, this is the premise of many advances in hearing aid technology. Binaural Spatial Mapping is no exception.

Binaural Hearing

Binaural hearing is hearing with two ears. This is advantageous – compared to monaural hearing – when differences exist between the signals for the two ears. These advantages are greatest in complex and dynamic listening environments, such as restaurants, cars and large groups (Noble & Gatehouse, 2006).

When located directly in front of or behind a listener, the characteristics of a sound are essentially the same at the left and right ears, and binaural hearing provides no benefit over monaural hearing. Moving the sound to, say, the left side has two effects. First, the sound is louder at the left ear than at the right ear, resulting in an interaural level difference (ILD) that is most prominent at frequencies above ~1000 Hz. And, second, the sound arrives at the left ear before the right ear, resulting in an interaural timing difference (ITD) that is most prominent below ~1000 Hz. ILDs and ITDs are the primary binaural cues for spatial release from masking, a phenomenon more commonly referred to as the cocktail party effect (Cherry, 1953).

Complex listening environments are known to increase difficulty in recognizing speech. Further, greater similarity between speech and any interfering noise increases the confusion. One relatively simple method of alleviating this difficulty is to spatially separate the speech from the noise. In persons with normal hearing, this spatial release from masking produces a 12-16 dB improvement in the speech reception threshold in noise (Beutelmann & Brand, 2006).
Signal processing in hearing aids tampers with the naturally-occurring ILDs and ITDs in many ways. For example, wide dynamic range compression could reduce ILDs by applying less gain where the incoming sound is louder and more gain where the incoming sound is softer. Similar effects can occur with other features when, for example, only one device is in the directional mode or more noise reduction is applied in one device than in the other. Directionality and noise reduction are intended to aid listening in complex environments. As such, it is important to consider how often these features are in agreement – i.e., in the same state – in everyday listening situations. According to Banerjee (2011), independent signal processing in a bilateral pair of hearing aids is in agreement – i.e., in the same state – 75-95 percent of the time. Accordingly, binaural cues are intact a large majority of the time.

Is it problematic that binaural cues could be disrupted when signal processing in a bilateral pair of hearing aids is in disagreement (as much as 25 percent of the time)? Beutelmann and Brand (2006) have shown that persons with impaired hearing obtain significantly less benefit from binaural cues compared to persons with normal hearing. Stated differently, the presence of hearing loss diminishes the ability to effectively use binaural cues. Thus, preservation of binaural cues through forced synchronization of signal processing in a bilateral pair of hearing aids may not be the optimal solution. Could it be that asymmetric signal processing is a part of the solution rather than the problem? Consider, for example, a situation where the hearing aid wearer is engaged in a conversation with a child in the back seat en route to soccer practice (Figure 1). Ideally, the hearing aids should maintain audibility of the child’s voice in one ear and minimize any interference from road noise in the other. Asymmetric signal processing – where, for example, one hearing aid remains omnidirectional while the other switches to the directional mode – would appear to be advantageous in this situation.

The Case for Collaborative Signal Processing

Traditionally, laboratory-based hearing aid research has been conducted in symmetrical sound fields – for example, where the speech signal of interest is located directly in front of the listener and the background noise is diffuse or located directly behind the listener. As noted previously, such a configuration results in identical inputs to the two ears and requires no intervention for ensuring binaural benefit. However, the use of asymmetric test set-ups in two studies provides insight into the judicious use of collaborative signal processing with wireless capabilities.

The first study by Hornsby and Ricketts (2007) examined the effect of symmetric and asymmetric microphone modes under three listening conditions: 1) speech in front with surrounding noise, 2) speech in front with noise on the left side and 3) speech on the right side with noise on the left side. For speech located in front (conditions 1 and 2), directionality in at least one device yielded improved speech understanding in noise, and directional benefit was greatest when both devices were in the directional mode. Interestingly, noise location had no impact on directional benefit – i.e., bilateral directionality was equally beneficial with noise surrounding the listener or only on the left side. For speech located on the right side, a
significant decrease in speech understanding was observed with the right device in the directional mode; the status of the left device did not affect on the outcome. The authors concluded that, when speech is located to the side, the reduction in speech audibility resulting from directional processing on that side is detrimental to speech understanding.

In the second study, Banerjee (2010) demonstrated similar results in subjective preference for directionality based on the location of the speech signal. Figure 2 shows the relative – compared to the bilateral omnidirectional (O-O) condition – likability of various microphone configurations; large, positive values indicate better outcomes. For speech located in front, listeners preferred some directionality (O-D or D-O) over none at all (O-O), and bilateral directionality (D-D) was preferred most of all. When speech was located in the rear right, however, listeners had a significant dislike for directionality on the right side; the status of the left device did not affect the results. This is interpreted as an aversion to reduced audibility of speech that occurs behind the directional hearing aid.

The scenarios evaluated in both of these studies are similar to the hypothetical (but realistic) one mentioned previously – a hearing aid wearing parent in the driver’s seat engaged in conversation with a child in the back seat of a car (as shown in Figure 1).

To evaluate the implications of these findings, let us first consider synchronized processing in systems where both hearing aids are forced into the same mode. If the right device was forced into the directional mode because that was the mode selected by the left device (closer to the noise), audibility of the speech signal would be severely impaired. Although speech audibility would be unaffected if the left device was forced into the omnidirectional mode by the right device (closer to the speech), interference from the noise may require the hearing aid wearer to expend more effort in listening (Mackersie & Cones, 2011). Increased listening effort can cause stress, taking cognitive resources away from the task of driving, and possibly leading to increased fatigue over time. Thus, neither outcome of synchronized signal processing is desirable.

The goal of collaborative signal processing is to optimize the overall outcome based on the information available at each ear. Sometimes, this means that asymmetric signal processing will yield the best outcome. In the car, for example, the right device may remain omnidirectional because the directional mode degrades the signal-to-noise ratio (SNR); the left device, finding no SNR advantage in either mode, could favor the directional mode in the interest of maintaining comfort. This asymmetric configuration yields maximum speech audibility with minimum listening effort. This power of collaborative signal processing is harnessed in Binaural Spatial Mapping.
Design of Binaural Spatial Mapping

Binaural Spatial Mapping is Starkey's wireless ear-to-ear communication protocol. It continuously analyzes the acoustic environment surrounding the hearing aid wearer and applies the appropriate signal processing strategy for InVision Directionality, AudioScapes and Voice iQ. Binaural Spatial Mapping can only be achieved with inputs from two hearing aids with wireless features.

The design of the algorithm is based on two guiding principles: 1) preserve audibility whenever speech is present and 2) maintain comfort if speech is absent and/or overall input levels are high.

Speech, the primary vehicle for communication, is arguably the single most important sound for hearing aid wearers. As such, the significance of preserving it cannot be overstated. Hearing aids must rely on a relatively degraded input – mixed in with noise and reverberation – at the microphone of the device to determine the presence of speech in the environment. When both devices are constantly scanning the environment and sharing information, it effectively improves the detection of speech at the far ear by as much as five dB. The practical implication is, that with Binaural Spatial Mapping, speech audibility can be preserved at SNRs that are too poor for a single hearing aid to detect the presence of speech.

Speech audibility is preserved in two ways. First, InVision Directionality selects the microphone mode (omnidirectional or directional) that yields the higher (i.e., better) SNR at each ear. And, second, fast-acting Voice iQ reduces background noise without adversely impacting the speech signal (Pisa, Burk, & Galster, 2010).

Noise is generally considered undesirable and the hearing aid wearer, like anyone else, wants to listen to it as little as possible. Enhanced speech detection, made possible by Binaural Spatial Mapping, allows a conservative approach to maintaining comfort in the presence of background noise. In other words, inadvertent loss of the speech signal at low SNRs is minimized. If only noise is present in the environment, the hearing aids go into the directional mode and apply noise reduction to maintain comfort.

According to Pearsons, Bennett and Fidell (1977), inputs exceeding ~80 dBSPL are typically comprised of noise. However, if a speech signal is detected in such environments, Binaural Spatial Mapping attempts to strike a balance between preserving speech audibility and maintaining loudness comfort. This is achieved through collaborative decision-making – i.e., the device with the better SNR preserves speech audibility while the other device maintains comfort. Thus, Binaural Spatial Mapping may intentionally cause the left and right devices of a bilateral pair to be in different signal processing states under such conditions. Identical states in both devices are not automatically forced.

Finally, an incidental benefit of Binaural Spatial Mapping is that auditory disturbances arising from signal processing algorithms are reduced. Switching and/or adaptation in independently functioning hearing aids can occur with a noticeable time delay that many hearing aid wearers find distracting. Collaborative decision-making causes any switching and/or adaptation to occur in both devices simultaneously, thereby minimizing the distraction caused by this behavior.

Validation

Galster and Burk (2011) described a large-scale study of 47 patients at various clinics throughout the United States. The study examined various aspects of IRIS™ Technology in Starkey's Wi Series™ hearing aids, with Binaural Spatial Mapping. IRIS Technology is Starkey's wireless communication protocol, which uses the 900 MHz band within the Industrial and Scientific Medical Spectrum. It is the only wireless hearing aid system that allows wireless ear-to-ear communication, wireless programming and wireless media streaming without any relay devices.

Of particular relevance to the present discussion are patient reports on two standardized questionnaires that target real-world hearing experiences.
The Device-Oriented Subjective Outcome (DOSO) scale (Cox, et al., 2009) asks respondents to rate: 1) their ability to hear speech cues [speech], 2) amount of listening effort expended in noisy situations [effort], 3) pleasantness of amplified sound [pleasant], 4) quietness of the hearing aids [quiet], 5) convenience of manipulating the devices and 6) daily use of hearing aids. The first four subscales are directly (speech cues and listening effort) or indirectly (pleasantness and quietness) related to Binaural Spatial Mapping. As shown in Figure 3, study participants indicated significantly better performance – i.e., higher ratings – with Starkey’s Wi Series hearing aids compared to their own devices on the relevant subscales of the DOSO scale.

The Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox & Alexander, 1995) is a self-assessment inventory where respondents report the amount of problems experienced in: 1) communicating under relatively favorable conditions [EC – ease of communication], 2) communicating in reverberant rooms [RV], 3) communicating in noisy environments [BN] and 4) unpleasantness of environmental sounds [AV – aversiveness]. As shown in Figure 4, compared to their own devices, study participants indicated significantly better performance – i.e., fewer problems – with Starkey’s Wi Series hearing aids in reverberant and noisy listening situations. There was also a non-significant trend toward reduction of problems in favorable conditions with Starkey’s Wi Series.
Summary

Binaural Spatial Mapping, illustrated in Figure 5, is Starkey’s wireless ear-to-ear communication protocol. It applies the combined speed and power of multiple dual-core platforms to achieve parallel processing benefits. This new protocol queries, analyzes and maps the acoustic space surrounding the hearing aid wearer, applying the appropriate signal processing strategy for InVision Directionality, AudioScapes and Voice iQ. Binaural Spatial Mapping can only be achieved with inputs from two Wi Series hearing aids.

Binaural Spatial Mapping’s collaborative decision-making allows speech audibility to be preserved, while simultaneously maintaining loudness comfort. This yields demonstrated, real-world benefits to hearing aid wearers.

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References


