Older Adults in Complex Listening Environments

Karen S. Helfer

Abstract

A very common complaint of older adults (especially those with hearing loss) is difficulty understanding talkers in situations where there are other competing conversations. This paper will describe why these types of situations can be difficult for all listeners and then will discuss reasons why older adults in particular are so negatively affected by the presence of competing speech. Research on competing speech perception by older adults will be summarized. Finally, some suggestions will be offered for helping our older patients cope in these environments.

Why is Understanding Speech in a Competing Speech Situation so Difficult?

Successfully navigating a situation in which people are talking simultaneously can be very taxing, even for young, normally-hearing listeners. Figure 1 displays a diagram of the steps involved in decoding a message in the presence of competing speech. In order to do this successfully, the listener must first figure out the message or conversational partner of interest and direct his/her attention to that talker. Next, the target message must be parsed out from the background of other competing voices. The listener then must maintain his/her attention on the target message while ignoring the background conversations. At any point in time the listener may switch or divide his/her attention to monitor other conversations or to include additional people in the conversation.

Problems at any of these levels are likely to lead to misunderstanding. For example, the inability to segregate the target message from the background could cause the listener to attend to a non-target message and therefore miss the intended message. Even if the process of segregating and attending/ignoring goes perfectly, listeners still might not be able to understand the message due to peripheral (e.g., hearing loss, the presence of background noise) and/or cognitive (e.g., working memory, attention) factors. Peripheral hearing loss also affects several of the processes mentioned above. For example, hearing impairment may increase the amount of time needed to parse the auditory scene which will in turn slow down selective attention (Shinn-Cunningham & Best, 2008). As examination of Figure 1 demonstrates, there are many paths to misunderstanding in these types of listening situations.

It is well documented that people with hearing loss have greater difficulty in the presence of background noise, as compared to young, normally-hearing listeners. Less well-established is what happens when the background noise consists of other voices. A body of research has determined that speech has the potential to cause two types of masking: energetic and informational. Energetic masking is when physical energy in the masker obscures information in the target. Informational masking refers to masking above and beyond that which would be produced by noise with the same acoustics as the interfering speech. Traditionally, informational masking was attributed to confusion between the target and masking signals and/or uncertainty about what information belongs to the target vs. the masker (e.g., Durlach et al., 2003). Informational masking also has a second component: higher-level interference, such as when attention is allocated to the masker rather than to the target. It is likely that cognitive re-

Address correspondence to: University of Massachusetts, Dept. Of Communication disorders, 358 N. Pleasant St., Amherst, MA 01003, +1 413-545-4014, khelfer@comdis.umass.edu

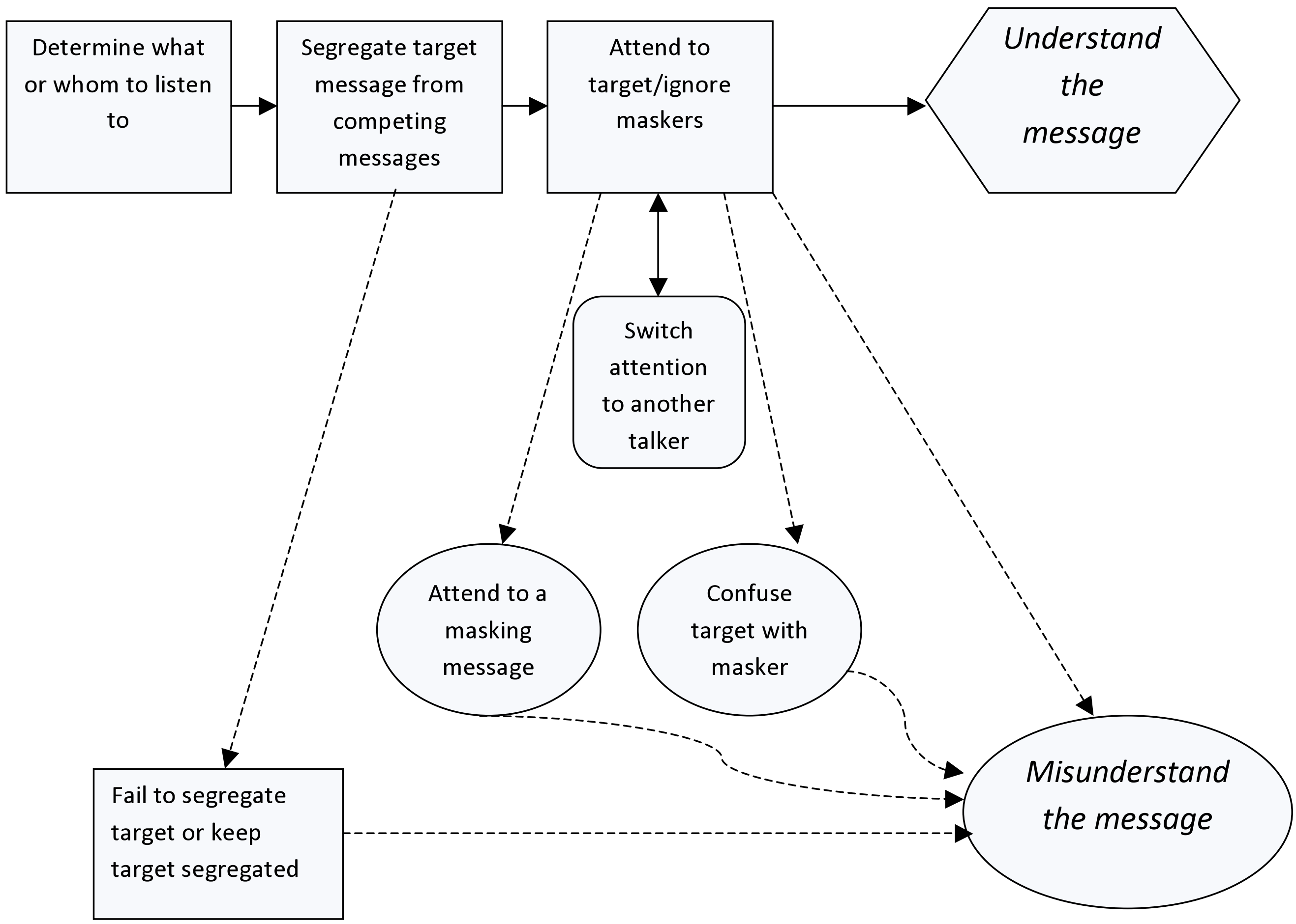

Figure 1. The steps to understanding (or misunderstanding) a speech signal in the presence of competing talkers.

sources within an individual listener exert a potent impact on the relative contribution of these factors in competing speech situations. For example, listeners with age-related changes in cognitive functioning (such as a reduced ability to allocate attention effectively) would have a greater contribution of the second (higher-level) informational masking component than a young, normally-hearing listener who has optimal attentional resources. It also is likely that the peripheral hearing loss which accompanies aging has a negative influence on cognitive processes that are important for successfully communicating in complex listening environments (e.g., Murphy, Daneman, & Schneider, 2006).

A number of external factors also contribute to the relative difficulty produced by competing talkers. In general, anything that helps differentiate the target message from the background will lead to a reduction in informational (and sometimes energetic) masking. The following discussion reviews a number of these factors.

Signal-to-Noise Ratio: A major determinant of difficulty in competing speech situations is the intensity of the target message in relation to that of the competing voices (i.e., the Signal-to-Noise Ratio, or SNR). There is a well-established relationship between SNR and speech understanding: the poorer the SNR, the more energetic masking, and therefore the greater the difficulty. This relationship in general also holds true for informational masking, with one exception: listeners (at least normally-hearing listeners) can sometimes use relative intensity as a cue and focus on a quieter voice in a situation where there is one competing talker (Brungart, 2001), leading to a non-linear relationship between SNR and performance.

Number of masking voices: A background competition consisting of a small number of masking voices will have both temporal and spectral fluctuations that can reduce masking efficiency. Young, normally-hearing listeners can take advantage of these fluctuations and "listen in the gaps". However, as will be discussed below, sensorineural hearing loss reduces the ability to benefit from masker fluctuations. The number of competing talkers also can influence higher-level aspects of informational masking. When there is a small number of competing talkers, words within the masking complex may be audible and therefore draw a listener's attention. As the number of competing talkers increases, fluctuations in the background are reduced; the masking complex becomes more like a steady-state noise and individual words are no longer understandable.

Similarity between target and masking voices: In general, the more similar the masking voices are to the target voice, the more difficult the listening situation. For example, masking by same-sex talkers is greater than that produced by speakers who differ in sex from the target talker (e.g., Brungart, 2001). There are at least two reasons why similarity affects masking. First, greater similarity in the frequency domain means more spectral overlap between the target and masker, and hence greater energetic masking. Second, similar voices are more easily confused (and perhaps more difficult to segregate and/or ignore) than are less similar voices.

Spatial separation: One of the most effective means of reducing both energetic and informational masking is by spatially separating the target voice from the competing voices. Spatial release from energetic masking is produced by a combination of head-shadow effects and binaural interaction (i.e., masking-level differences). It has been demonstrated that spatial release from masking is even greater for a masker that has the potential to cause informational masking (e.g., Freyman et al., 1999). This is probably because listeners are unlikely to confuse target and masking voices that are spatially separated.

Of course, in face-to-face communication situations different talkers always occupy different spatial positions and so their messages are invariably spatially separated. However, there are real-life situations in which listeners are unable to take advantage of spatial separation. Individuals who are forced to listen monaurally do not have access to most of the cues used for spatial separation. Another example is when listeners must understand a mono signal (such as from the television or telephone) containing a mixture of voices.

Visual speech cues: Research from our lab has demonstrated that lipreading cues are even more effective in the presence of competing speech than in competing steady-state noise (Helfer & Freyman, 2005). It has long been known that lipreading helps fill in phonetic information that is masked by noise, and this undoubtedly occurs when the noise consists of other voices. However, we believe that lipreading provides another important benefit in the presence of competing speech – it helps segregate the target talker's voice from the background. This is because the visual signal produced by the target talker (but not that of a masking talker) is time-locked to the target auditory signal.

Understandability of the maskers: Maskers that are understandable produce more informational masking than those that are not understandable (e.g., when they are spoken in an unfamiliar foreign language or, in experimental studies, when they are presented in a time-reversed fashion). This holds true for maskers that are potentially confusable with the target; specifically, when the target and maskers are produced by talkers of the same-sex and are presented in a spatially co-located configuration (e.g., Rossi-Katz & Arehart, 2009).

Familiarity with the target talker or target message: Studies have shown that, in the presence of background noise, familiar voices are easier for older and younger adults to understand than unfamiliar voices (e.g., Naveh-Benjamin & Craik, 1996; Pilotti & Beyer, 2002; Yonan & Sommers, 2000). Recently, this familiarity effect has been demonstrated in the presence of competing speech, for both younger and older listeners (Johnsrude, 2009). Providing information about the content of the target message also may assist listeners in acoustically complex environments. Research from our lab has demonstrated that prior exposure to the beginning of an utterance can make the end of the message more intelligible, especially in the presence of competing speech (Freyman, Balakrishnan, & Helfer, 2004).

Why Might Older Listeners have Particular Difficulty in Complex Listening Environments?

Perhaps the most obvious reason why many older adults have problems in situations with multiple talkers is because of the presence of sensorineural hearing loss. The filtering and attenuation produced by sensorineural hearing loss leads to increased susceptibility to energetic masking by competing speech in both younger and older adults (e.g., Arbogast, Mason, & Kidd, 2005;

Hallgren et al., 2005; Larsby et al., 2005; Helfer & Freyman, 2008; Marrone, Mason, & Kidd, 2008a).

Besides causing filtering and attenuation, sensorineural hearing loss also reduces a listener's ability to use spectral and temporal gaps in a masking complex (e.g., Takahashi & Bacon, 1992; Dubno, Horwitz, & Ahlstrom, 2002, 2003; Summers & Molis, 2004; George, Festen, & Houtgast, 2006). Hence, background competition that consists of a small number of voices has a greater masking effect for listeners with sensorineural hearing loss than for those with normal hearing.

Peripheral auditory changes also can interfere with the segregation of sound sources. For example, research has shown that the ability to identify concurrently-presented sounds declines with age and/or hearing loss (e.g., Summers & Leek, 1998; Snyder & Alain, 2006; Alain & McDonald, 2007; Vongpaisal & Pichora-Fuller, 2007). Reduced spectro-temporal processing from peripheral hearing loss can lead to the target and masking voices sounding perceptually more similar, thereby negatively affecting the ability to separate these sources. Hence, older adults with hearing loss might have particular difficulty segregating target speech from masking speech in a complex auditory scene.

Several studies have shown that hearing loss reduces the benefit derived from spatially separating a target speech signal from speech maskers (e.g., Duquesnoy, 1983; Festen & Plomp, 1990; Arbogast et al., 2005; Murphy, Daneman, & Schneider, 2006; Marrone et al., 2008a). However, even though hearing-impaired (especially older hearing-impaired) listeners receive less benefit from separating sources, most older adults do derive some advantage relative to conditions with no spatial separation.

It stands to reason that the ability to learn and/or discriminate between voices should influence how successfully a listener can understand one talker in the presence of other talkers. Several studies have shown that aging negatively affects the learning of voice information (e.g., Naveh-Benjamin & Craik, 1996; Yonan & Sommers, 2000; Pilotti & Beyer, 2002; Helfer & Freyman, 2008; Rossi-Katz & Arehart, 2009). The extent to which this limits speech recognition is not yet known.

Understanding a message in the presence of competing speech can be a cognitively-demanding endeavor. Hence, age-related changes in various aspects of cognition likely influence the ability to cope in complex listening environments. It is beyond the scope of this paper to discuss these changes in depth; below is a very cursory description of how cognitive factors might contribute to age-related speech perception problems.

According to the diminished-resource hypothesis (e.g. Craik & Byrd, 1982; Tun & Wingfield, 1999), individuals have a limited pool of cognitive resources available to process incoming information. If more resources are needed to segregate the signal (as might happen in individuals with hearing loss), fewer resources would remain for understanding the target and ignoring the maskers. This resource issue could be compounded by reduced efficiency of inhibitory mechanisms (e.g., Hasher & Zacks, 1988), leading to problems with attending to the target and/or ignoring the maskers. Finally, the well-established age-related problems of slowing in processing speed and reduction in working memory could lead to difficulty understanding speech in real-time, especially when listeners need to divide their attention among several conversational partners (or when they try to eavesdrop on other conversations!).

Results of Competing Speech Research in Older Listeners

Before discussing results of research on understanding speech in complex listening environments, it is perhaps important to establish that this is indeed a problem outside of the laboratory. Anecdotally, we often hear complaints of difficulty in these situations from our patients. There also is research evidence to support these claims. Agus et al. (2009b) analyzed data from 414 middle-aged and older individuals who completed the SSQ (Speech, Spatial, and Qualities of Hearing) questionnaire (Gatehouse & Noble, 2004). Their analysis demonstrated that tasks involving the understanding of competing speech messages were perceived as being more difficult than situations requiring the understanding of a single talker in quiet or in continuous background noise.

Laboratory-based research has confirmed that understanding speech in a multitalker situation is indeed problematic for older listeners. Studies examining this issue have invariably found significant differences between younger, normally-hearing adults and older adults with varying degrees of hearing loss (e.g., Duquesnoy, 1983; Hygge et al., 1992; Wiley et al., 1998; Tun & Wingfield, 1999; Divenyi, Stark, & Haupt, 2005; Humes, Lee, & Coughlin, 2006; Gates, Feeney, & Mills, 2008; Helfer & Freyman, 2008; Marrone et al., 2008a; Singh, Pichora-Fuller, & Schneider, 2008; Humes & Coughlin, 2009; Rossi-Katz & Arehart, 2009). Another finding that has been reported in the literature is that older adults sometimes are challenged when the masker is spoken by talkers who are of different sex than the target talker; this rarely presents a problem for younger listeners (e.g., Divenyi et al., 2005; Humes et al., 2006; Helfer & Freyman, 2008; Humes & Coughlin, 2009; Rossi- Katz & Arehart, 2009). And, although hearing loss in older adults may limit the benefit from spatially separating a speech target from speech maskers (e.g., Marrone et al., 2008a), most (but not all) older and/or hearing-impaired listeners obtain some benefit from spatial separation of speech sources (e.g., Duquesnoy, 1983; Festen & Plomp, 1996; Arbogast et al., 2005; Murphy et al., 2006; Helfer & Freyman, 2008; Marrone et al., 2008).

Why are older adults so susceptible to masking by competing speech? Some research supports the idea that peripheral factors can explain all or most of the noted age-related changes in acoustically complex environments. For example, the often-cited reduced ability to ignore irrelevant information is based on studies of visual perception (e.g., Hasher & Zacks, 1988). There is evidence that suggests little or no age difference in the ability to ignore information in an auditory speech masker (e.g., Murphy, McDowd, & Wilcox, 1999). A study by Li et al. (2004) also supports little cognitive involvement in age-related differences in competing speech perception. In their study, older listeners needed about 3 dB better SNR than younger adults, regardless of whether the masker was speech (which, like the target, consisted of sentences that were syntactically correct but made no sense semantically) or noise. The use of cues related to location certainty, which presumably would take some cognitive resources to exploit, does not appear to differ between older and younger adults (Singh, Pichora-Fuller, & Schneider, 2008). Finally, older adults are no more prone than are younger listeners to making errors that involve confusing words in the target with those in the masker (Humes et al., 2006; Agus et al., 2009a). This could be taken as evidence of a lack of age differences in the ability to ignore or inhibit auditory information. However, this result also could be a function of older adults not processing information in the speech masker as deeply as younger adults do (e.g., Tun, O'Kane, & Wingfield, 2002).

Results of other studies cannot be explained by purely peripheral factors. The finding that older adults have greater difficulty in the presence of meaningful (vs. non-meaningful) maskers, as compared to younger adults (e.g., Tun et al., 2002; Larsby et al., 2005; Rossi-Katz & Arehart, 2009) cannot be attributed to peripheral hearing loss. Moreover, the large degree of individually variability in older adults' perception of speech in multi-talker situations cannot be explained entirely by amount of hearing loss (e.g. Tun et al., 2002; Humes et al., 2006; Helfer & Freyman, 2008; Helfer & Vargo, 2009; Rossi-Katz & Arehart, 2009).

Our lab has conducted several studies examining speech recognition by older adults in difficult listening environments. In one study (Helfer & Freyman, 2008) we measured speech understanding in the presence of three types of maskers: a same-sex speech masker, a different-sex speech masker, and modulated noise. At the end of data collection we also assessed how well our subjects were able to discriminate the target talker's voice from that of the two same-sex masking talkers. Results showed that the presence of high-frequency hearing loss in our older subjects limited performance in several listening conditions. However, older and younger participants obtained similar amounts of spatial release from masking. Perhaps the most notable finding was that in relative terms, the largest group differences between older and younger listeners were found in the presence of the opposite-sex speech masker, which could be an indication of increased susceptibility with age to the distraction component of informational masking. Finally, some of our older subjects showed reduced performance on the voice discrimination task, but scores on that measure were not significantly correlated with speech perception results.

When do these age-related speech perception changes begin? In another study (Helfer & Vargo, 2009) we explored the ability of middle-aged women to understand speech in noise and in competing speech. In this study we also measured gap detection ability (using the clinical Gaps-in-Noise (GIN) test (Musiek et al., 2005)). The motivation for including a temporal processing measure was that previous studies have demonstrated this ability to be particularly susceptible to early aging (e.g., Grose, Hall, & Buss, 2006). Results showed that our middle-aged listeners obtained significantly poorer speech recognition scores in the presence of a same-sex speech masker that was spatially co-located with the target speech, as compared to younger listeners. Differences in performance between groups in the other conditions (with spatial separation of target and masker, and in the presence of steady-state noise) were not statistically significant. Middle-aged subjects also had significantly poorer temporal processing than younger listeners and this was correlated with speech recognition in the presence of the spatially-co-located speech masker. Interesting, the slight high-frequency hearing loss noted in our middle-aged participants was significantly correlated with speech perception in steady-state noise, but not with scores obtained in the presence of a speech masker.

Taken together, research from several labs suggests that older adults (especially those with hearing loss) have difficulty in situations with competing speech. The largest differences between younger and older listeners may occur in situations where the uncertainty/confusion portion of informational masking is minimal and, in fact, research suggests that this factor does not appear to change with age (e.g., Li et al., 2004; Agus et al., 2009). However, situations where there is little confusion between the target and masker but potential for cognitive, higher-level interference (e.g,, when the masker is from talkers who are opposite in sex from the target talker, or when the masker is understandable) do appear to pose more problems for older than for younger listeners (e.g., Tun et al., 2002; Larsby et al., 2005; Rossi-Katz & Arehart, 2009). Finally, although the benefit from perceiving the target talker to be spatially separated from the masking talkers is reduced in many older listeners, for the most part older adults do retain some advantage from spatial separation in multi-talker environments (e.g., Duquesnoy, 1983; Festen & Plomp, 1996; Arbogast et al., 2005; Murphy et al., 2006; Marrone et al., 2008a).

Clinical Considerations

It may be useful to consider theoretical reasons why hearing aids might or might not be helpful in situations with a small number of competing talkers. Amplification could be of benefit in these environments simply because restoring audibility of the target speech signal will make it easier to understand the message, leading to more resources available for higher-level processing (such as ignoring the masking talkers). Provision of high-frequency amplification may allow listeners to use interaural level difference cues to help separate target from background, which should be beneficial when the environment contains more than one talker. Hearing aids with directional microphones and noise reduction circuits should improve the relative SNR of target talker to background voices, thereby reducing energetic masking and perhaps, alleviating the load on working memory (Sarampalis et al., 2009). And, any enhancement in the ability to localize sounds would help the listener find the target talker visually, leading to better (and more rapid) use of visual speech information.

Why might hearing aids not be helpful? Since binaural hearing aids are fit independently, the interaural cues that are necessary for localizing sounds, segregating sources, and obtaining spatial release from masking may be disrupted. Another unwanted side-effect of hearing aids is that they may improve the audibility of competing voices, which would likely cause increased informational masking. Directional microphones may be detrimental in real-life situations in which the listener would like to be able to monitor outside conversations (Shinn-Cunningham & Best, 2008). Noise reduction algorithms may not identify competing speech as "noise", especially in situations with only one or two competing talkers. Finally, background noise may actually reduce informational masking by masking the competing speech (e.g., Freyman, Balakrishnan, & Helfer, 2001; Kidd, Mason, & Gallun, 2005; Agus et al., 2009a). The reduction of background noise might therefore lead to more informational masking.

What does research tell us about the helpfulness of hearing aids in situations with a small number of background talkers? Few studies have been conducted to date that could help us make evidenced-based decisions regarding the effectiveness of hearing aids in the presence of audible background conversations. Based on the small number of studies that have been conducted, it appears that hearing aids might be useful for older adults in situations with one competing talker (Hallgren et al., 2005) but could provide less benefit when there are additional masking voices (Hornsby, Ricketts, & Johnson, 2006). Marrone, Mason, & Kidd (2008b) found that bilateral hearing aids had little effect on spatial release from masking in either older or younger listeners with hearing loss, although unilateral hearing aid fitting resulted in slightly reduced spatial release from masking. Perhaps most relevant is that even when speech stimuli are spectrally shaped to restore audibility, older hearing-impaired listeners demonstrate poorer speech-on-speech perception than young, normally-hearing listeners (Humes et al., 2006; Humes & Coughlin, 2009; Rossi-Katz & Arehart, 2009). Hence, restoring audibility is unlikely to resolve problems in competing speech situations. Taken as a whole, there is little research evidence to suggest that hearing aids will provide substantial benefit in situations with a small number of competing talkers. It should be noted, however, that very few studies have been conducted to address this question and many factors that likely influence aided benefit (e.g., the effect of directional microphones and noise reduction processing) have not yet been explored systematically.

Helping our Older Patients Cope in Complex Listening Situations

How can we help our older patients cope in situations with competing talkers? First, we need to consider that there is a large amount of individual variability in age-related changes in speech recognition ability, especially in complex listening environments. Although amount of high-frequency hearing loss can explain some of this variability, there are other factors that we do not typically measure that affect age-related changes. We should routinely use questionnaires, such as the SSQ (Gatehouse & Noble, 2004) or the COSI (Dillon, James, & Ginis, 1997), to better define the precise nature of the problems each of our individual patients experiences.

Research has shown that, although the ability to benefit from spatial separation between target and masking speech is reduced in older, hearing-impaired listeners, most individuals do obtain some benefit from spatial separation. Fitting binaurally (rather than monaurally) may preserve whatever spatial separation advantage our patients retain.

Directional microphones should help to improve the SNR in complex listening situations, especially in rooms with low levels of reverberation. This technology also might reduce informational masking by making the competing talkers in the background less audible. However, patients should be informed that their ability to monitor other conversations in their environment will be reduced when using directional microphones in hearing aids. Moreover, there is some evidence that directional microphones interfere with the ability to localize sources in non-frontal locations (e.g., van den Bogaert et al., 2008) which may lead to difficulty parsing a complex acoustic environment and/or using lipreading cues efficiently when switching between target talkers.

The effectiveness of noise reduction algorithms in competing speech situations is still undetermined; however, any type of processing that accentuates the target speech and de-emphasizes the masking voices should be advantageous. As long as the competing speech is classified as "noise" by the noise reduction algorithm, the overall SNR will be improved. Hence, one key factor in the efficacy of noise reduction circuitry in real-life environments is whether the competing speech of one or two talkers is indeed classified by the system as "noise". And, as mentioned earlier, background noise may actually help to decrease informational masking by masking the competing messages. It is clear that there is still much research that needs to be done on noise reduction technology in complex listening situations.

Finally, we should stress to our patients the importance of using communication strategies in challenging situations. Patients should be counseled about the substantial benefits that can be derived from the use of visual speech cues. Specifically, listeners and their communication partners need to know that lip-reading cues are vital in situations where there are competing conversations. Moreover, the communication partner should be informed that any strategy that will help differentiate his/her voice or message from that of the background talkers (for example, using "clear speech" or simply increasing vocal level in a competing speech situation) should help alleviate problems in complex listening environments. Lastly, staying on topic or cueing the listener into topic changes will likely be beneficial in helping the listener use context to supplement a less-than-ideal signal.

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