EFFECTS OF SIMULATED CATARACTS ON SPEECHREADING

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DEDICATION

To my loving husband, my family and close friends who
have supported me through this journey

For, after all, everyone who wishes to gain true knowledge must climb the Hill Difficulty alone, and since there is no royal road to the summit, I must zigzag it in my own way. I slip back many times, I fall, I stand still, I run against the edge of hidden obstacles, I lose my temper and find it again and keep it better, I trudge on, I gain a little, I feel encouraged, I get more eager and climb higher and begin to see the widening horizon. Every struggle is a victory. One more effort and I reach the luminous cloud, the blue depths of the sky, the uplands of my desire. I am not always alone, however, in these struggles.

— Helen Keller (The Story of My Life)

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ABSTRACT

Watching a speaker's face can improve a listener's speech understanding, especially at poorer signal-to-noise ratios (SNRs). Little is known, however, about the effects of visual impairments on speechreading. In a series of studies, young adults' visual enhancement to speech intelligibility under normal vision and simulated cataract vision was tested. In Study 1, speech intelligibility was tested while Central Institute for the Deaf *Everyday Speech Sentences* were presented via live-voice at a fixed -13 dB SNR under normal vision and mild cataract conditions. In Study 2, speech intelligibility was tested while Speech in Noise (SIN) Sentences were presented via high luminance, recorded talker at SNRs ranging from 0 to -21 dB under normal vision and moderate-to-severe cataract vision. In Study 3, speech intelligibility was tested while SIN Sentences were presented via natural luminance, recorded talker at SNRs ranging from 0 to -21 dB under normal vision and simulated mild cataract vision. In Study 4, speech intelligibility was tested while SIN Sentences were presented via natural luminance, recorded talker at SNRs ranging from 0 to -21 dB under normal vision and simulated severe cataract vision. In Study 5, speech intelligibility was tested while SIN Sentences were presented via recorded talker at eight luminance levels using neutral density (ND) filters ranging from 0 to 4.2 ND at .6 steps under normal vision and simulated mild cataract vision. In Study 6, speech intelligibility was tested while SIN Sentences were presented via recorded talker at eight luminance levels using neutral density filters ranging from 0 to 4.2 ND at .6 steps under normal vision and simulated severe cataract vision. Participants' ability to use visual information to support speech understanding was significantly reduced under simulated mild cataracts and was nearly eliminated under simulated severe cataracts. This effect was observed under natural levels of luminance of the talker's face and was mitigated by high levels of luminance.

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LIST OF ABBREVIATIONS/NOMENCLATURE

A or AO	Auditory or Auditory-only
AD	Right Ear (Auris Dextra)
AMD	Age-related Macular Degeneration
ANSI	Ambient Noise Standards Institute
AS	Left Ear (Auris Sinistra)
(A)SNR-50	Signal-to-Noise Ratio at which 50% accuracy is obtained under auditory conditions
AV	Audiovisual or Auditory-Visual
BE	Better Ear (Pure-tone Threshold)
cd/m^2	candelas per meter squared
CID	Central Institute for the Deaf
CS	Contrast Sensitivity
D	Diopters (of blur)
dB	Decibels
dB HL	Decibel Hearing Level
dB SPL	Decibel Sound Pressure Level
ESS	Everyday Speech Sentences
ETDRS	Early Treatment Diabetic Retinopathy Study
FA	Far Acuity
Hz	Hertz
IAC	Industrial Acoustics Company
LCD	Liquid Crystal Display
m	meter(s)

LIST OF ABBREVIATIONS/NOMENCLATURE (continued)

NA	Near Acuity
ND	Neutral Density
OU	Binocular (Oculus Uterque)
PE	Poorer Ear (Pure-tone Threshold)
S-MLV	Self-Monitored Live Voice
SIN	Speech in Noise Sentences
SNR	Signal-to-Noise Ratio
SNR-50	Signal-to-Noise Ratio at which 50% accuracy is achieved
VE	Visual Enhancement
VU	Volume Units
WSU	Wichita State University

CHAPTER 1

INTRODUCTION

Patients with visual impairment sometimes refer to their glasses as their "*hearing aid"* and prefer to wear them when engaging in face-to-face conversations or watching television (Massaro & Cohen, 1995). Anecdotal comments from patients suggest that visual degradation can interfere with the acquisition of visual cues associated with vocalizations that facilitate verbal communication. Similarly, professionals in the speech and hearing sciences hypothesize that cataracts and other forms of visual impairment hinder speechreading (Erber & Scherer, 1999; Karp, 1988; Tye-Murray, 2009). Erber (2002) suggested that clinicians should consider not only a patient's conversational fluency, but also their vision when determining rehabilitative options for hearing impaired listeners. It is important to investigate the intuition of patients and professionals regarding the supportive or at times detrimental role that vision can play in speech perception.

Speechreading is the process of understanding the message of a talker by watching the movements of their face (Calvert & Campbell, 2003). The term "speechreading" has taken the place of the term "lipreading". Although the two terms are used interchangeably at times, the term lipreading is regarded by some as misleading since it implies that only the lips provide information about speech (e.g. Hipskind, 2002). The term speechreading is preferred since it encompasses all the cues used for audiovisual speech perception, including areas of the face beyond the mouth, gestural cues, and contextual cues (Walden, Prosek, Montgomery, Scherr, & Jones, 1977). In this paper, the terms speechreading or audiovisual speech perception will be used to refer to the process of understanding speech using both visual and auditory cues. Additionally, the term silent speechreading (Campbell, 2008) will be used to refer to the process of using visual cues in the absence of all auditory cues for speech understanding. Finally, auditory-only speech will refer to listening to the speech of a talker without seeing the face of the talker.

A large body of evidence supports the importance of visual cues in speech perception. The classic study of Sumby and Pollack (1954) demonstrated that visual cues are particularly important in conditions where the auditory signal is masked by extraneous noise. Sumby and Pollack tested speech recognition with and without the view of the talker's facial and lip movements under different signal (speech)-to-noise ratios (SNR). Viewing the speaker's face significantly improved speech recognition when the noise made speech otherwise unintelligible. Recent findings have shown that the perception of a talker's face not only facilitates speech recognition but also improves the detection thresholds of speech embedded in noise (Grant, 2001; Grant & Seitz, 2000) and makes the speech more intelligible (Schwartz, Berthommier & Savaraux, 2004).

Despite the large body of evidence regarding the importance of viewing a talker's face while listening to speech in noise, little research has investigated the impact of visual impairments on this process. Dioptric blur, or refractive error, is the form of visual impairment that has received the most attention in regard to how it may affect a person's ability to speechread. These studies have found that the process of speechreading is robust against dioptric blur. Researchers have found that blurring the image of a talker's face reduces listeners' ability to use visual cues for speech detection (Campbell, Zihl, Massaro, Munhall, & Cohen, 1997; Erber, 1979); however, listeners still receive benefit from viewing the talker. This is true even when the face is degraded beyond recognition (Thorn & Thorn, 1989). These findings challenge the claim that visual impairment should interfere with face-to-face communications.

Dioptric blur is just one form of visual impairment that a listener may experience. The most common causes of visual impairment in elderly persons in developed countries are age-related macular degeneration (AMD), glaucoma, cataracts, and diabetic retinopathy (Quillen, 1999). Each eye disease degrades vision through a variety of mechanisms. For instance, cataracts cause diffusive blur and disability glare. Other forms of eye disease are associated with image distortions, scotomas, visual field loss and reduced contrast sensitivity (Quillen, 1999) that may affect speech reading. To date the effects of eye disease on speechreading have received little attention.

Cataracts represent the foremost cause of correctable visual impairment in adults over age 75 and the most common cause of blindness worldwide (Kahh et al., 1977).   Half of adults between the age of 52 and 64 and 70% of adults age 70 and older have cataracts (Rosenthal et al., 1999). Despite the prevalence of cataracts, their role in speechreading has not been experimentally investigated. Common symptoms associated with cataracts include diffusive blur, glare and/or light sensitivity, reduced contrast sensitivity, changes in color perception and poor central vision (Lee et al., 2005), all of which may limit individuals' functioning level. Cataracts may not only restrict the quality of the visual input, but are also implicated in higher cognitive disruptions as well (Wood, Chaparro, Anstey, et al., 2009). Considering the complexity of speech perception and the many processes involved, disruptions at sensory and cognitive levels could result in less than optimal speech comprehension.

This work will review the literature regarding the extent to which speechreading can be improved or degraded by changes in the auditory signal, visual signal, and cognitive processing. Additionally, theories of audiovisual speech perception will be discussed. This work will guide understanding of how cataracts may interfere with speech processing.

CHAPTER 2

LITERATURE REVIEW

Many researchers have shown that older adults do not perform as well as younger adults on speech perception tasks (Gordon & Allen, 2009; Sommers, Tye-Murray, & Spehar, 2005). This disparity could stem from a wide variety of sensory and cognitive differences between the two groups. One likely explanation is that older adults tend to have higher hearing thresholds than younger adults (i.e. a tone must be presented much louder for older adults to detect it equally as well as younger adults). Hearing loss, which is a common condition among older adults, can account for some but not all of the differences between the two groups' performance in speech comprehension tasks. Older listeners have been shown to have comparatively poorer performance on speech comprehension tasks than younger adults, even when they have been matched by hearing thresholds (Schneider, Daneman, & Pichora-Fuller, 2002). This suggests that other factors contribute to older adults' poorer performance.

The ability to filter or tolerate background noise is another important auditory factor that may determine speech recognition in everyday conversational settings. Older adults tend to struggle more than their younger counterparts when listening to speech in noise, regardless of their hearing abilities, which indicates a decline in the cognitive ability to suppress background noise (Tun, O'Kane, & Wingfield, 2002). Listeners show improvement in their speech comprehension in noisy environments by viewing the facial movements of a talker and integrating these cues with the acoustic information. This integration requires good cognitive function which may decline with age. Older adults also derive less benefit from bi-sensory information than their younger adult counterparts. Stine, Wingfield, and Myers (1990) evaluated the ability of young and older participants to recall an excerpt from a recording of a news story under three conditions: an audio track with the accompanying video track, an audio track supplemented with a written transcript of the track, and an auditory-only baseline condition. They reported that older adults showed no benefit from the supplemental sensory information. The researchers also found that age and working memory were negatively correlated. Working memory deficits accounted for nearly all of the performance differences in the auditory-only condition due to age, but could not account of the performance differences in the audiovisual condition due to age. The researchers believed that older listeners lose the ability to integrate bi-sensory information as they age and this decline interferes with face-to-face speech comprehension.

The cognitive process of integrating auditory and visual speech information in older adults has been shown to be comparable to younger listeners. Elderly listeners make the same consonant confusions as middle-aged listeners while demonstrating a similar benefit from viewing a talker's face while listening to speech (Walden, Busacco, & Montgomery, 1993). Additionally, older listeners have the same amount of visual and auditory enhancement from combining visual and auditory speech signals once baseline silent speechreading performance is adjusted for age (Sommers et al., 2005). Both studies, however, showed that older listeners' ability to detect the visual cues to speech was impaired. This research suggests that the difficulty older listeners have with understanding face-to-face conversations may largely stem from an inability to process visual speech cues.

An older adult with normal hearing and cognitive functioning who still struggles to speechread may be hindered by age-related visual changes. The impact of visual impairment on face-to-face speech communication in the elderly is an area of study that has historically received little attention. This review examines the literature on speechreading, the important components of speech perception, and how visual impairment may prevent listeners from utilizing those components.

Theories of Audiovisual Speech Perception

How listeners integrate visual cues in speech perception is complex and even perplexing, given that the acoustic information does not always correspond to the visible (and non-visible) articulatory movements of a talker. Speechreading with no auditory signal, or silent speechreading, is quite difficult and typically results in minimal intelligibility (Dickinson & Taylor, 2011). To complicate matters, silent speechreading can vary considerably across participants (Bernstein, Demorest, & Tucker, 1998). Speech intelligibility is greatly improved, however, when an auditory signal is presented with the visual signal, even if the auditory signal is barely discernable in noise. This boost in performance can be greater than the sum of the intelligibility of visual-only and auditory-only speech perception measured independently (Breeuwer & Plomp, 1986). This shows that the use of visual and auditory cues in speech is not a simple additive function, but is super-additive. The super-additivity of visual and auditory speech intelligibility makes it difficult to identify the relative contributions of visual and auditory processes to speech perception. MacLeod and Summerfield (1987) developed an experimental paradigm to quantify the amount of visual contribution to speech by subtracting performance in an auditory-only speech perception condition from an audiovisual speech perception condition. Their findings demonstrated that the contribution of vision to understanding speech varies across individuals; however, environmental factors can help to predict the degree of visual interaction. Specifically, visual contributions decline when the sentence difficulty increases and when there is less background noise competing with the speech signal (MacLeod & Summerfield, 1987).

Correlated versus Redundant Speech Cues

Theorists propose that vision supports speech understanding in one of two ways: by providing correlated information, commonly referred to as redundant information, or by providing complementary information (Campbell, 2008; Grant & Seitz, 2000; Ohrstrom & Traunmuller, 2006). Speech has historically been regarded as a predominately auditory process with vision playing a supportive role supplying redundant information and has only recently been considered to provide complementary information (Grant & Seitz, 2000). The onset and offset of phonetic signals, as well as frequency changes in the auditory stream, could be reinforced through visually redundant information. Additionally, some visible positions of the lips are highly correlated with the auditory signal since the lip and tongue positioning creates the articulation that distinguishes one sound from another (Campbell, 2008). Visual information supports the discrimination of sounds in which the auditory signal alone does not. For example, the sounds ‘m’ and ‘n’ are acoustically confusable but are visually distinct (Campbell, 2008). Complementary visual information can boost speech perception of sounds that are difficult for a listener to otherwise discern.

Redundancies between visual speech and the accompanying auditory signal have been shown to enable speech intelligibility even when each modality has been degraded to the point that they are unidentifiable alone (Calvert & Campbell, 2003). These auditory and visual redundancies assist in top-down cognitive process such as perceptually segmenting a continuous auditory stream of speech and help to accentuate the prosody (i.e. the stress, rhythm, and intonation) of the conversation (Summerfield, 1987). The movements of a talker’s head also aid listeners in detecting the onset and offset of speech (Campbell, 2008). Similarly, the opening and closing of the talker’s lips typically corresponds to the acoustic envelope of the speech signal

(Summerfield, 1987). Furthermore, the degree of lip opening and the modulation of overall amplitude of the auditory signal are correlated (Grant & Seitz, 2000). These examples illustrate the redundant visual information available when viewing a talker's face.

Ohrstrom and Traunmuller (2006) argue that visual information is rarely correlated with the acoustic properties of the speech signal and that proposed redundancies are uncommon. They suggest that it is impossible for the visual cues of speech to match the complexity of the auditory signal due to the limited range of movements and shapes of a talker's mouth and lips. The appearance of lip shapes are shared by several different vowels during their production and can be confusing or ambiguous in the absence of an auditory signal, which ultimately leads to confusion in vowel identification (Ohrstrom & Traunmuller, 2006). Some of the ambiguity stems from coarticulation, or overlapping of phonemes in a speech segment, which results in several phonetic sounds accompanying a single gesture or an event in the vocal tract (Liberman & Mattingly, 1985). Additionally, many of the articulators that shape speech sounds are inside the mouth cavity and cannot be seen by a listener (Watkins, Strafella & Paus, 2003). Confusion matrices relating lip shape and phonetic perception suggest that visual speech cues often fail to aid speech perception and comprehension, especially in the absence of an auditory signal (Owens & Blazek, 1985). Auer and Bernstein (1997) argue that confusion matrices exaggerate the frequency of shared lip shapes and confusions of vowel and fricative sounds. They explain that previous confusion matrices included sound combinations that resulted in words that do not exist in the English language, such as "Moom" which would not be an acceptable substitution for "Mom", and hence, it is not likely that this confusion that would be observed under natural conditions.

Grant and Walden (1996) speculate that if visual information is redundant then it should minimally improve speech perception beyond auditory-only conditions because no additional information is provided. They argue that the enhancement of speech perception by viewing a talker's face can only occur if the visual cues provide information not present in the acoustic signal. This, however, may not apply under conditions of noise where cross modality redundancies help boost comprehension by reinforcing the degraded information. The impact of noise on speech perception must be examined, since most instances in which we have face-to-face conversations are fraught with competing noise. In these cases, the visual signal of a speaker can be invaluable to the listener as it contains many redundant cues to support the degraded perception of the auditory speech signal.

<u>Motor versus Auditory Speech Perception Theory</u>

Competing theories exist regarding how auditory and visual cues are integrated into speech perception and whether speech engages special perceptual processes differently than other auditory processes. Classic speech perception theorists state that the elements of speech are just sounds and that there is no specialized or dedicated processing of articulation or speech sounds (Liberman & Whalen, 2000). Alternatively, other theorists counter that humans have an innate ability to attend to the human voice as well as automatically process speech (Tun et al., 2002) and that the objects of speech are articulatory gestures, not sounds (Liberman & Mattingly, 1985).

The motor theory of speech perception was the first theory to propose that speech perception is an innate human ability that is processed by dedicated cortical circuits (Diehl, Lotto, & Holt, 2004). Liberman (1957) found in studying synthetic speech that coarticulation (i.e. the overlapping of phonemes) makes speech very complex, and subsequently discovered that the articulators of speech production corresponded more closely to perceived phonemes than does the acoustic signal. Given the relationship between perception and motor movements, Liberman, Cooper, Shankweiler, and Studdert-Kennedy (1967) argued that listeners must perceive speech through neural motor representations identical to those that are activated when the listener speaks and engages in the motor processes of speech production. The motor theory of speech perception was later revised with theorists Liberman and Mattingly (1985) proposing the existence of a 'module' specialized to detect the intended gestures of the speaker that are the basis for phonetic relationship between gestures and phonetic categories. Under this account, the listener perceives the intended gestures of the speaker and creates a comparison in the motor 'module' of how the listener would produce the same gesture. This comparison allows the listener to perceive the meaning of the intended articulations of the talker through a comparison of their own articulations within the same motor process. This view assumes that speech is broken down into articulatory gestures, that articulation and coarticulation of gestures are species specific, and that gestures are processed by modules specific to language communication (Liberman & Whalen, 2000).

The motor theory of speech perception has received support from research examining listeners' neural processes to identify a possible speech 'module' that specifically processes speech information. The left hemisphere is an area of the brain known to be active while listeners are deciphering sounds (Zatorre & Belin, 2001). Within the left hemisphere, the left anterior sulcus has been shown to respond to phonetic sounds and intelligible speech (Scott, Blank, Rosen, & Wise, 2000). These findings offer some support to the claim that the perception of speech is a special process mediated by a specific 'module' independent of other auditory processes. Additionally, motor and premotor areas and speech-to-motor pathways in the left hemisphere have been shown to be active in listeners who perceive speech through speechreading (Scott et al., 2000; Watkins et al., 2003).

The motor theory of speech has also received support from research examining mirror neurons, which are activated both when an observer perceives an action and performs the same action (Gallese & Goldman, 1998). Neurons in monkeys have also shown selectivity to auditory and visual action stimuli, termed audiovisual mirror neurons (Kohler et al., 2002). The activity in the left hemisphere during the imitation of speech may be due to the presence of these “mirror” neurons, which would allow for the imitation and recognition of speech (Watkins et al., 2003). The motor theory’s hypothesized speech ‘module’ for articulatory gestures may be part of these neural structures that are activated by motor gestures, verbal gestures and speech stimuli.

Classical theorists on the other hand, argue against the motor theory of speech perception and propose that perception of audiovisual speech is not accomplished through a language specific modality, but rather is perceived through separate auditory and visual pathways that are integrated in early cognitive processes (Grant & Seitz, 2000; Liberman & Whalen, 2000). The classical view holds that speech and non-speech sounds are processed in a similar fashion, that gestures are not speech specific, and that speech perception is equivalent to all other forms of auditory perception (Liberman & Whalen, 2000). This position is supported by research showing that speech and non-speech sounds share the same temporal processes and auditory mechanisms (Diehl et al., 2004). Additionally, non-humans can respond to speech in the same way as humans, yet they cannot produce speech. This contradicts the tenets of motor theory and demonstrates that speech perception may not be a unique human ability.

Visual Contributions to Speech Comprehension

Sumby and Pollack (1956) demonstrated that listeners increasingly utilize visual cues to support speech comprehension as the signal-to-noise ratio (SNR) declines (i.e. the background noise becomes louder than the speech signal). They found that for normal hearing listeners, visual cues are only beneficial when high levels of noise accompany a speech signal. At higher SNRs the auditory signal alone provides enough information to support speech recognition. The contribution of vision to speech increases as the SNR declines, reaching its maximum contribution at an intermediate SNR (i.e. -12 dB) and diminishes thereafter (Ross, Saint-Amour, Leavitt, Javitt, & Foxe, 2006). This finding is consistent with the results of Sumby and Pollack showing that optimal integration of audio and visual speech information is obtained at intermediate SNRs.

Seeing a talker’s face not only improves listeners’ speech comprehension but also makes the auditory signal appear “louder” (Schwartz et al, 2004). This “loudness” effect has been attributed to the correlation between the amplitude of the acoustic speech signal and the distance between (i.e., bilabial distance) the speaker’s lips (Grant & Seitz, 2000). Greater bilabial distance cues the listener to expect greater speech amplitude, and likewise smaller bilabial distance encourages the listener to anticipate lower speech amplitude and attend more carefully. Observing the spatial and temporal correlations among speech and visual signals may support more accurate auditory scene analysis by helping to group auditory streams and identify their location and origination (Summerfield, 1987; Schwartz et al., 2004).

Although Sumby and Pollack (1956) found that listeners rely on visual speech cues in noisy conditions, McGurk and MacDonald (1976) demonstrated that a visual signal can change the perception of speech even in optimal listening conditions. Their study showed that when participants are presented with auditory clips of a talker voicing /ba/ paired with an incongruent video clip showing the talker voicing /ga/, they do not report /ba/ or /ga/, rather they report hearing the "fusion" percept /da/. Similarly, when the visual /ba/ is paired with an auditory /ga/, listeners report, although less commonly, the "combination" percept /gabga/ (Green & Norrix, 1997). This phenomenon, now known as the McGurk effect, demonstrated that speech perception is a multimodal process that supports the most plausible pairing between what is seen and what is heard. Although the McGurk effect is often cited as an example of speechreading, it is not an accurate depiction of speechreading processes, since the individual /da/, /ba/, and /ga/ phonemes are not common in most speech interactions. True speech production and perception is much more complex since phonemes often overlap one another during coarticulation (Liberman & Mattingly, 1985). Furthermore, the original McGurk experiment is not representative of real speech since the stimuli provide no contextual cues to help the listener anticipate the intentions of the talker. Later work by McGurk (1981), however, demonstrated the McGurk effect in speechreading, using coarticulation and context, in which the verbal representation "My bab pope me poo brive" and the visual representation "My gag koke me koo grive" resulted in the unified percept of "My dad taught me to drive". These findings illustrate the power of our visual system to not only assist our auditory system but also to ultimately bias our perception.

Important Components of Speechreading

The recognition that vision can influence speech perception has focused investigative efforts on identifying the specific features of a talker's face that provide the supporting information. Research demonstrates that listeners use a variety of visual cues made in synchrony with speech, including the shape and movements of the lips and tongue, and features of the upper face including the eyebrows and movements of the head (Cosatto & Graf, 1998; Munhall, Jones, Callan, Kuratate, & Vatiliotis-Bateson, 2004; Rosenblum, Johnson, & Saldana, 1996). It is still unclear which features are necessary and sufficient for speech perception. It is difficult to identify the exact cues and their weighted contribution to speechreading because of large individual differences across listeners' speechreading abilities (Watson, Qui, Chamberlain, & Li, 1996).

There are a number of factors that can influence an individual's ability to speechread, including gender and age. Several studies have found that females tend to speechread better than males (Daly, Bench, & Chappell, 1996; Dancer, Krain, Thompson, Davis, & Glenn, 1994; Johnson, Hicks, Goldberg, & Myslobodsky, 1988). More recent research, however, has reported no difference between males and females (Tye-Murray, Sommers, & Spehar, 2007). Age has been found to be a better predictor of speechreading ability in that performance tends to decline as listeners age (Sommers et al., 2005; Tye-Murray, Sommers, & Spehar, 2005). Although some listeners can benefit from speechreading training later in life, typically listeners born deaf are the most skilled speechreaders (Bernstein et al., 1998).

Despite the large variability in speechreading skills, researchers have found a variety of ways to examine which facial cues are most important for visual speech perception by visually isolating talkers' facial features or articulators. Rosenblum, Johnson, et al. (1996) used point-light technology to reduce the visible features of a talking face to strategically placed lights that represent the pattern of a talker's facial movements and gestures. They concluded that increasing the number of lights on the face contributed to more accurate speech perception; however, they also found that lights placed only on the lips were sufficient to boost speech perception in noise. The researchers also noted that the number and placement of lights on the talker's lips determines the extent of visual enhancement. Thomas and Jordan (2004) found that viewing the information in the area of the mouth (excluding the larynx and mandible) was as effective as viewing the entire moving face; concluding that both oral and extraoral facial movements can influence audiovisual speech perception. Additionally, Rosenblum and colleagues found that lights placed on the teeth and tongue enhance perception by providing articulatory information.

Eye tracking technology has been used to identify where listeners look while they are engaging in face-to-face conversations. Listeners tend to move their gaze to different regions around the mouth during speechreading (Lansing & McConkie, 1994) and while speechreading McGurk stimuli. Interestingly, Paré, Richler, ten Hove, and Munhall (2003) found that listeners demonstrated the McGurk effect even when the viewer's gaze was displaced 60˚ from the talker's face. This research suggests that the advantage of viewing a talker's face does not require high acuity, foveal vision. Listeners show a preference for fixating on the right side of a talker's face while perceiving audiovisual speech (Everdell, Marsh, Yurick, Munhall, & Paré, 2007). This may be because most talkers tend to open the right side of their mouth wider than the left side (Graves & Landis, 1990) and listeners may adapt their viewing preference toward the part of the face with the most movement. Everdell et al. observed this preferential viewing tendency even when the talker's facial movements were symmetrical, but also found that the viewing preference to the right side did not improve speechreading accuracy. Future research using eye tracking technologies may reveal how expectancies, fatigue, and important auditory cues impact eye gaze (Lansing & McConkie, 1994).

Synthetic talking head technology has been used to isolate important facial movements for speechreading by providing controlled talker gestures and movements through computer simulation. This research has shown that information gained from tongue movements during speech is so rich that this process has been called *tongue reading*; however, this is only true when listeners are limited to only viewing the tongue but no other movements of the mouth or lips (Badin, Tarabalka, Elisei, & Bailly, 2008). Talking head technology has shown that the timing of eyebrow and head movements along with the auditory signals of speech contribute to speech intelligibility (Cosatto & Graf, 1998; House, Beskow, & Granstrom, 2001). This is contrary to the findings of Rosenblum, Johnson, et al. (1996), who found no significant contribution of eyebrow movements to speechreading using point-light technologies and additionally found no contribution of cheeks, jaw, or nose-tip to speechreading. Munhall, Jones, et al. (2004) also utilized computerized talking head movements to test speech intelligibility in noise in young, normal Japanese participants. They found that participants performed best when they were able to view the natural head movements of the talker. These results were surprising since Japanese listeners have been shown to demonstrate fewer instances of the McGurk effect leading some to believe that they rely less on visual information in speech perception (Sekiyama, & Tohkura, 1991). These studies support the idea that visual prosody plays an important role in audiovisual speech perception (Cosatto & Graf, 1998; House et al., 2001; Munhall, Jones, et al. 2004).

Some research has suggested that vowel identification is a key predictor that distinguishes good speechreaders from poor speechreaders and many researchers have examined the visual components associated with vowel production (Auer, 2007). Physical measurements of talker lip movements have been shown to predict vowel perception, accounting for up to 50% of variance in vowel identification (Montgomery & Jackson, 1983). The type of lip rounding also provides important visual cues, especially with respect to vowels (Ohrstrom & Traunmuller, 2006). Lip position has been shown to help listeners identify sets of vowels (depicted in Figure 1) such as front open vowels (e.g. the vowel sound /æ/ in “had”), versus rounded back vowels (e.g. the vowel sound /u/ in "boot"), but not further differentiation within a vowel group (Fromkin, 1964).

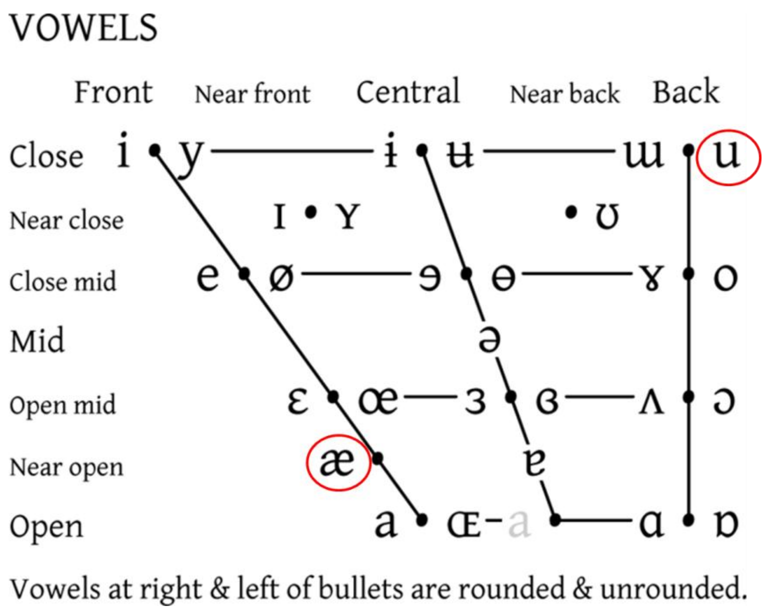

Figure 1. International Phonetic Alphabet (IPA) Vowel Chart (IPA, 1999). The vertical axis illustrates the vowel height (i.e. distance between the top and bottom lip) and the horizontal axis illustrates the vowel's backness (i.e. the position of the tongue in the oral cavity).

The protrusion of the lower lip provides information in the absence of lip rounding and the distance in teeth opening provides some distinction for back vowels. These findings show the importance of lip rounding, lip protrusion, and teeth opening in the identification of vowels, but also illustrate the potential ambiguity of lip movements in the absence of an auditory signal.

Although much of the research has focused on the role of vowel identification in speechreading (Auer, 2007; Fromkin, 1964; Ohrstrom & Traunmuller, 2006), consonant identification is also believed to predict individuals' ability to identify audiovisual speech. Grant, Walden, and Seitz (1998) tested how well consonant recognition could predict auditory-visual integration of speech in hearing impaired listeners. The researchers found that place of articulation, (e.g. an active bottom lip touching a stationary top lip), and auditory manner plus voicing, (i.e. the way in which the tongue, lips, and jaw make contact in voiced sounds), were the most important visual cues that predict listeners' accuracy in consonant recognition. This study showed that the accuracy of listeners improved by 26% when viewing consonant production over auditory-only conditions.

The literature discussed above has identified visual cues that listeners utilize to assist speech perception. Listeners appear to rely on a wide range of facial cues including head, brow, jaw, teeth, and tongue movements. Lip movements have specifically been shown to provide important cues about vowel and consonant information. Most importantly, listeners rely more on the visual cues as the auditory conditions are increasingly compromised. Redundant and complementary visual and auditory information not only improves speech perception thresholds in noise, but also creates the perception of louder, clearer speech.

Degraded Sensory Inputs in Speechreading

Previous research has demonstrated that the visual system supports and interacts with the auditory system in the perception of speech. The experimental use of ambient or background noise shows how listeners utilize visual cues when the auditory signal is degraded by competing sounds. Other factors impact how the visual system supports speech perception. The use of vision in speech perception is especially important in older populations since they are likely to experience other sensory and cognitive changes that may affect speech perception (Grant & Seitz, 2000).

Speechreading with Hearing Loss

The role of vision for speech perception is especially important to listeners with hearing loss. Blumsack (2003) explains that the initial loss of auditory functions can impair the performance of daily living activities, such as communication. Many older adults experience presbycusis or age-related hearing loss, which affects detection of high frequency pure-tones, and this may become more dependent on visual cues to aid speech perception (Thorn & Thorn, 2002; Tun et al., 2002). Approximately 40% of adults age 75 and older report difficulties in hearing frequencies that are necessary for speech recognition (Tun & Wingfield, 1999). Poorer detection of higher frequencies can impair the perception of speech produced by young children, women, or other individuals with high-pitched voices. Additionally, older adults with presbycusis struggle to perceive fricatives (e.g. s, f, or th consonant sounds) which are composed of high frequencies (Dougherty & Welsh, 1966). Older adults with high frequency hearing loss will find it especially difficult to detect fricatives spoken by young children, with high pitched voices, and may report hearing children "mumble" as a result. Erber (2002) found that individuals with high-frequency hearing loss and normal vision could overcome the loss through speechreading. Individuals with high-frequency hearing loss and visual impairment, however, may not be able to compensate for their auditory loss through speechreading. Degraded vision may cause a loss of high spatial frequencies that would make it difficult to detect the fine spatial differences of a talker producing consonant sounds. Erber suggested these individuals with severe visual loss would benefit more from a hearing aid than from speechreading training.

Changes in the available acoustical information, due to high-frequency hearing loss, could have deleterious effects on audiovisual integration abilities and ultimately on speech perception. The strength of the McGurk effect has been shown to vary according to the strength of the auditory stimulus (Green & Norrix, 1997). The results showed that both fusions (i.e. auditory /ba/ + visual /ga/ = /da/ percept) and combinations (i.e. visual /ba/ + auditory /ga/ = /gabga/ percept) were increased by raising the amplitude of the bursts and aspirations of the auditory stimulus. Degrading the bursts and the aspirations of the auditory signal, however, reduced the frequency of the combination percept. These findings from Green and Norrix are important because they suggest that a degraded auditory signal may change the way visual cues are integrated into speech perception.

Despite the prevalence of presbycusis among older adults, it may not be the sole cause of their poor speech intelligibility. This is primarily because the frequencies of speech with the greatest energy tend to fall below 1000 Hz (Nerbonne & Schow, 2002). Thus, while presbycusis degrades speech perception, especially in noise, the increased thresholds for high frequencies typically do not include "speech frequencies." Regardless of hearing loss, older adults have more difficulty understanding speech in everyday situations than younger adults (Tun et al., 2002; Schneider et al., 2002). This suggests that other factors, beyond hearing acuity, are complicit in older adults' difficulty in speech perception.

Speechreading with Visual Constraints

It is clear vision plays an important role in speech comprehension in optimal viewing conditions. Listeners may at times have difficulty using visual speech cues for speech perception because viewing conditions are often less than ideal due to poor lighting, viewing angle, and distance between the viewer and the talker. There is little agreement among researchers about which of the suboptimal viewing conditions affect speechreading the most. Part of this difficulty stems from variability in experimental methods and the visual parameters that were investigated across research teams.

Effects of Distance on Speechreading. Several studies have found that speechreading is relatively robust to changes in distance between a listener and talker. Johnson and Snell (1986) found that deaf college students, with 20/30 visual acuity or better, could effectively speechread at distances of 2.7 to 6.7 meters (m), though speechreading performance began to diminish at further distances. Similarly, Jordan and Sergent (2000) found audiovisual perception of McGurk stimuli was resistant to distance changes from 1 to 10 m, but performance declined beyond 20 m. Studies of lipreading also show that performance is relatively constant for viewing distances ranging from 1.5-12 m. Erber (1974) also showed that speech intelligibility of profoundly deaf children was improved from 11% to 75% after changing the viewing distance from 30.5 to 1.5 m. Erber found the viewing angle between the talker and listener, i.e. directly in front or to the side, was a better predictor of speechreading performance than distance.

Effects of Viewing Angle on Speechreading. Speechreading has been shown to be influenced by viewing angle, although these effects are modest. It may seem intuitive that a talker should automatically orient their face directly to the listener; however, talkers and listeners do not always recognize the optimal conditions for communication. Additionally, listeners with monaural hearing loss often turn their head to put their best ear closest to the talker (Rickets, 2000). These tendencies may result in a listener viewing a talker at an angle rather than directly face-to-face. Rickets explains that listeners with monaural hearing loss will benefit from turning their head in this way, but had not examined the degree that this would impact visual speech detection. Jordan and Thomas (2001) tested this by presenting listeners with audiovisual McGurk stimuli recorded at 0˚, 45˚, and 90˚ degree viewing angles. They found no effect of viewing angle on audiovisual performance in quiet conditions and found that noisy conditions imposed a very minor effect of angle on silent speechreading.

In contrast, a decline in audiovisual speech perception from suboptimal viewing angles has been demonstrated. Erber (1974) examined the impact of vertical viewing angles by illuminating the talkers face at 0˚ (directly in front of face), 45˚ (intermediate), and 90˚ (directly above). The 0˚ and 45˚ angle are beneficial because the interior of the mouth is illuminated which provides more visual voicing cues (Erber, 1974). The impact of horizontal viewing angle was tested by positioning the talker's chair to 0˚ (front view), 45˚ (intermediate), and 90˚ (profile view). Results showed that the 0˚ and 45˚ degree angles were the best conditions for speechreading, particularly in the vertical viewing angles because of the added benefit of illuminating the oral cavity. This study, however, may reveal more about the role of directional lighting than the role of viewing angle since Erber used a lighting method to isolate the features seen at each angle. Especially considering that the study by Jordan and Thomas (2001) found little impact of viewing angle on speechreading by using a method that did not involve illuminating the talker's face at different angles.

Effects of Lighting on Speechreading. Lighting angle may be a more important environmental factor to control than viewing angle when attempting to optimize a face-to-face conversation. Ideal lighting angles may maximize any appearance of a talker's face by making important voicing cues and articulators become more visible to the listener. Zhou and Boyce (2001) examined the role of directional illumination of a talker's mouth and oral cavity. They tested subjects' ability to report mono- and bi-syllabic words while viewing a televised talker with six variations of indirect to direct lighting conditions. They found that direct illumination of the mouth was most beneficial for bi-syllabic words and when speech is presented in noise. This suggests that some of the most important visual cues to aid speech perception lie within the oral cavity.

High illumination levels can improve the use of visual cues in addition to the angle of the light source. Some conversational settings can have restricted illumination and facial or skin characteristics can reflect light differently than others. Gagne, Laplante-Levesque, Labelle, Doucet, and Potvin (2006) investigated the effects of skin color (i.e. light and dark skin pigmentation) and the effects of illumination (ranging from 2 to 600 footcandles (fc)) on speechreading performance using an Audiovisual-FM system (i.e. frequency modulation system used to assist individuals with hearing loss). The researchers showed that speechreading performance was significantly degraded at low illumination levels in both skin color conditions. No difference between the skin colors of the talkers was observed at illumination levels above 16 fc. Light skin conditions did yield slightly better scores in speechreading under high illumination levels, but these differences were minor. These results support the need for well-illuminated faces for audiovisual speech perception and may explain why older adults tend to report difficulty understanding speech in restaurants (Newman, Weinstein, Jacobson, & Hug, 1990). In addition to the noisy conditions of a restaurant setting, many restaurants tend to dim their lights in the evening to achieve a certain ambiance. Both of these environmental factors may make speech understanding especially difficult for older adults.

Effect of Inversion on Speechreading. The spatial relationship or configuration of the components of the face and movements of the jaw in relation to the movements of the lips has been shown to improve detection of speech in noise (Grant et al., 1998; Hall, Haggard, & Fernandes, 1984). The importance of these exact configurations to speechreading has been tested by inverting the contrast and color information of the face. Studies have shown that contrast inversion of black and white faces can impede facial recognition, a similar process to speechreading (Itier & Taylor, 2002). This phenomenon may extend to color inversion since this would alter information regarding texture, shape, and contrast, which may have a disturbing effect on viewers and disrupt speechreading. McCotter and Jordan (2003) presented participants with McGurk stimuli under conditions of normal color, grayscale, contrast inverted, color inverted (e.g. changing green hues to red and yellow hues to blue), and contrast/color inverted conditions. Performance was worse in contrast and contrast/color inverted conditions, but these effects were modest. These results show that contrast information provides spatial information about the face and articulators, but the natural configuration of this information is not necessary for audiovisual speech perception.

Researchers have also examined the effects of inverting aspects of a face, such as the mouth (e.g. the lips are inverted, but the face is upright). Violating a viewer's expectations about the natural movements and gravitational aspects of a face can be quite disturbing, especially when only some aspects are inverted. Rosenblum, Yakel, and Green (2000) sought to determine if speech perception, like facial recognition, would also be disrupted by facial inversions. The researchers tested audiovisual integration of McGurk stimuli on subjects who viewed talkers with inverted faces, lips, or combinations of both and found that an upright face and inverted mouth disrupted silent speechreading. Thomas and Jordan (2002) tested the effects of inverted faces in normal and blurred conditions using consonant/vowel/consonant stimuli. Blurring the inverted faces reduced speechreading compared to normal viewing conditions demonstrating that viewers are able to extract visual cues to assist speech perception from inverted faces. Contrary to the Rosenblum et al. study, Thomas and Jordan reported no effect of inversion under normal viewing conditions. The different experimental findings may stem from differences in the test stimuli. The absence of an effect of inverted mouths on speechreading may be explained by the fact that listeners are sensitive to the bilabial relationship of a talker's lips and this distance is unaffected by inversion. These studies show that the visual cues that support audiovisual speech recognition (e.g. the lip rounding and bilabial distance) are not sensitive to the orientation of the articulators in relation to the rest of the face, and may be assessed independently by viewers.

Effects of Blur on Speechreading. The visual requirements of audiovisual speech perception appear to be relatively modest since observers derive visual enhancement of speech even when the mouth is viewed using peripheral vision (Paré et al., 2003) or the image is made very small (Jordan & Sergeant, 2000; Munhall, Kroos, Jozan, & Vatikiotis-Bateson, 2004; Neely, 1956). Additionally, visual enhancement of speech perception has been shown to occur even when visual acuity is reduced (Campbell et al., 1997; Erber, 1979). Thorn and Thorn (1989) measured the speechreading ability of hearing and hearing-impaired adults who viewed a silent video of the Central Institute of the Deaf *Everyday Speech Sentences* under varying degrees of dioptric blur. The researchers reported that performance was only modestly affected by 4 diopters (D) of blur (i.e. a visual acuity of approximately 20/125). They found, however, that both young and old listeners were able to quickly adjust and overcome the effects of 1 and 2 D of blur (i.e. a visual acuity of approximately 20/30 and 20/50 (Zacharia & Miller, 1988), respectively) after just 5 sentences. Webster, Georgeson, and Webster (2002), similarly found that when participants were shown faces that were blurred or overly sharpened they reported that the faces appeared less blurred or sharp after prolonged viewing. They explained that this effect is a rapid neural adjustment to images outside of the normal spectrum, and this adaptation can be transferred to other similarly blurred images. This adaptation process might ameliorate the effects of visual impairment on visual performance. Figure 2 illustrates the deleterious effects of diffusive blur compared to dioptric blur. Both images feature the same visual acuity; however, it is clear that the diffusively blurred image is more degraded. This illustration demonstrates that visual acuity can underestimate the visual effects of some forms of visual degradation and their effects on performance (e.g. speechreading or driving; Wood, 2002).

Figure 2. “Photographs of an image formed by an artificial eye (3 mm diameter pupil) for three conditions of viewing. In-focus (A), defocus (B), and diffusive imagery (C) are compared. The defocus and diffusing filters had identical acuity (high-frequency) response, and all conditions were equated for the same total diffuse transmission. The diffuser, which affects low frequencies as well as high frequencies, produces a more visually debilitating result than the equivalent focus. (p. 433)” from Hess and Woo (1979).

Research investigating the role of vision in speech perception tends to stress either the robustness or the vulnerability of visual enhancement for speech perception. Research as a whole shows that speech perception is affected by visual impairment. While the minimum amount of blur necessary to cause a measurable decline in speechreading is a matter of debate, it is clear that more severe levels of blur (i.e. visual acuity near 20/200 or poorer) affect performance (Erber, 1979; Thomas & Jordan, 2002). Under severe optical distortion, only gross movements of the face can be observed, providing minimal support to speech perception; however, this is best observed with silent speechreading and has less impact on audiovisual speechreading (Erber, 1979).

These findings are consistent with clinical recommendations (Romano & Berlow, 1974) that propose speechreading training is not likely to benefit a patient if their best corrected visual acuity is 20/200 or worse (a visual acuity of 20/200 is the accepted definition of "legal blindness"). Osborn, Galletti and Erber (2000) compared the effects of background noise on the perception of speech in older adults with normal and severe visual impairment (i.e., best visual acuity of the low vision group was ≤ 20/200). Not surprisingly, they found that the participants with low vision performed more poorly than the normal participants on both word and phrase identification.

Findings by Johnson and Snell (1986) suggest the visual requirement of audiovisual speech may be more stringent. They examined deaf college students and found that speechreading performance was negatively affected by visual acuities between 20/40 and 20/80. A slight decline in visual acuity (i.e. 20/30), however, was not related to speechreading performance. Johnson and Snell's results are inconsistent with Hardick, Oyer, and Iron (1970) who found that slight declines in visual acuities (i.e. 20/20 to 20/40) were significantly related to poorer performance in speechreading. A later study produced support for the effect of a slight decline in visual acuity (i.e., 20/15 to 20/20) on speechreading (Dickinson & Taylor, 2011). This study used occlusion foils and found that modest occlusion on young listeners was sufficient to produce significant declines in speech intelligibility. Occlusion foils are lenses with small prisms that not only degrade visual acuity, but also decrease viewers' contrast sensitivity. It may be the slight reduction in contrast sensitivity, rather than the reduction in visual acuity, that accounts for the results of their study.

Audiovisual speech perception in older adults has also been investigated using degraded visual stimuli (Gordon & Allen, 2009; Tye-Murray et al., 2008). Tye-Murray et al. evaluated discourse comprehension by young and older adults under favorable and unfavorable visual conditions. Unfavorable visual conditions were created by reducing the contrast of the original video files by 98%. Older adults were disproportionally affected by the contrast reduction. Likewise, Gordon and Allen reported that visual enhancement under simulated blur (estimated to be comparable to a visual acuity of 20/50) was abolished for older adults but not for a group of younger participants. Scoring on the Speech Perception In Noise: Revised (SPIN-R) test used by Gordon and Allen was based on the subject's recall of the last word of each sentence which limited the number of scoreable items for evaluating performance. This task may have been too easy for younger participants and the small set of data may have reduced statistical sensitivity limiting the ability to detect a small difference in performance between visual conditions for young participants.

Despite arguments regarding the amount of blur necessary to diminish listeners' ability to use visual information, all of these studies found that blur does reduce performance but the contribution of vision to speech perception is rarely completely eliminated. The findings of the effect of dioptric blur on speechreading suggest that useful information for speechreading may be found at higher spatial frequencies. However, the researchers did not specifically manipulate the spatial frequencies available to listeners, hence; it is not clear which spatial frequencies are necessary for speechreading from these studies.

Effect of Spatial Frequency on Speechreading. Researchers have investigated which spatial frequencies are important for speechreading by using high, low, and bandpass filters to restrict the range of spatial frequencies available in a video image. Studies using spatially filtered video clips (Munhall, Kroos, et al., 2004) indicate that information supporting speech recognition exists over a range of spatial frequencies except perhaps at very low spatial frequencies (i.e., <1.8

cycles/face) and that a mid-to-low band of spatial frequencies (~11 cycles/face) provide the greatest enhancement to audiovisual performance. The strength of the McGurk effect is diminished slightly at lower spatial frequencies suggesting that observers are still able to derive useful information from large image features. Thomas and Jordan (2002) found that visual enhancement could only be derived from Gaussian blurred images with 8 cycles per face width or higher. This supports the importance for mid- and high-range spatial frequencies in speechreading. Isolating which frequencies are important can help identify which facial features or cues may support audiovisual speech perception. The high frequencies typically lost in dioptric blur tend to be fine details of a face, such as the creases around the mouth, and would not typically include more course features, such as the shading of a cheek, which are typically seen at lower frequencies.

The importance of high- and mid-range spatial frequencies on speechreading has also been examined by pixelating a talker's face and varying pixel size. MacDonald, Andersen, and Bachmann (2000) presented McGurk stimuli from a talker whose video image was presented normally and gradually degraded to as few as 11.2 pixels per face, illustrated in Figure 3.

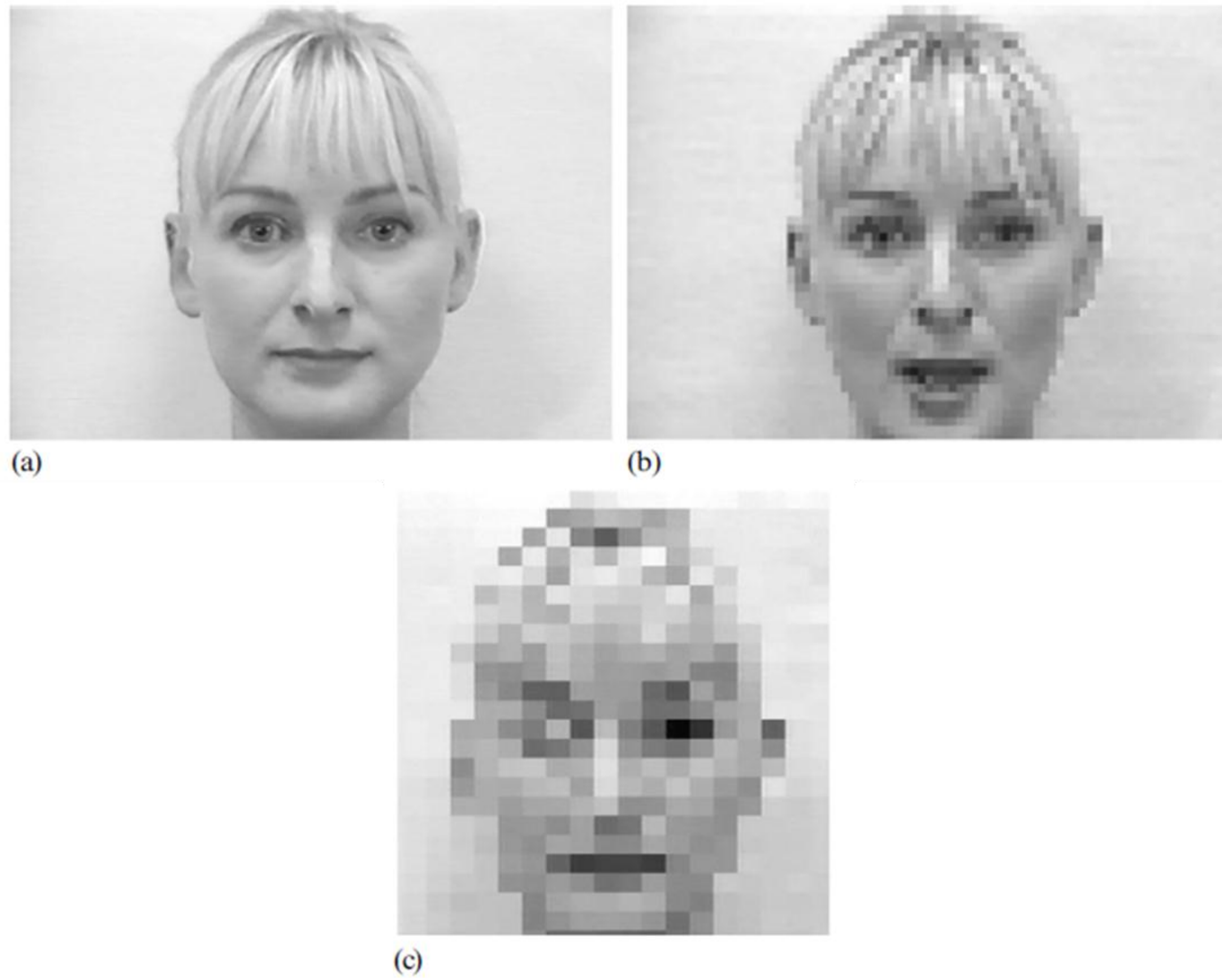

Figure 3. Image of a still of the face stimulus presented under the audiovisual conditions. (a) The original video-recording level 0; (b) level 5 of quantisation (19.4 pixels/face); (c) the coarsest quatisation (11.2 pixels/face), level 9 (p. 1157)." from MacDonald et al., (2000).

They found that the McGurk illusion was diminished as spatial quantization increased. The performance of some participants, however, was quite robust against degradation, while some participants never reported McGurk illusions regardless of the pixilation level. The difference between the two groups may not be evidence of a difference in tolerance to pixilation but may be a result of participants' susceptibility to incongruent auditory and visual stimuli, i.e. the McGurk effect. MacDonald and colleagues concluded that the interaction of auditory and visual signals occurs at coarse-spatial-scale levels, suggesting that low spatial frequencies hold the important information for speechreading. The reduced incidence of the McGurk illusion as the visual image is degraded is perhaps not because the image is unusable but is because the viewer may simply ignore the visual image altogether.

In addition to spatial resolution, contrast and temporal resolution have also been experimentally manipulated to determine their role in audiovisual speech perception. Vitkovitch and Barber (1996) asked participants to speechread televised spoken numbers under different amounts of spatial, temporal, and contrast degradations. The spatial resolution was manipulated by increasing the pixel size of the video image and was not found to have an effect on speechreading performance. The temporal resolution of the video clips was varied by manipulating the video frame rate, and they found that speechreading performance was worse at slower frame rates. Manipulations of the contrast resolution, or grayscale levels, also had a detrimental impact on speechreading, possibly because contour and shading information is lost as the number of grayscale levels is reduced. This is the information most likely to be affected by cataracts. The researchers found that the effects of contrast degradation lessened after prolonged exposure.

Cataracts' Impact on Vision

Cataracts are a natural component of the aging process and are the foremost cause of correctable visual impairment in adults over age 75 (Leske et al., 2004). Adults aged 52 to 64 have a 50% chance of having cataracts and those aged 70 and older have a 70% chance of having cataracts (Klein, Klein, & Linton, 1992). The prevalence of cataracts is also partially determined by family history, diabetes, medications, race, and excessive ultraviolet exposure (American Academy of Ophthalmology, 2007). Cataract formation is largely the result of degenerative changes in the proteins of the lens which scatters some of the light reducing the contrast of the image on the retina (Spector, Li, & Sigelman, 1974). Severe cataracts can lead to blindness (Frozena & Odle, 2006). Cataracts do not always form evenly throughout the lens and their effects on vision depend on the place of formation. If a cataract forms directly behind the pupil, vision will greatly be impaired in comparison to it forming in the peripheral edges of the lens (Frozena & Odle, 2006). Common symptoms associated with cataracts include glare and light sensitivity, reduced contrast sensitivity, changes in color perception and poor central vision (Lee et al., 2005).

The impact of cataracts on other types of functioning and quality of life issues has been studied by a number of researchers. Individuals with visual impairment, including those with cataracts, report difficulties reading, driving, seeing clearly, and mental health functioning as a result of their reduced vision (Mangione et al., 1998). According to Owsley et al. (1999), cataracts can also be associated with reduced cognitive status, which may have implications for speech intelligibility similar to the effect of reduced contrast sensitivity. Wood and Carberry (2006) reported that older individuals with cataracts may avoid certain driving situations, such as driving long distances or at night, and may be less safe driving than their peers without cataract impairment. Crash risk is increased for those with advanced contrast sensitivity impairment, usually from cataracts, even if the impairment is severe in only one eye (Driving Competence, 2003). The same study suggests that it is a dangerous practice to assess a person's contrast sensitivity from their superior eye because of their risk of an accident or other injury.

In most cases, cataract removal surgery has a high success rate and few complications (Patel, Elliot, & Whitaker, 2001). Cataract surgery has become one of the most commonly performed procedures worldwide (Wood & Carberry, 2006). According to the American Academy of Ophthalmology (2007), every year over 1.4 million individuals undergo cataract removal surgery in the United States and approximately 95% experience no complications. There are four major levels of cataract, but the interference with daily activities (not the level) determines the need for surgery (American Academy of Ophthalmology, 2007). Cataract removal surgery is capable of enhancing visual acuity to 20/40 or better (Frozena and Odle, 2006) and greatly enhances performance, such as driving, largely due to the improvement of contrast sensitivity post-surgery (Wood & Carberry, 2006). While cataracts are easily treated through surgery, not all individuals have access to surgery for various reasons such as insurance or monetary difficulties or comorbid eye disease. Older adults are less likely to be approved for cataract removal surgery if they also are suffering from macular degeneration disease because of a higher risk of complications (Patel et al., 2001).

Despite evidence demonstrating the importance of visual information for speech perception, surprisingly little is known about the effects of real or simulated visual impairment on speech perception. However, a small scale study (n = 4) of the effects of monocular central scotomas on the McGurk effect found comparable performance for three of the four participants regardless of whether the participants viewed the stimulus using the eye with the scotoma or the visually normal eye (Wilson, Wilson, ten Hove, Paré, & Munhall, 2008). Importantly, two of the patients had very small scotomas (< 2° dia meter) that might interfere only minimally with speech perception. One participant, however, showed a greater disruption of the McGurk effect that was likely a result of the participant placing the scotoma over the mouth of the talker which was later confirmed using eye tracking. Wilson et al. found that audiovisual speech perception was significantly worse in AMD patients with visual acuities of 20/200-20/3200, compared to age-matched normal observers.

While researchers and clinicians commonly cite cataracts as an example of a visual condition that may impede good speechreading (Erber, 2002; Erber & Scherer, 1999; Karp, 1988;

Tye-Murray, 2009), there is little experimental evidence supporting this claim. In fact, we are not aware of any systematic investigation of the effects of real or simulated cataracts on speechreading. Recent investigations of bilateral congenital cataracts revealed that they can interfere with the normal development of visual speech perception. Adults who had had bilateral congenital cataracts during infancy show both a reduced McGurk effect and poorer speechreading skills (Putzar, Hötting, & Röder, 2010) and are significantly poorer at speechreading than age matched controls who had normal vision during infancy (Putzar, Goerendt, Lange, Rösler, & Röder, 2010).

Cognitive Processing in Speech Perception

The perception and recognition of speech is a dynamic and complex cognitive process. The ability to perceive, discern, and comprehend speech is fascinating given that listeners are able to do this across talkers who vary in pitch, speed, and pronunciation. This process becomes even more complex as listeners not only perceive the acoustic signal of speech, but also perceive the optic signal of speech, which includes just as much variability as the acoustic signal, and then integrate the two signals into a cohesive percept. Research previously discussed has shown that there is a great deal of variability in listeners' ability to speechread that cannot be accounted for by low level sensory differences, such as hearing thresholds (Schneider et al., 2002). This suggests that differences in speechreading ability (i.e. what separates good speechreaders from poor speechreaders) may stem from differences in cognitive processing. If this is true, there are many levels of audiovisual speech processing to consider in examining the role that cognition has in speechreading performance.

An important area of study concerns the role of attention in audiovisual integration. Some researchers have offered evidence suggesting that the binding of visual and acoustic information is automatic and is unaffected by the performance of a secondary task (Gagne, Laplante-Levesque, Labelle, & Doucet, 2002; Massaro, 1987; Soto-Faraco, Navarra, & Alsius, 2004). Recent empirical evidence suggests that the integration of visual and auditory sensory information is susceptible to attentional load (Alsius, Navarra, Campbell, & Soto-Faraco, 2005; Anderson, Tiippana, Laarni, Kojo & Sams, 2009; Tiippana, Andersen, & Sams, 2004). If audio and video signals are integrated automatically then attention would not be necessary to ensure integration takes place. Conversely, if integration does not occur automatically then speechreading would be affected by attentional distractors and age-related declines in cognitive functioning.

Automatic Audiovisual Speech Perception

The automaticity of audiovisual integration has been investigated using a dual task paradigm in which participants are asked to pair auditory and visual signals together and perform a secondary distractor task designed to draw attention from the audio-visual speech stimuli. Several studies have found that speechreading was largely unaffected by dual tasks (Massaro, 1987; Soto-Faraco, Navarra, & Alsius, 2004). Research by Gagne, Laplante-Levesque, Labelle, and Doucet (2002) revealed that visual distractions, orientation of the camera, distracting colorful backgrounds, or number of head movements of the talker, did not interfere with speechreading in a classroom setting using an audiovisual FM-system, a listening aid for individuals with hearing loss. Evidence of the McGurk effect are obtained even when participants’ attention is directed away from the incongruent syllable which created the fused percept (Soto-Faraco et al., 2004) and when they were told to ignore the visual information and only report the auditory information (Massaro & Cohen, 1983).

In addition to the dual task paradigm, researchers have tested how well listeners can integrate visual speech and auditory speech signals when they are not aware that they are viewing visual speech cues. Any enhancement to speech perception by these non-transparent visual speech cues are considered to be support for the theory that auditory and visual speech cues are integrated automatically. Rosenblum and Saldaña (1996) presented point-light images of a talker's mouth while listeners listened to and reported auditory syllables. Listeners were not able to recognize that the point-light movements were a talker's mouth and typically reported that the dots represented a moving butterfly or other animal, shown in Figure 4. Regardless of participants' naivety that they were viewing a moving mouth while listening to the syllables, most participants experienced increased accuracy in reporting the auditory syllable. This literature supports that audiovisual speech integration is automatic or at the very least requires little attention.

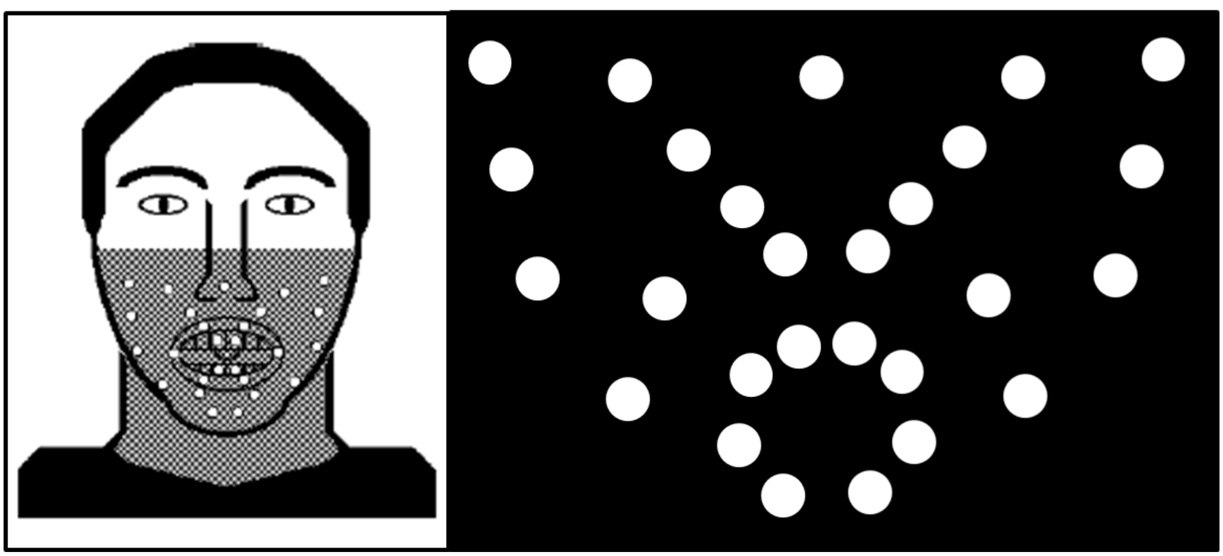

Figure 4. Schematic representation (left image) of point light configuration taken from Rosenblum and Saldaña (1996). The right image is an adaptation of the left image showing the image that was visible to participants which was believed to be a butterfly, not face.

Effortful Audiovisual Speech Perception

Several recent papers dispute the claims of automaticity in audiovisual speech perception and have found evidence that audiovisual integration is modulated by attentional demands (Anderson, Tiippana, Laarni, Kojo & Sams, 2009; Tiippana, Andersen, & Sams, 2004). Alsius, Navarra, Campbell, and Soto-Faraco (2005) found a drastic reduction in audiovisual integration abilities when participants were engaged in a concurrent unrelated task. They had participants engage in a visual detection task superimposed over the face of the televised talker or an auditory detection task presented simultaneously with the speech of the televised talker, shown in Figure 5. Participants were less susceptible to the McGurk effect when performing the secondary task. Tiippana and colleagues (2004) also found that a visual distractor consisting of a transparent image of a leaf moving across the face of a speaker interfered with the McGurk effect. Additionally, Anderson, et al. (2009) presented two videos of a talker, on either side of a central fixation point, with one auditory speech track. They found that directing the viewer's attention, but not fixation, to one video of a talker would cause the viewer to integrate the visual movements of the attended talker's face into auditory signal. These papers suggest that attentional demand appears to moderate the integration of visual and auditory speech signals.

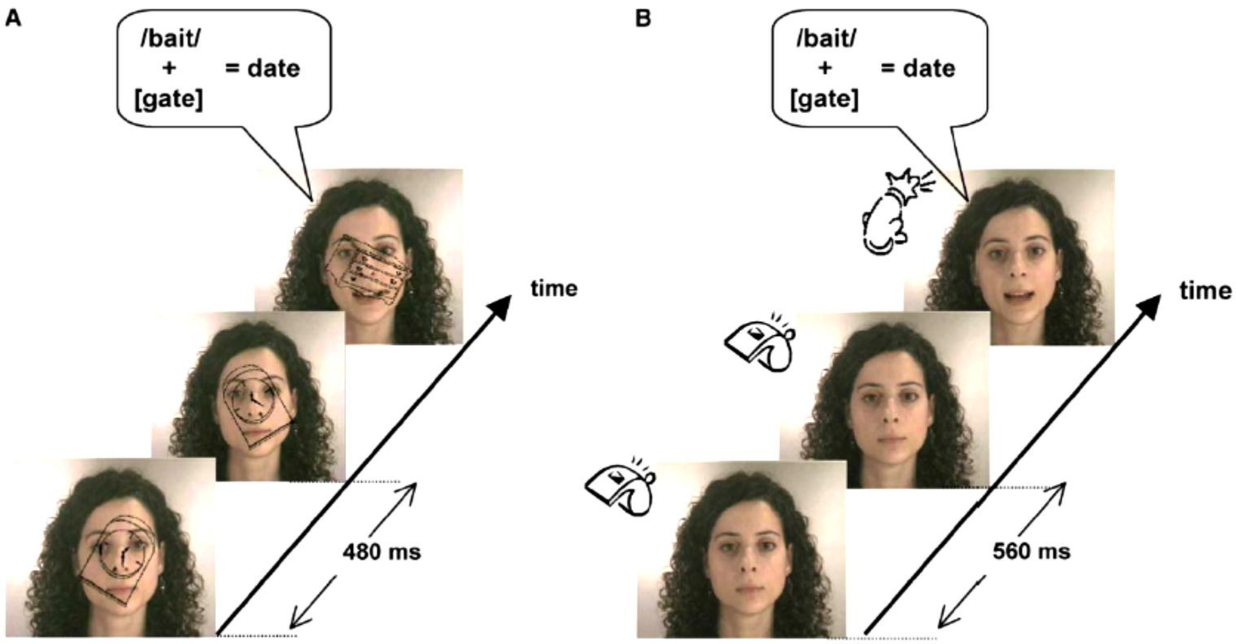

Figure 5. Image demonstrating the visual (A) and auditory (B) detection task used in the Alsius et al. (2005) study examining the role of attention in audiovisual speech processing.

Influence of Age on Cognitive Processing

Selectively attending to speech requires cognitive skills including auditory selective attention (Barr & Giambra, 1990), inhibitory processes (Eckert et al., 2008) and working memory (Dalton, Santangelo & Spence, 2009), all of which decline with age and might account for the one-third of older adults who experience increased difficulty following conversations and understanding speech in noise (Schneider et al., 2002). This is true even for elderly listeners that have minimal or no hearing loss, but who struggle, feel fatigued, or distracted when listening to speech in noisy conditions (Pichora-Fuller, Schneider, & Daneman, 1995; Tun et al., 2002). Young adults are typically more capable in these situations and are able to segment speech from other competing sounds in noisy conditions (Schwartz et al., 2004), known as the “cocktail party effect” (Pollack & Pickett, 1957).

The magnitude of noise interference in speech processing depends not only on the intensity of the noise but also the type of competing noise (one/two/multi-talker babble or white noise). Tun et al., (2002) found that white noise is distracting to all listeners but single talker or meaningful babble tends to be more detrimental for older listeners than younger listeners. Declining cognitive function may explain why older adults tend to have more difficulty than their younger counterparts in filtering non-target speech, especially if it closely resembles the nature of the target speech (Schneider et al., 2002; Tun & Wingfield, 1999; Tun et al., 2002). This may shed light on necessary early-stage filter mechanisms for speech communications in noisy environments. Although, it is unlikely that early cognitive processing is the only location where interference may occur. Other processing such as context, conversational fluency, speed of processing, and memory are also critical for good speech perception.

The contextual cues have been shown to have an impact on listeners' ability to speechread. Colin, Radeau, and Deltenre (2005) found a higher incidence of McGurk fusions when "multiple choice" answers were provided than when "free response" answers were provided. This shows that context can influence the rate at which visual information is integrated into auditory information. There is disagreement among researchers regarding older listeners' ability to use contextual information to aid speech comprehension. Pichora-Fuller and colleagues (1995) found that older and presbycusics listeners are less able to identify low-context SPIN-R end-words than their younger counterparts, but gained more support from high-context sentences than did younger listeners. These results were not supported by Gordon and Allen (2009) who found that younger but not older listeners benefited from high-context SPIN-R sentences. Gordon and Allen's findings may be an artifact of the noise level they used in their experimental conditions which might have affected older listeners' performance to a greater degree. Older listeners correctly identified only 10 and 20 percent of the target words for low- and high-context, respectively, in the auditory-only conditions. Given the low level of performance, it would be unreasonable to expect older listeners to gain much contextual information when so few words could be detected.

Cognitive processing speed or the rate of neuronal operations (Wingfield & Tun, 2001) also impacts a listener's ability to perceive and comprehend conversations. The reductions in the rate of processing and working memory capacity are believed to be key factors in declining speech comprehension performance among the elderly (Cohen, 1987). Following the speech of a fast talker may impose an extra strain on older listeners who not only must keep up with the rate of speech but must also quickly analyze and store the content and context of the conversation (Wingfield & Tun, 2001). This may be even more problematic if cognitive effort is allocated to support diminished sensory input from hearing or vision. Musacchia, Arum, Nicol, Garstecki, and Kraus (2009) found that participants with hearing loss had significantly less audiovisual integration than the normal hearing group. The researchers hypothesized that the hearing loss imposed an increased attentional load that prevented full use of the visual information.

Older listeners may be able to follow the conversation of a fast talker or a talker in noise, but may lack sufficient memory storage capabilities. If a listener is unable to store or retrieve memories from a conversation then their conversational fluency will be reduced, impacting comprehension. Pichora-Fuller et al. (1995) investigated the role of storage and retrieval functions in working memory and found that older listeners had greater difficulty than younger listeners in remembering sets of end-words, regardless of set length (varying from 1 to 8), in favorable listening conditions. Additionally, older adults with superior hearing abilities for their age tend to have poorer recall for short sentences in noise than younger adults (Tun & Wingfield, 1999). This research suggests that higher-level cognitive limitations may be more detrimental to speech comprehension than lower-level sensory declines.

The large body of literature that suggests attention is necessary for speechreading indicates that listeners are restricted by higher-level cognitive processing limitations. However, a study by Andersson, Lyxell, Ronnberg, and Spens (2001), found that higher level cognitive abilities - including working memory, verbal inference making, and verbal ability - were not correlated with visual speech understanding in hearing-impaired adults aged 21-76 (M = 53, SD = 16). Their results did show that lexical identification speed, phonological lexical decision speed, and rhyme judgment speed were correlated with visual speech test performance; however, the latter two measures were not significantly correlated with visual speech test performance after controlling for age. Given these findings, future research may explore the importance of early-stage cognitive and visual processing to better understand the relationship between visual speech processing and cognitive function.

The results of a study by Andersson et al. (2001) support the notion that the sensory level of processing is a primary point of interference which may prevent elderly listeners from fully benefiting from audiovisual speech. Mullennix, Pisoni and Martin (1998) had previously suggested that early stage processing is the source of interference in speech perception because speech perception is primarily a process of extracting pertinent information from the acoustic signal. They explained that the process of listening to and understanding speech even in quiet conditions requires cognitive effort. Given that speech is so variable within and between talkers, a listener must normalize these differences, as well as segment the continuous auditory signal created by coarticulation and rate into a simplified percept to identify and comprehend the talker’s speech (Mullennix et al., 1989; Waldrop, 1988). This cognitive processing takes place at the early stages of speech perception and should be most vulnerable to sensory interferences.

Rather than use tests that measure higher-cognitive processes to screen the cognitive audiovisual speech capabilities of listeners, we argue that low-level sensory screening, such as the Pelli-Robson Contrast Sensitivity test for visual processing capabilities could be a better predictors of audiovisual speech recognition performance. However, it may be difficult to separate low level processing from higher level processing since high level processes should depend on low level capabilities (Cohen, 2001). Given that there is an apparent interaction between bottom-up and top-down processes in speech perception (Wingfield & Tun, 2001), a more systematic investigation is needed to identify the contribution of each, as well as the extent of their vulnerabilities to age-related declines.

CHAPTER 3

RESEARCH PURPOSE

The purpose of this research was to examine the impact that simulated cataracts had on speechreading in young adults. Six studies were conducted to compare the amount of visual enhancement to speech intelligibility under normal and simulated cataract viewing conditions. Cataract density, competing noise level and the luminance of the talker's face was manipulated to examine how environmental conditions affect speech perception. Participant demographics, i.e. age, gender, vision and hearing, were examined to determine which qualities were associated with superior speech intelligibility under the simulated cataract condition.

1. Study 1 examined the impact of simulated mild cataracts on participants' speech intelligibility, compared to normal vision.
2. Study 2 examined the impact of simulated severe cataracts on participants' speech intelligibility, compared to normal vision.
3. Study 3 examined the impact of simulated mild cataracts on participants' speech intelligibility, compared to normal vision, under luminance-controlled conditions.
4. Study 4 will examine the impact of simulated severe cataracts on participants' speech intelligibility, compared to normal vision, under luminance-controlled conditions.
5. Study 5 will examine the impact of simulated mild cataracts on participants' speech intelligibility, compared to normal vision, under eight levels of luminance-controlled conditions.
6. Study 6 will examine the impact of simulated severe cataracts on participants' speech intelligibility, compared to normal vision, under eight levels of luminance-controlled condition

CHAPTER 4

METHODOLOGY

Study 1: Effects of Simulated Mild Cataracts on Speech Intelligibility

Previous research has demonstrated that visual information aids speech intelligibility under noisy auditory conditions (Grant 2001; Grant & Seitz, 2000; Schwartz et al., 2004; Sumby & Pollack, 1954) and that speechreading performance declines with some forms of visual impairment (Gordon & Allen, 2009; Hardick et al., 1970; Tye-Murray et al., 2008). Study 1 investigated whether simulated mild cataracts interfere with young adults' ability to use visual cues to help disambiguate speech in the presence of auditory noise. Young participants were selected for testing so that the visual effects of simulated cataracts on speech could be investigated independently of co-existing cognitive and sensory changes that are common with older adults. This may provide insight into the breadth of improvements patients may experience after cataract removal surgery.

The aim of the study was to investigate the effects of simulated cataracts on speech intelligibility using a live-voice presentation. A pilot experiment showed that presentation with a recorded talker may have poor validity because participants reported that the televised talker's face viewed with the cataracts looked unaltered, but a real face viewed with the cataracts looked severely degraded. This discrepancy was hypothesized to be due to the fact that a real face reflects light whereas a television is a light-emitting device and its increased luminance may mitigate the simulated cataracts' effect. Even with standard screen adjustments (i.e. brightness and contrast settings), the speaker's face on the high resolution, digital television seemed to be too bright to evaluate the effects of cataracts on speechreading performance.

There are other disadvantages to a digital television for investigations of speechreading. A two-dimensional televised face lacks the 3-dimensional shape cues of a live talker, which may prevent optimal auditory-visual interaction (Jordan & Thomas, 2001). This is important since listeners have been shown to derive more benefit from speechreading as the movements of the talker's face appear to be more natural (O'toole, Roark, & Abdi, 2000). Additionally, the mouth and perceived location of the voice do not coincide due to the placement of the loudspeaker and cannot achieve the natural auditory-visual integration afforded by a live talker.

The use of live-voice presentations in research is problematic because there is an increased risk of variability both within and across presentations. When recorded speechreading tests are used clinically or in research, the intensity of the speaker's voice is calibrated via a volume unit (VU) meter on an audiometer. Conversely, the intensity of the speaker's voice is rarely monitored with live-voice speechreading tests, which can bias speechreading. For instance, even when speakers monitor their vocal intensity during live-voice speechreading tests (e.g., with a sound level meter), they may consciously or subconsciously introduce bias by altering their rate, articulation, or prosody.

To address these issues, an innovative technique was developed called Self-Monitored Live-Voice (S-MLV) presentation. S-MLV preserves both the external validity advantages of face-to-face speechreading presentations and internal reliability advantages of recorded speechreading presentations. The talker in this technique mimics an audio recording to improve consistency across presentations. S-MLV is described more fully in the General Methods section.

General Methods: Study 1A & 1B

Participants were recruited from the SONA systems online research site at Wichita State University and received course credit for their participation. Participants were required to be at least 18 years of age but no older than 40 years of age. Participants were required to speak Mainstream-American English, have normal or corrected-to-normal vision and no history of hearing loss or color blindness. Participants' binocular vision was screened to ensure normal contrast sensitivity using the Pelli-Robson Contrast Sensitivity Chart, normal near and distance acuity using the Early Treatment Diabetic Retinopathy Study (ETDRS) acuity chart, and normal color vision using the Ishihara Color Plates. Participants were excluded from the study if their visual acuity was poorer than 20/40 which is the minimum recommended visual acuity to support speechreading in everyday speech communications (O'Neil, & Oyer, 1981). All participants were screened to ensure normal hearing sensitivity in both ears as defined by pure-tone hearing threshold levels lower than or equal to 20 dB HL at octave frequencies between 250 Hz and 8000 Hz.

Testing was performed in a sound-treated booth, also used for hearing screening. The monitor/experimenter was housed in a single-wall Industrial Acoustics Company (IAC) booth and the participant and talker were housed in a double-wall IAC booth that met ambient noise standards (ANSI S3.1-1991) for threshold testing. Speech perception with various visual conditions was assessed using sentence lists from the Central Institute for the Deaf (CID) *Everyday Speech Sentences* (Davis & Silverman, 1970). The CID Everyday Speech Sentences are shown in full in Appendix D.

The S-MLV employed one female talker, age 25, who was used throughout the study to better ensure consistent presentation from subject to subject. The talker practiced speaking the CID *Everyday Speech Sentences* material by mimicking an audio recording of the sentences.

During presentations, the talker wore insert earphones to listen to and repeat a pre-recorded audio track of a female talker saying the *Everyday Speech Sentences*. To further ensure a more consistent presentation of speech across sentences and participants, the live-voice female talker mimicked the intensity, rate, articulation and prosody of the pre-recorded talker. The intensity of the audio recording presented via insert earphones was adjusted so that the live talker's intensity was approximately 62±2 dB SPL. The talker always wore a black button-down short-sleeved shirt and had her hair pulled back in the same fashion during each presentation.

The participant and talker were seated facing one another approximately one meter apart; this resulted in a visual angle of approximately 5˚ from pupil to pupil of the talker's eyes. A small desk was placed between the talker and participant, depicted in Figure 6, to allow the participant to write responses during speechreading testing. The participant was positioned in between the two loud speakers at approximately +125˚ and -125˚ azimuth.

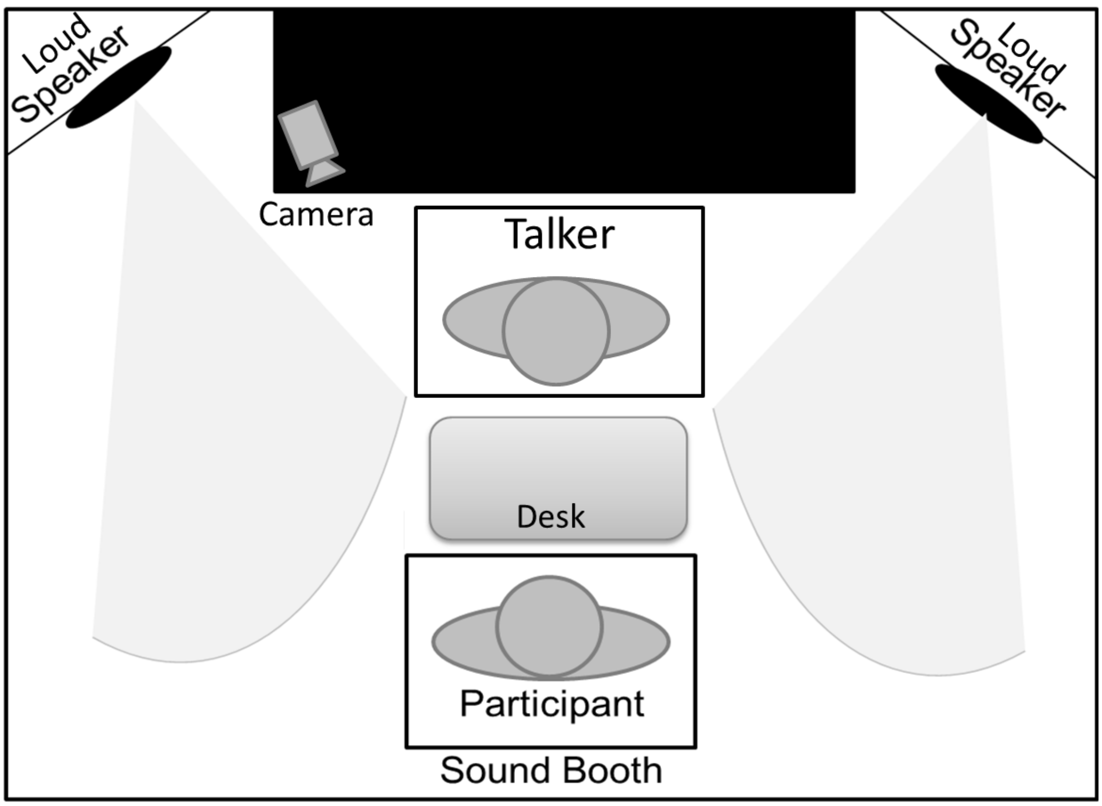

Figure 6. Schematic illustrating the experimental layout of the testing room. Figures indicate participant and talker position as well as the location of the loud speakers, writing desk and monitoring camera relative to the participant.

Participants wore color coded glasses for each visual condition. Instructions at the top of each page specified which pair of color coded glasses participants were to wear during each list of sentences; this was randomized across conditions. Moreover, to reduce bias, the talker wore opaque glasses preventing her from recognizing the test conditions. The participants were told that the talker's vision would be masked and were instructed to keep the sheet of paper out of the talker's view while her glasses were removed. A second experimenter monitored the participants' progress on a television screen, which streamed a live-video feed of the participant, from the monitoring booth outside of the sound booth, as shown in Figure 7.

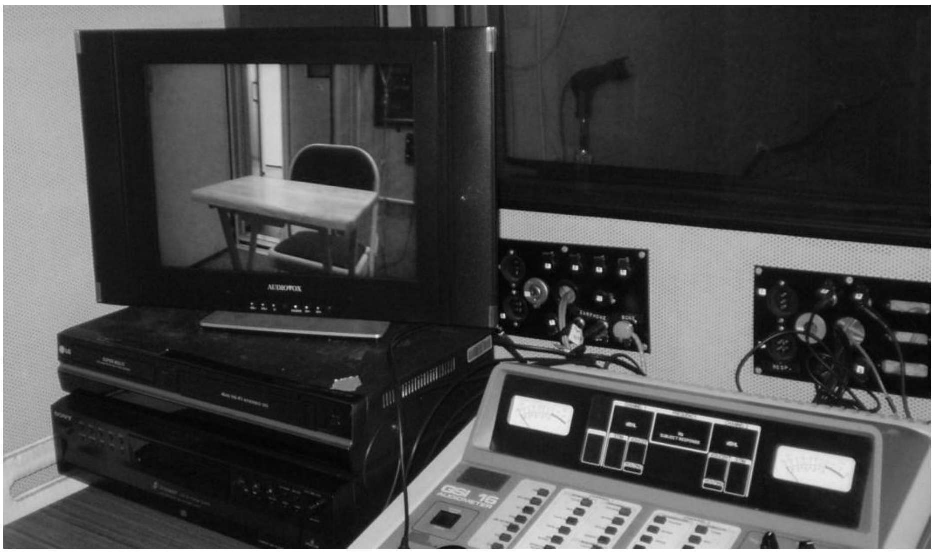

Figure 7. An image of the monitoring booth. The television in the top left shows the video stream which experimenters used to view participants' progress. Participants were seated in the chair shown on the monitoring screen.

The lengths of the CID sentences varied from 2 to 13 words. Due to the variability of sentence length, a desk bell was rung by the talker immediately preceding and following the sentence to mark its beginning and end. Participants were instructed: to write the sentence on the sheet of paper when they heard the second bell chime; to write what they thought they heard the talker say, exactly as they heard it; to leave blanks in the sentences where they could not make out certain words; and to guess in cases when they felt they did not understand anything the talker said. The instructions provided to participants are outlined in Appendix C. Each list of 10 sentences contained 50 key words and performance (i.e., number of key words correctly reported) was calculated independently for each list and subsequently averaged. Subjects' written responses were scored by a second examiner blind to the participants' test condition. Correct responses included: answers that matched the key words and were spelled correctly, answers that were homophones of the correct key word, answers that had errors in spelling but were identifiable from the context of the sentence, answers that incorrectly applied or failed to correctly apply plurals but did not change the meaning of the key word; any other mistakes were deemed incorrect.

Study 1A: Determining Auditory Speech Intelligibility Threshold

The aim of Study 1A was to determine listeners' auditory-only speech intelligibility threshold under auditory-only conditions. Participants were presented with *Everyday Speech Sentences* under five SNRs to determine the SNR that participants reported approximately 50% of the key words. The purpose of identifying the speech intelligibility threshold was to present a SNR in Study 1B that supported optimal audiovisual integration, preventing ceiling performance in audiovisual conditions, and preventing floor performance in auditory-only conditions. According to Ross et al. (2007), listeners will rely solely on either visual or auditory information when the other sense is severely degraded and they will optimally integrate both sensory modalities at intermediate SNRs. Ross et al. reported a "special zone" at a SNR of -12 dB where auditory and visual speech integration was maximal. At this intermediate SNR, speech comprehension improved 3-fold compared to auditory-only conditions (Ross et al., 2007).

Study 1A Hypothesis

a. Participants will correctly report 50% of the target words in the auditory-only speech intelligibility task at intermediate signal-to-noise ratios.

Methods

Nine participants (18-40 yrs, M = 23, 2 males and 7 females) with normal or corrected-to-normal vision and hearing within normal limits were recruited for the study. Participant screening results are shown in Table 1.

TABLE 1

MEAN SCREENING SCORES

	Average	Std. Deviation
Far Acuity- OU	15/20	3.75
Near Acuity- OU	25/20	0
Contrast Sensitivity- OU	1.78	0.05
Pure Tone Average- BE	1.67 dB	5.20
Pure Tone Average- PE	4.81 dB	5.17

Notes: Group mean scores and standard deviation for binocular (OU) near and far visual acuity and contrast sensitivity. Participants' pure tone average (and standard deviation) hearing thresholds in better ear (BE) and poorer ear (PE).

Procedure

Participants wore one of two sets of glasses for each of the experimental conditions including frames without lenses for the audiovisual condition (color coded white) and frames with opaque lenses for the auditory-only condition (color coded brown). The audiovisual condition was a control condition, implemented to reduce bias of the talker, and was not scored.

Five intensity levels of a recorded four-person babble audio track (i.e. four voices of continuous speech spoken simultaneously) were presented in the booth through two stationary Grason-Stadler loudspeakers while the talker presented the *Everyday Speech Sentence* via live-voice. The five SNRs, determined through pilot testing, were -7, -9, -11, -13, and -15 dB. Participants were first presented with two practice sentences in quiet conditions and were instructed to verbally repeat what they heard the talker say to ensure they understood the task.

Participants were then provided with instructions for the speech intelligibility task, shown in Appendix C. Participants were then presented with two blocks of sentences lists, each block contained five lists and each list contained 10 sentences, demonstrated in Table 2. Participants wore one of the color coded glasses through the first block and switched to the other color coded glasses for the second block. This order was counterbalanced across subjects. All five babble intensities were presented in each block and one intensity level played through an entire list. The order of the intensities was randomized within each block. A five minute break was provided after completion of the first block to prevent fatigue of both participant and talker. The experiment (including screening and practice sessions) lasted approximately one hour and thirty minutes.

TABLE 2

VISUAL AND AUDITORY CONDITIONS BY EXPERIMENTAL BLOCK

SNR	Block 1 Auditory-only	Block 2 Normal Audiovisual
-7 dB	10 sentences	10 sentences
-9 dB	10 sentences	10 sentences
-11 dB	10 sentences	10 sentences
-13 dB	10 sentences	10 sentences
-15 dB	10 sentences	10 sentences

Notes: Visual conditions were divided into two blocks and counterbalanced. Each of the 5 SNRs used in this study were used and randomized in each experimental block. Ten sentences were presented to participants under each visual and auditory condition.

Results

Participant responses were scored using the aforementioned scoring criterion. Participants' accuracy in reporting the key words was computed for all five SNRs. The -11 dB SNR level supported performance (i.e. 42%) approaching the 50% level (i.e. nearest to correctly reporting 25 of the 50 target words). The performance distribution, however, was bimodal showing two distinct groups, high and low performers. Low performers averaged 29.6% correct and high performers averaged 63.8% correct at the -11 dB SNR. The 50% thresholds determined for each group were analyzed independently and are shown in Figure 8.

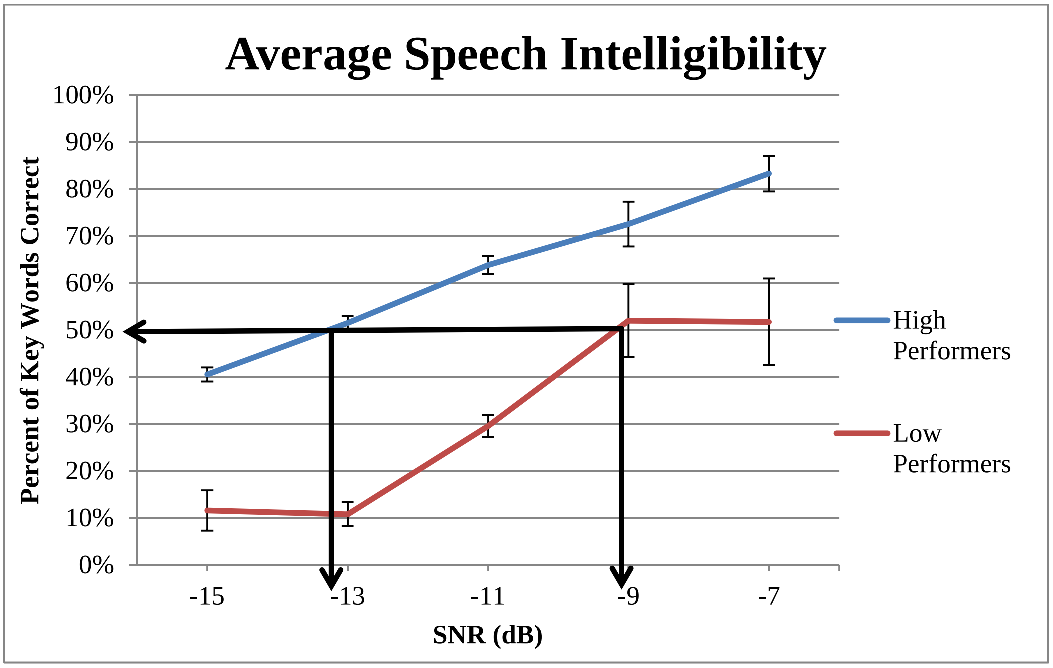

Figure 8. Mean speech intelligibility of high (n=4) and low (n=5) performers as a function of signal-to-noise ratio (SNR). The arrows indicate the SNRs supporting 50% correct speech intelligibility (i.e. SNR50). Error bars show standard error.

In order to avoid ceiling effects at high SNR, the data for the four best performers was used to identify the optimal SNR for the auditory-only condition that was used in Study 1B. These four participants also had accuracy scores most consistent with changing levels of SNRs. The average speech intelligibility results of the five SNRs are displayed in Figure 8. Fifty percent accuracy was achieved with a SNR of -13 dB by the best four performers.

Discussion

The range of SNRs used in this experiment was not wide enough to document the full range of performance (i.e. 0-100% accuracy) on the speech intelligibility task. Under the best (-7 dB) and worst (-15 dB) SNR level, participants achieved accuracy levels of 67.5% and 26.1%, respectively. Based on these results, an approximately -13 dB SNR would be appropriate for testing speech intelligibility in the auditory-only and audiovisual conditions.

The results of this study are consistent with the findings of Ross et al. (2007). The SNR of -13 dB is very similar to the "special zone" they identified for optimal audiovisual integration (i.e. -12 dB SNR). The speech-to-noise conditions should maximize participants' audiovisual speech perception to add power to Study 1B to observe an effect of the cataract simulation glasses on speech intelligibility, if it does exist.

Study 1B: Effects of Simulated Mild Cataracts on Speech Intelligibility

The purpose of this study was to determine whether simulated cataracts impaired listeners' ability to use visual information to support speech intelligibility. We are not aware of any systematic investigation into the effects of real or simulated cataracts on speech intelligibility. Most published studies have investigated the effects of blur on speechreading. For instance, Thorn and Thorn (1989) investigated the effects of dioptric blur on speechreading in one patient with cataracts and reported no effect. Dioptric blur have been shown to have little effect on speechreading, suggesting that performance is robust and that visual acuity must be severely reduced, (in the range of 20/80 and 20/200) to observe a significant decline in speechreading (Erber, 1979; Johnson & Snell; Thomas & Jordan, 2002). The few published studies suggest that some forms of visual impairment which can produce modest changes in visual acuity (i.e. 20/20 to 20/40) can have a significant effect on speechreading performance (Dickinson & Taylor, 2011; Hardick et al., 1970).

The studies that investigated the effects of dioptric blur, however, may not generalize well to the effect of cataracts, which cause diffusive blur which produce visual effects which differ from those produced by dioptric blur. Cataracts scatter light, reducing image contrast across a broad range of visual scales (Hess & Woo, 1978), whereas dioptric blur primarily affects fine image details or high spatial frequencies. It is hypothesized that diffusive blur should have a greater detrimental effect on vision and on speech intelligibility in noise. Finally, the effect that blur has on speech perception is most commonly evaluated by testing participants' silent speechreading performance under conditions of visual degradation (e.g. Johnson & Snell, 1986; Thorn & Thorn, 1989). This method may not reveal the contribution of vision to speech perception because intelligibility tends to be poor for speechreading devoid of an auditory signal.

The diffusive blurring effects along with the consequent reduction in contrast sensitivity caused by simulated cataracts should result in significantly less audiovisual speech intelligibility and visual enhancement than in normal viewing conditions even though participants' visual acuity is only minimally reduced.

Study 1B Hypotheses

a) Audiovisual speech intelligibility will be significantly reduced by simulated cataracts compared to normal viewing conditions.
b) Visual enhancement will be significantly reduced by simulated cataracts compared to normal viewing conditions.

Methods

Twenty-one participants (18-31 yrs, M = 22.05, 7 males and 14 females) with normal or corrected-to-normal vision and hearing within normal limits were recruited for the study. Participant screening results are shown in Table 3.

TABLE 3

MEAN SCREENING SCORES

	Average	Std. Deviation
Far Acuity- OU		
Normal	20/15	3.64
Cataract	20/32	6.36
Near Acuity- OU		
Normal	20/25	3.27
Cataract	20/40	4.72
Contrast Sensitivity- OU		
Normal	1.8	.07
Cataract	1.2	.07
Pure Tone Average- BE	1.23 dB	3.11
Pure Tone Average- PE	3.33 dB	3.12

Notes: Group mean scores and standard deviation for binocular (OU) near and far visual acuity and contrast sensitivity measured under both normal and simulated cataract conditions. Participants' pure tone average (and standard deviation) hearing thresholds in better ear (BE) and poorer ear (PE).

Procedure

Participants wore one of three sets of glasses for each of the experimental conditions: frames without lenses for the normal audiovisual condition (color coded white); frames with cataract simulation filters for the cataract audiovisual condition (color coded black) and frames with opaque lenses for the auditory-only condition (color coded brown). Vistech™ cataract simulation filters were used to simulate the visual degradation caused from cataracts and other age-related changes (Vistech Consultants Inc., Dayton, OH). The Vistech™ simulation goggles produce wide-angle light scatter with a similar angular distribution to normal and cataractous eyes (Elliot, Bullimore, Patla & Whitaker, 1996). In addition, they have been shown to reduce contrast sensitivity more than visual acuity (Elliott et al., 1996). The cataract simulation glasses reduced participants' visual acuity to an average of 20/32 from 20/15 under normal viewing conditions. The simulation glasses reduced contrast sensitivity measured using the Pelli-Robson Contrast Sensitivity Chart from a mean score of 1.65 under normal viewing conditions to a mean score of 1.2 under the cataract simulation condition. Figure 9 illustrates the blurring and contrast effects of the Vistech™ simulation goggles.

Figure 9. Two digital photos taken of the same image. Image 1 demonstrates normal vision as the camera had an unobstructed lens. Image 2 demonstrates the simulated cataract vision as the camera's lens was overlaid with a filter from the Vistech™ cataract simulation goggles.

Participants' speech intelligibility was tested at the -13 dB SNR level under three visual conditions: auditory-only, simulated cataract audiovisual, and normal audiovisual. Participants were presented with two practice sentences and instructed to verbally repeat them to the experimenter. Additionally, a practice list of nine sentences, presented amid four-person babble at a SNR of +5 dB, was given to allow participants to practice listening to and writing three sentences in each of the three visual conditions. Once the practice sessions were completed, participants were presented with a full list of sentences under each of the three visual conditions and this process was repeated in three blocks, totaling nine lists, depicted in Table 4. Sentences were presented via the S-MLV mimicry presentation method among four-person babble, presented through two Grason-Stadler loudspeakers, at a SNR of -13 dB. The live talker always wore frames with opaque lenses for all experimental conditions to minimize bias. Five minute breaks were taken after completion of block one and after block two to prevent fatigue of the participant and talker. The experiment (including screening and practice sessions) lasted approximately one hour and thirty minutes.

TABLE 4

VISUAL CONDITIONS BY EXPERIMENTAL BLOCK

Visual Condition	Block 1	Block 2	Block 3
AO	10 sentences	10 sentences	10 sentences
Cataract	10 sentences	10 sentences	10 sentences
Normal	10 sentences	10 sentences	10 sentences

Notes: Experimental testing was divided into three blocks. Each of visual conditions (auditory-only (AO), cataract audiovisual, and normal audiovisual) was presented in each block and randomized. Ten sentences were presented under each visual condition.

Results

Participants' responses were scored by a second experimenter, using the aforementioned scoring criterion described in Study 1, who was masked to the experimental conditions. The mean intelligibility for each visual condition in each block was computed and is displayed in Table 5. Visual enhancement (VE) scores for normal and simulated cataract visual conditions, displayed in Table 5, were calculated using Equation 1 where VE, AV and A represent the mean number of correctly reported words for the Auditory + Vision and Auditory-only conditions, respectively (Gordon & Allen, 2009).

$$VE = AV - A \qquad (1)$$

TABLE 5

AVERAGE SPEECH INTELLIGIBILITY AND VISUAL ENHANCEMENT BY VISUAL CONDITION AND BLOCK

Visual Condition	Block 1 *M* (SD)	Block 2 *M* (SD)	Block 3 *M* (SD)	Overall *M*
Auditory-only	.50 (.17)	.57 (.18)	.57 (.17)	.55 (.14)
Normal Vision	.84 (.11)	.91 (.06)	.90 (.10)	.88 (.06)
Cataract Vision	.78 (.12)	.83 (.13)	.85 (.12)	.82 (.09)
Normal VE	.34 (.17)	.34 (.19)	.33 (.16)	.35 (.12)
Cataract VE	.28 (.17)	.26 (.17)	.28 (.16)	.27 (.12)

Notes: Participants' speech intelligibility score expressed as mean percent correct and standard deviation (shown in decimal form) for each visual condition and test block. The last two rows display the calculated visual enhancement (VE) score from Equation 1.

A 2x3 within-subjects analysis of variance (ANOVA) was conducted to evaluate the effect of visual condition and time (i.e. determining if any learning occurred across the three blocks) on visual enhancement. This analysis was conducted to test Hypothesis 1B-b which predicted that the simulated cataracts would provide significantly less visual enhancement to speech intelligibility than normal vision. The dependent variable was VE, calculated with Equation 1 to determine the degree of speech intelligibility improvement each visual condition had over the auditory-only condition speech intelligibility performance. The within-subjects factors were visual condition with two levels (normal vision and simulated cataract vision) and time with three blocks. The ANOVA indicated a significant main effect for visual condition, $F(1, 20) = 19.426$, $p < .01$, partial eta squared (η_p^2) = .493 and no significant main effect for time, $F(2, 19) = .050$, $p = .952$, $\eta_p^2 = .005$. Additionally, no significant interaction was found between visual condition and block, $F(2, 19) = .294$, $p = .741$, $\eta_p^2 = .031$.

Table 5 displays the mean intelligibility and visual enhancement scores for each visual condition. A paired sample t-test between the VE of the normal viewing condition and simulated cataract viewing condition revealed a difference of 6.29%, shown in Figure 10, was statistically significant, $t(20) = 4.25$, $p < .01$, Cohen's $d = 0.5$.

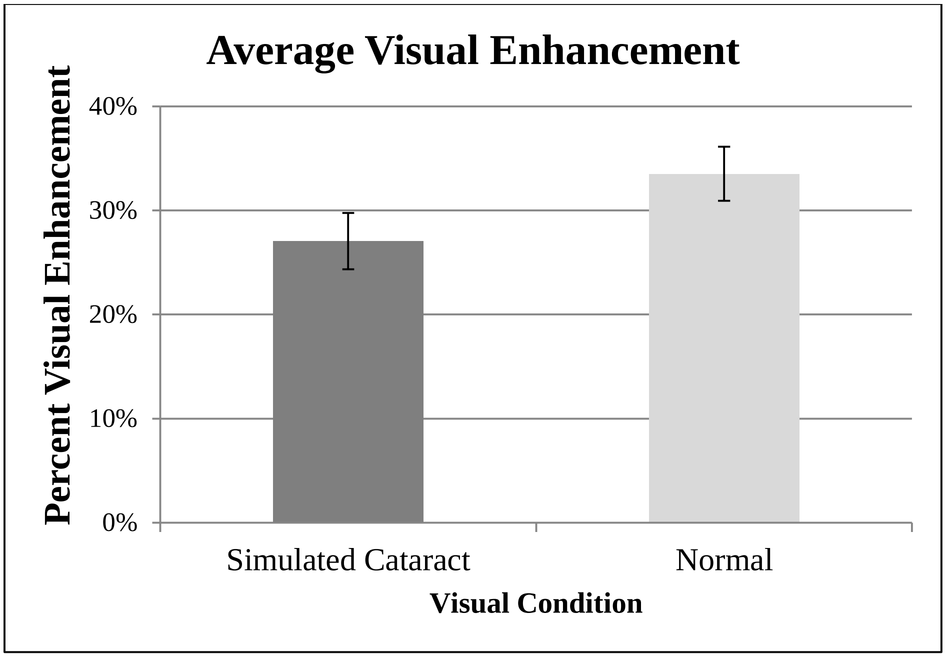

Figure 10. The effects of normal vision and simulated cataract vision on audiovisual (AV) gain. Mean VE (N=21) across the three blocks is displayed with simulated cataract VE = 27.05% and normal VE = 33.52%. Error bars in the figure represent standard error.

A logistic binomial regression was conducted to evaluate how well the visual conditions, experimental block, and screening measures predicted speech intelligibility performance. The predictors included in the analysis were the three visual conditions (auditory-only, cataract audiovisual and normal audiovisual), experimental blocks (1-3), and 10 screening measures (age, gender, near and far visual acuity (normal and cataract), contrast sensitivity (normal and cataract), and pure tone threshold averages (better ear and worse ear)). The analysis compared performance under the cataract audiovisual and auditory-only conditions to a baseline performance under the normal audiovisual condition to test Hypothesis 1B-a. Additionally, performance of experimental blocks 2 and 3 were compared to the baseline performance of block 1. The null deviance of the speech intelligibility scores in this study was 1990.45 (deviance). A stepwise selection method was applied through forward inclusion and backward elimination. Predictors were added, by expected importance, to the model through forward inclusion if they met the following criterion: they reduced the residual deviance by more than one point and they reduced the Akiake Information Criterion (AIC) value by more than one. Predictors were removed from the model through backward elimination if they met the following criterion: their removal did not increase the residual deviance by more than one point and/or did not increase the AIC value by more than one.

The predictors added to the model that met the criterion through forward inclusion were: visual condition, experimental block, age, gender, pure-tone threshold (better ear), far acuity (cataract and normal), near acuity (cataract and normal), and contrast sensitivity (normal). Pure-tone threshold (poor ear) and contrast sensitivity (cataract) did not meet forward inclusion criterion. Predictors retained in the model after backward elimination were: visual condition, experimental block, age, gender, pure-tone threshold (better ear), near acuity (cataract and normal), and contrast sensitivity (normal). Visual acuities (cataract and normal) were removed because they met the backward elimination criterion. The resulting residual deviance was 686.35 (residual deviance = 686.35, null deviance = 1990.45, and AIC = 13.96). The results of the regression analysis are displayed in Table 6.

This model allows the prediction of an individuals' speech intelligibility performance given their visual condition (normal, cataract, or auditory only), contrast sensitivity, gender, experimental block, pure-tone average for their better ear, age, and near visual acuity (normal and cataract) are known. The y-Intercept denotes place in which the regression line crosses the y axis. This value demonstrates the predicted number of key words a participant may correctly report when all of the predictors equal zero. Each B weight included in the regression model signifies the amount of change to the y-intercept predicted by a change in the predictor values. A positive B weight value signifies an increase in the y value with each increase in the predictor value. Conversely, a negative B weight value signifies a decrease in the y value with each increase in the predictor value. The predictors are arranged in the table according to their B weight; however, each predictor's contribution to the speech intelligibility scores varies depending on the range of the predictors' values (i.e. gender's value changes from 0 to 1 for male and female, respectively, but age may vary from 18 to 40).

TABLE 6

COEFFICENTS IDENTIFIED AS PREDICTORS OF PERFORMANCE

Coefficients	B weights	Std. Error	z value	p value
(Intercept)	-3.50	1.05	-3.34	< .001
Auditory-only	-1.89	0.07	-28.09	< .001
Cataract Audiovisual	-0.53	0.07	-7.25	< .001
Contrast Sensitivity: Normal	2.13	0.50	4.26	< .001
Gender	0.62	0.06	10.07	< .001
Block 2	0.37	0.06	5.89	< .001
Block 3	0.38	0.06	6.05	< .001
Pure Tone Average: BE	0.10	0.01	10.10	< .001
Age	0.08	0.01	7.77	< .001
Near Acuity: Normal	-0.08	0.01	-6.13	< .001
Near Acuity: Cataract	0.03	0.01	4.45	< .001

Notes: Results of the logistic binomial regression analysis. Predictors (coefficients) of speech intelligibility performance are listed on the left.

The participants' visual condition (normal, cataract, and auditory-only) was found to be a significant predictor of speech intelligibility performance. Compared to normal audiovisual conditions, participants had significantly poorer performance under auditory-only conditions (p < .001; â = -1.89) and cataract audiovisual conditions (p < .001; â = -0.53). This demonstrates that listeners with cataracts or occluded vision are predicted to have poorer speech intelligibility than if they were allowed full vision of the talker's face. These results support Hypothesis 1B-a which predicted that participants would have poorer speech intelligibility under simulated cataracts compared to normal vision.

Participants' contrast sensitivity score measured under normal viewing conditions was the largest significant predictor of speech intelligibility performance ($p < .001$; â = 2.13). Participants with better contrast sensitivity tended to perform better overall at the speech intelligibility task than those with poorer contrast sensitivity.

Gender was found to be a significant predictor of speech intelligibility performance ($p < .001$; â = .62). These results indicate that female participants tended to perform with better accuracy at the speech intelligibility task than male participants. The distribution of males (n=7) and females (n=14) was not equal and hence it is unclear if there is a sufficient sample size of male participants to draw conclusions between the two genders.

The regression analysis revealed that participants' speech intelligibility performance improved as a function of time. This demonstrates that there may have been a learning or practice effect throughout the experiment. Participants experienced the most improvement from block 1 to block 2 ($p < .001$; â = .37) and experienced only slightly more improvement from block 1 to block 3 ($p < .001$; â = .38). There was no significant interaction between time and visual condition. This suggests that participants experienced a comparable level of improvement in each visual condition throughout the experiment.

Participants' pure tone average (PTA) in participants' better ear (BE), the ear with more sensitivity hearing, was found to be a predictor of poorer speech intelligibility ($p < .001$; â = .10). The PTA (BE) is the ear that has the lowest hearing thresholds at 500, 1000, and 2000 Hz. Participants with higher thresholds (i.e. poorer hearing) in their better ear were found to have better performance than those with lower thresholds (i.e. better hearing) in their better ear. This may be caused by a heavier reliance on visual speech perception (i.e. participants with poorer hearing may have learned to rely more on visual speech to assist them in speech perception). Participants with lower thresholds may have less need to utilize visual speech for speech perception.

Older participants were predicted to have better speech intelligibility performance than younger participants ($p < .001$; â = .08). Despite the limited age range of participants in this study, 18 to 31 years, the older participants had higher performance compared to younger participants. This difference may be attributed to motivation given that participants near 18 years old may have been less motivated to focus on the task and the older participants near 31 years old may have taken the task more seriously.

Near visual acuity measured under normal viewing conditions was found to also be predictive of speech intelligibility performance ($p < .001$; â = -0.08). Participants with worse normal near visual acuity tended to perform more poorly than those with better acuity. The opposite effect of visual acuity on performance was found with near visual acuity measured with the simulated cataracts ($p < .001$; â = 0.03). Poor visual acuity with the simulated cataracts was found to be predictive of more accurate performance on the speech intelligibility task. It is unclear why poorer near visual acuity with the cataracts predicts better speech intelligibility performance, but this may be due to an increase in effort by the participant.

Discussion

This study demonstrates that simulated cataracts have a significant impact on an observer's ability to use visual cues for supporting speech perception. Compared to normal viewing conditions, simulated cataracts produced only nominal changes in contrast sensitivity and visual acuity but significantly reduced visual enhancement. Importantly, these results suggest that individuals with mild real cataracts, which may not be considered clinically significant, may nonetheless have a significant effect on speech intelligibility under noisy conditions.

In light of these findings, it is surprising that the simulated cataracts that reduced visual acuity to 20/32 also negatively impacted visual enhancement. Although, it may not be acuity per se that is important for speech perception, but rather the reduction in contrast at lower spatial frequencies. Although, the contrast sensitivity score measured with the cataracts was not found to be predictive of speech intelligibility performance, the regression analysis revealed that participants' normal contrast sensitivity was a large contributor of their speech intelligibility. Low contrast, coarse image features such as the nose (Thomas & Jordan 2004), cheeks (Scheinberg, 1980), eyes (Thomas & Jordan, 2004) and the mouth (Summerfield, 1979), are known to aid visual speech perception. Likewise information supporting speech recognition is distributed over a range of spatial frequencies including the mid- to-low band of spatial frequencies (~11 cycles/face). Given these findings, cataractous diffusive blur, which affects visibility of both high and low spatial frequencies (Hess & Woo, 1978), might be expected to have a greater detrimental effect on speech perception than dioptric blur which primarily affects higher spatial frequencies.

Studies comparing the effects of simulated cataracts and blur on complex tasks like driving (Wood, Chaparro, & Hickson, 2009), walking (Anand, Buckley, Scally, & Elliott, 2003), and on tests of cognitive abilities (Wood et al., 2009) show that cataracts are often deleterious to performance even when visual acuity is matched across conditions. Despite this, visual acuity was demonstrated to be a strong predictor of speechreading performance highlighting the importance of normal near and far visual acuity for speechreading performance.

Participant gender was also found to be important in predicting higher speech intelligibility performance. Female participants outperformed male participants on the speech intelligibility task overall. This is consistent with past research showing that women are better at speechreading than men (Daly et al., 1996; Dancer et al., 1994; Johnson et al., 1988). However, there was no interaction between gender and visual condition, meaning that male participants not only had poor performance in the conditions which involve speechreading, but were poorer in the auditory-only condition as well. The small sample size of male participants could have caused this discrepancy or it could be a demonstration of women's superior verbal skills. Past research has shown that females have higher verbal intelligence (Bolla-Wilson & Bleecker, 1986) and verbal and episodic memory (Lewin, Wolgers, & Herlitz, 2001).

It is unclear why poor cataract near visual acuity was associated with better speech intelligibility, but it may be due to the fact that participants' cataract visual acuity scores were highly correlated with their normal visual acuity scores which already accounted for much of the variance. Another potential cause is that participants with poorer cataract visual acuity simply ignored the visual signal and devoted more attentional resources to the auditory speech signal. This attentional trade-off may have boosted their overall speech intelligibility performance.

Participants improved at the speech intelligibility task over time; however, the ANOVA revealed that the amount of visual enhancement in both visual conditions was not significantly different throughout the experiment. Additionally, the logistic binomial regression did not indicate an interaction between time and visual condition, suggesting that the performance improvement over time was similar across the three visual conditions. This is important to consider given previous findings which have shown viewers can quickly adapt to simulations of blur (Thorn & Thorn, 1989; Webster, Georgeson, & Webster, 2002). It does not appear that the participants in this study adapted to the simulated cataracts in particular, though they did experience some improvement overall during the experiment.

Study 2: Effects of Simulated Severe Cataracts on Speech Intelligibility

Study 2 expanded upon Study 1 by examining the effects of simulated cataracts on speechreading across a wider range of signal-to-noise ratios (SNRs). Ross and colleagues (2007) propose that when the SNR is too low, listeners will rely solely on vision to perceive speech. It is unclear whether the visual information gained from simulated cataracts contains enough information to support visual speech perception once the auditory signal is degraded beyond recognition.

New sentence stimuli were used in this experiment. The sentence material was changed from the *Everyday Speech Sentences* to the *Speech in Noise* (SIN) Sentences. One limitation of the *Everyday Speech Sentences* is that the number of scoreable items within each sentence range from 2 to 13 items per sentence. Thus, the sentences in effect are not weighted equally in the analysis. Using *Everyday Speech Sentences* materials, a participant could miss an entire sentence but answer all other sentences correctly within a list and could receive a score ranging between 74% and 96% correct, depending on the number of scoreable items in the missed sentence. In contrast, each of the SIN sentences contains five scoreable items. Using the SIN sentence materials, a participant could miss all scorable items of any one sentence and answer all other sentences correctly and would receive a consistent score of 90% correct.

The SIN sentence set has several additional benefits including a larger set of sentences whose equivalency and reliability have been demonstrated. The sentences are organized in nine blocks, each containing four lists, with each list containing 10 sentences for a total of 360 sentences. A study by Bentler (2000) found that blocks 1, 2, and 9 were equivalent and blocks 3, 4, and 5 were equivalent for listeners with normal hearing and found good test-retest reliability among these blocks. In light of these experimental findings, blocks 1, 2, and 9 (i.e. lists 1-8 and lists 33-36) were chosen for this study. Additionally, block 3 (i.e. lists 10-13) was chosen for verbal and written practice sentences but was not included in the data analysis because it was not demonstrated to be equivalent to blocks 1, 2, and 9 (Bentler, 2000).

The S-MLV presentation method employed in Study 1 was not feasible in this study given that the live-talker would be unable to maintain constant amplitude in the presence of different background babble amplitudes. This is a well-documented phenomenon called the Lombard reflex (Junqua, 1999). A recorded presentation of the same talker featured in Study 1 saying the chosen subset of the SIN sentences was used instead of a live-voice presentation. The video clips were recorded onto a DVD by Wichita State University (WSU) Media Services. Tracks in which the talker blinked or misread a sentence were re-recorded and the audio tracks were equalized to better ensure consistent voice intensity. The talker was recorded in front of a black backdrop, wore the same black shirt worn in Study 1, and had her hair pulled back in a similar fashion.

Study 1 showed that visual enhancement to speech perception was significantly reduced but not eliminated by the mild cataract simulation. The SNR in Study 1, however, did not completely degrade the auditory signal to test whether participants can use the visual cues afforded by the simulated cataracts to support visual speech perception. Using a televised presentation and presenting a range of babble intensities may help to determine the robustness of speechreading against diffusive blur. The effects of the cataract simulation lenses, however, were expected to be partially ameliorated by the brightness of the television. More specifically, the reduction in contrast caused by the cataract simulation glasses was expected to be lessened by the participants’ exposure to the high luminance liquid crystal display (LCD) television. This was supported by the work of De Valois et al. (1974), depicted in Figure 11, who found that human and macaque observers' contrast sensitivity improved and the high spatial frequency cutoff shifted toward higher frequencies as the absolute luminance level increased.

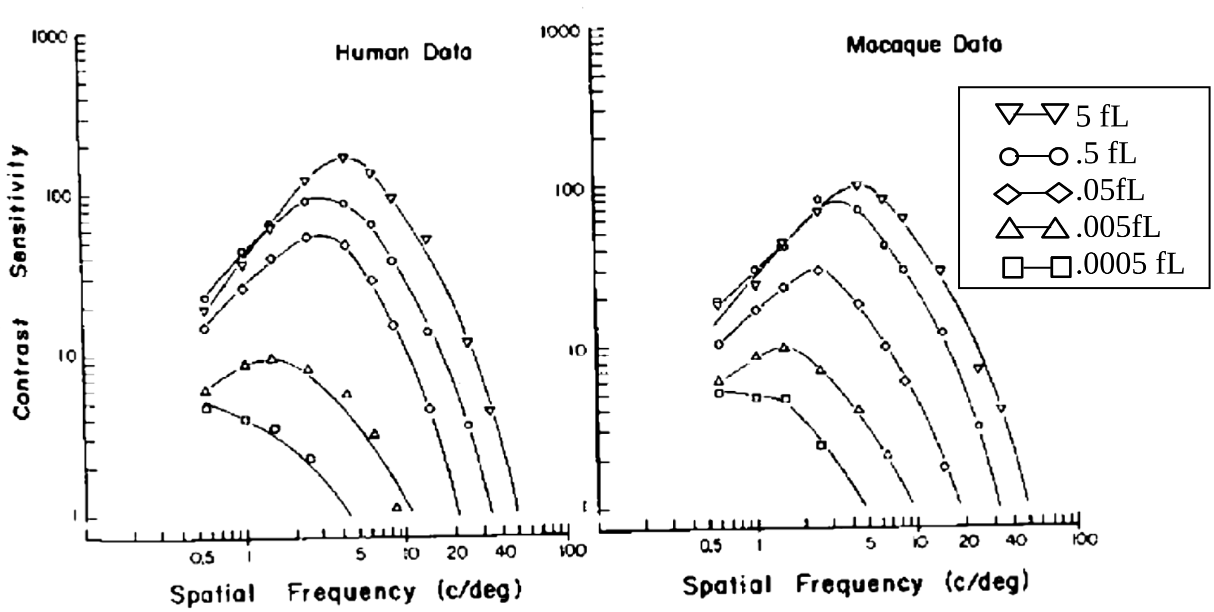

Figure 11. Taken from De Valois et al., (1974). "The luminance [contrast sensitivity function] CSF as a function of absolute luminance level. Contrast sensitivity was measured for both human and macaque observers for a range of spatial frequencies at each of the five adaptation levels (5, 0.5, 0.05, 0.005, and 0.0005 foot Lamberts, respectively). Note that the peak sensitivity shifts to lower spatial frequencies as luminance is reduced. At the same time, the low-frequency attenuation becomes less prominent, finally disappearing at the lowest luminance level."

The findings of De Valois et al. supports the notion that the contrast sensitivity reduction imposed by the cataract simulation lenses may be partially or completely offset by changes in contrast sensitivity when using the much brighter light-emitting television. The density of the cataract simulation lenses was increased by adding an additional lens to the Vistech filters to offset potential improvements in visual function associated with using the TV. The increased cataract manipulation was expected to not only test the robustness of visual enhancement in speechreading but also add power to the study given the number of signal-to-noise experimental conditions and the brightness of the television screen.

The Study 2 was designed to determine if the findings of Study 1, via live-voice presentation and *Everyday Speech Sentences*, would generalize to recorded-voice presentations on a television using different sentence materials.

Study 2 Hypotheses

a) Speech intelligibility will vary as a function of SNR, with the best performance at high SNRs and poorest performance at low SNRs.

b) Speech intelligibility performance will be significantly reduced by the simulated cataracts compared to the normal visual conditions.

c) Visual enhancement performance will be significantly reduced by the simulated cataracts compared to normal visual conditions.

d) The difference in visual enhancement between simulated cataract and normal vision will be most pronounced at intermediate signal-to-noise ratios.

e) The signal-to-noise ratio at which participants correctly report 50% of the key words (SNR-50) will be significantly higher for participants under the simulated cataract condition compared to normal vision.

f) Participants' speech intelligibility scores at the auditory-only SNR-50 ((A)SNR-50) will be significantly higher under the normal audiovisual condition compared to the cataract audiovisual condition.

Methods

Twenty participants (18-37 yrs, M = 20.45, 10 males and 10 females) with normal or corrected-to-normal vision, no history of hearing loss, and who spoke Mainstream American-English were recruited through the online university recruitment site and were given course credit for their participation. All participants had normal sensory functioning determined by standard screening measures of visual (contrast sensitivity and acuity) and auditory functioning (pure tone hearing screening). Participant screening results are displayed in Table 7.

TABLE 7

MEAN SCREENING SCORES

	Average	Std. Deviation
Far Acuity- OU		
Normal	20/15	4.17
Cataract	20/80	23.95
Near Acuity- OU		
Normal	20/25	0
Cataract	20/100	26.13
Contrast Sensitivity- OU		
Normal	1.8	.08
Cataract	.4	.13
Pure Tone Average- BE	4.08 dB	2.83
Pure Tone Average- PE	5.83 dB	3.92

Notes: Group mean scores and standard deviation for binocular (OU) near and far visual acuity and contrast sensitivity measured under both normal and simulated cataract conditions. Participants' pure tone average (and standard deviation) hearing thresholds in the better ear (BE) and poorer ear (PE).

Procedure

Participants wore one of three sets of glasses for each of the experimental conditions including: frames without lenses for the normal audiovisual condition (color coded white); frames with Vistech™ cataract simulation filters with an added filter for the cataract audiovisual condition (color coded black) and frames with opaque lenses for the auditory-only condition (color coded brown). Figure 12 (image 3) depicts the amount of contrast reduction imposed on an image by the additional filter. The cataract simulation glasses reduced participants' visual acuity to an average of 20/80 from 20/15 under normal viewing conditions. The simulation glasses reduced contrast sensitivity measured using the Pelli-Robson Contrast Sensitivity Chart from a mean score of 1.8 under normal viewing conditions to a mean score of .45 under the cataract simulation condition. The cataract simulation glasses reduced participants' visual acuity to an average of 20/80 from 20/15 under normal conditions. The simulation glasses also reduced participant contrast sensitivity to a mean score of .45 from a mean score 1.8 under normal conditions on the Pelli-Robson Contrast Sensitivity Chart.

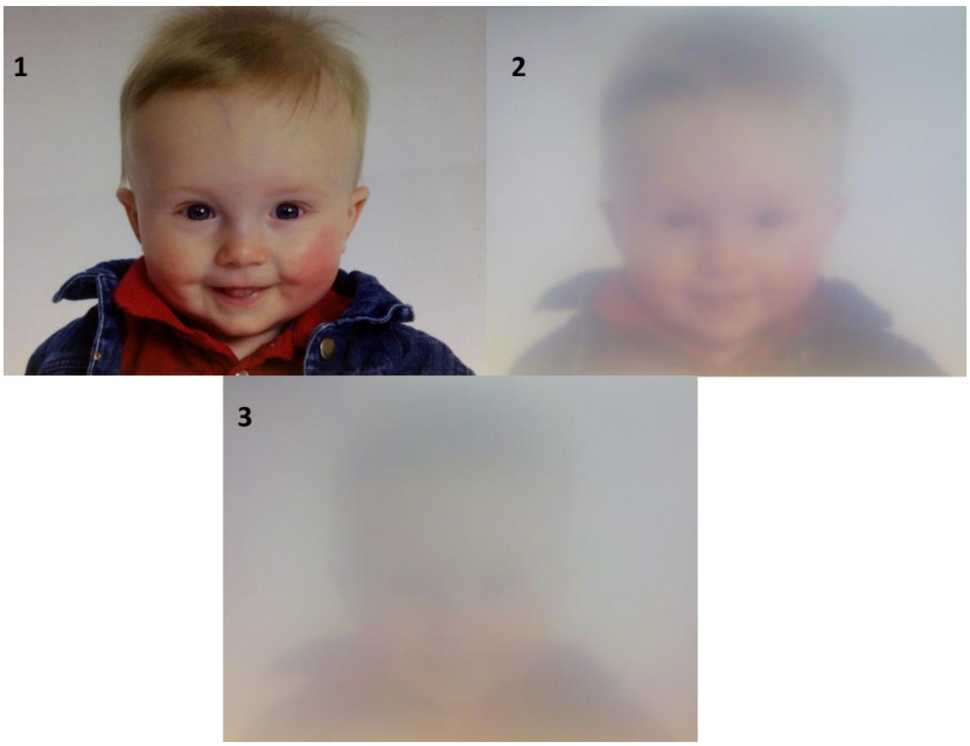

Figure 12. Three digital photos taken of the same image. Image 1 demonstrates normal vision (i.e. the camera had an unobstructed lens). Image 2 demonstrates simulated mild cataract vision (i.e. the camera's lens was overlaid with a filter from the Vistech™ simulation goggles). Image 3 demonstrates the additional amount of contrast reduction and blur on an image of a face by the second filters used in this study (i.e. the camera's lens was overlaid with a filter from the Vistech™ simulation goggles and an additional contrast reduction filter).

This experiment took place in the same sound booth described in Study 1. Speech intelligibility of the SIN sentences was tested while four-person babble was presented through two Grason-Stadler loud speakers. Participants listened and responded to the WSU recording of the SIN Sentences presented on a 32 inch LCD television with the audio track played through the television's loudspeaker at 65 dB SPL. The luminance of the talker's face on the LCD television measured with a photometer, between her eyes and just above the brow, was 61.3 candelas per meter squared (cd/m^2). Participants were seated approximately 1.4 meters from the television resulting in a visual angle of 4˚ from pupil to pupil of the talker's eyes, shown in Figure 13. A writing desk was placed in front of the participant to allow them to write the sentences. The participant was positioned in between the two loud speakers at approximately +125˚ and -125˚ azimuth. Experimenters monitored the participants' progress on a television screen, which streamed a live-video feed of the participant, from the monitoring booth outside of the sound booth. Each video track was played once the participants indicated they were ready by placing their pencil down and looking up to the television.

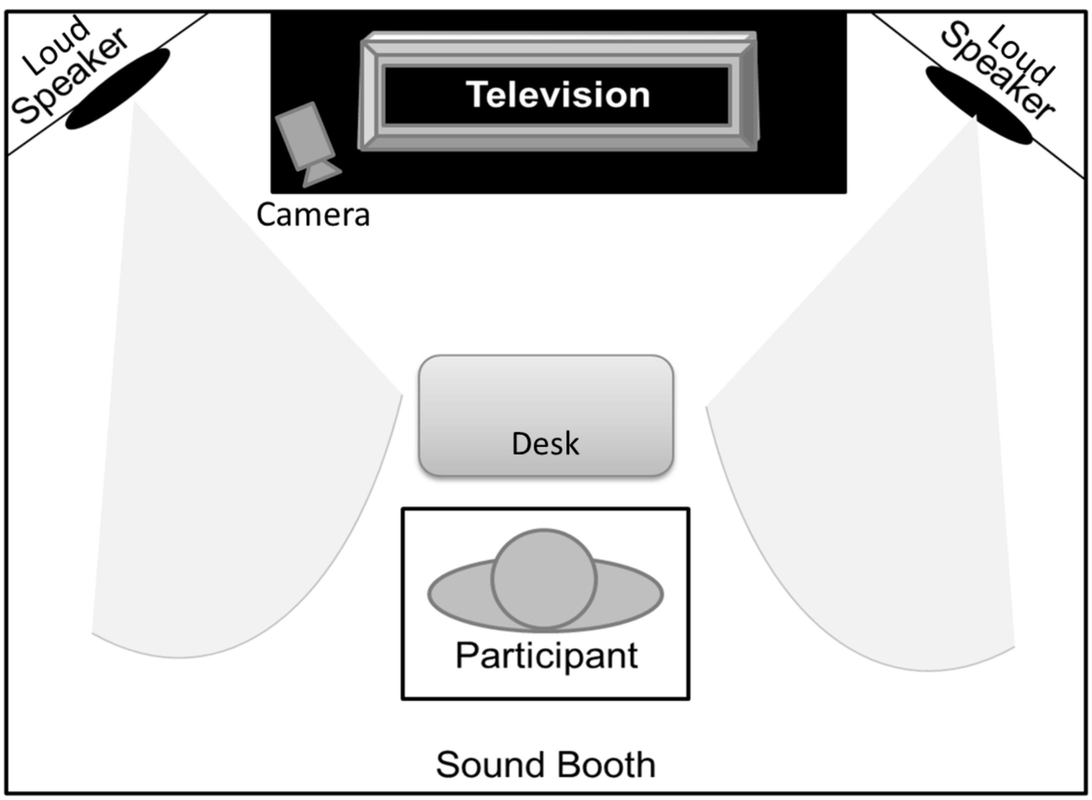

Figure 13. Schematic of the experimental layout of the testing room. Figures indicate participant position as well as the location of the loud speakers, television, writing desk, and monitoring camera relative to the participant.

Participants were given instructions to write what they believed the talker said, as detailed in Appendix E-1. Participants were presented with two practice sentences and instructed to verbally repeat what they heard the talker say. Additionally, a practice list of six sentences, presented in +5 dB SNR of four-person babble, were presented to allow participants to practice listening and writing sentences under the three visual conditions. Testing was divided into two blocks and speech intelligibility under all three visual conditions was tested in each block. Participants were presented with a two-list set of 20 sentences for each of the three visual conditions, totaling 6 lists in each block. The babble level at the start of each two-list set began at a SNR of -21 or -18 dB, counterbalanced across visual conditions, and decreased by 6 dB steps every five sentences ending in one of the most preferable SNRs, -3 or 0 dB, demonstrated in Table 8. This fixed-descending order of babble level, rather than a randomized order of intensity, was used to the experiment to ensure better participant motivation. According to Ariely and Zauberman (2000), people will report better satisfaction and will remember an unpleasant event as more pleasant if the sequence of the aversive stimuli improves at the end. This was an important consideration since pilot participants were reluctant to report any words they had heard the speaker say without urging from experimenters during the most difficult SNRs. Additionally, this method is more consistent with the noise presentation sequence of the version of SIN Test from which these sentences were taken. Participants were provided a five minute break between blocks to prevent fatigue. The experiment (including screening and practice sessions) lasted approximately one hour and fifteen minutes.

TABLE 8

VISUAL AND AUDITORY CONDITIONS BY EXPERIMENTAL BLOCK

Block 1					
SNR	AO	SNR	Normal	SNR	Cataract
-21 dB	5 sentences	-18 dB	5 sentences	-21 dB	5 sentences
-15 dB	5 sentences	-12 dB	5 sentences	-15 dB	5 sentences
-9 dB	5 sentences	-6 dB	5 sentences	-9 dB	5 sentences
-3 dB	5 sentences	0 dB	5 sentences	-3 dB	5 sentences
Block 2					
SNR	Normal	SNR	Cataract	SNR	AO
-18 dB	5 sentences	-21 dB	5 sentences	-18 dB	5 sentences
-12 dB	5 sentences	-15 dB	5 sentences	-12 dB	5 sentences
-6 dB	5 sentences	-9 dB	5 sentences	-6 dB	5 sentences
0 dB	5 sentences	-3 dB	5 sentences	0 dB	5 sentences

Notes: Experimental testing was divided into two blocks. Each of the visual conditions (auditory-only (AO), cataract audiovisual, and normal audiovisual) was presented in each block in a randomized order. Group A SNRs (-21, -15, -9, & -3 dB) and Group B SNRs (-18, -12, -6, & 0 dB) were alternated for each visual condition and counterbalanced. Five sentences were presented for each visual condition and SNR.

Results

Participants' responses were scored by a second experimenter, who was masked to the experimental conditions under which the data were collected, using the aforementioned scoring criterion described in Study 1. Average speech intelligibility and visual enhancement for each SNR and visual condition was calculated across all participants, presented in Table 9.

TABLE 9

AVERAGE SPEECH INTELLIGIBILITY AND VISUAL ENHANCEMENT BY VISUAL CONDITION AND SNR

SNR	Auditory-only	Cataract Audiovisual	Normal Audiovisual	Cataract VE	Normal VE
0 dB	.84 (.13)	.94 (.06)	.93 (.07)	.10 (.11)	.09 (.11)
-3 dB	.74 (.15)	.86 (.12)	.90 (.11)	.12 (.11)	.16 (.15)
-6 dB	.52 (.18)	.77 (.13)	.84 (.11)	.25 (.17)	.32 (.14)
-9 dB	.33 (.14)	.62 (.14)	.70 (.21)	.29 (.20)	.37 (.21)
-12 dB	.19 (.12)	.44 (.17)	.55 (.15)	.25 (.16)	.36 (.15)
-15 dB	.06 (.09)	.32 (.16)	.40 (.19)	.26 (.17)	.34 (.21)
-18 dB	.05 (.06)	.17 (.14)	.27 (.19)	.12 (.13)	.22 (.19)
-21 dB	.02 (.04)	.09 (.07)	.19 (.20)	.07 (.08)	.17 (.21)

Notes: Participants' speech intelligibility score expressed as mean percent correct and standard deviation (shown in decimal form) for each visual condition and SNR. The last two columns display the calculated visual enhancement (VE) score from Equation 1.

Figure 14 displays the mean intelligibility, expressed as the percentage of participants' speech intelligibility under the three viewing conditions. Performance was best at the highest SNR and demonstrated a systematic decline as the SNR was reduced. This supports Hypothesis 2a which predicted that speech intelligibility would be best under the highest SNR and would decline as the SNR declined. Accuracy was highest for the normal audiovisual condition, poorer for the cataract audiovisual conditions, and poorest for the auditory-only conditions.

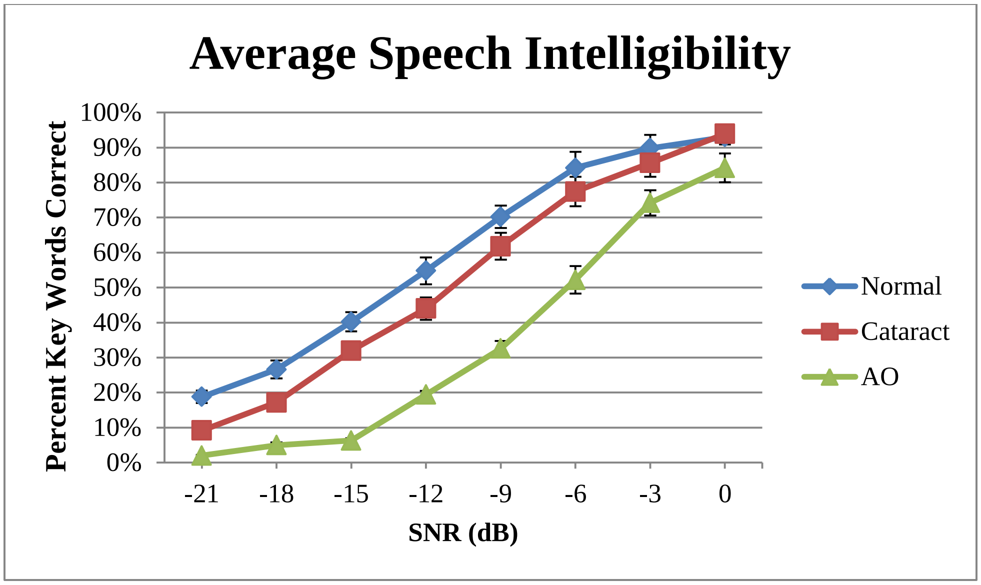

Figure 14. Psychometric functions showing mean speech intelligibility (N=20) for the normal vision, simulated cataract and auditory-only (AO) viewing conditions as a function of SNR. Error bars in the figure represent standard error.

A 2x8 within-subjects analysis of variance (ANOVA) was conducted to evaluate the effect of visual condition and SNR. This analysis was used to test Hypothesis 2c to determine if the simulated cataracts significantly reduced visual enhancement compared to normal visual conditions. Participants' visual enhancement score for each viewing condition and SNR was calculated using Equation 1: VE= AV-A (displayed in Figure 15). The within-subjects factors were visual condition with two levels (normal vision and simulated cataract vision) and SNR with eight levels (0, -3, -6, -9, -12, -15, -18, and -21 dB). The ANOVA indicated a significant main effect for visual condition, $F(1, 19) = 11.39$, $p < .01$, $\eta_p^2 = .38$ and a significant main effect for the level of the SNRs, $F(7, 13) = 7.42$, $p < .01$, $\eta_p^2 = .80$. Additionally, the ANOVA found no significant interaction between visual condition and the level of the SNRs, $F(7, 13) = 2.07$, $p = .12$, $\eta_p^2 = .53$.

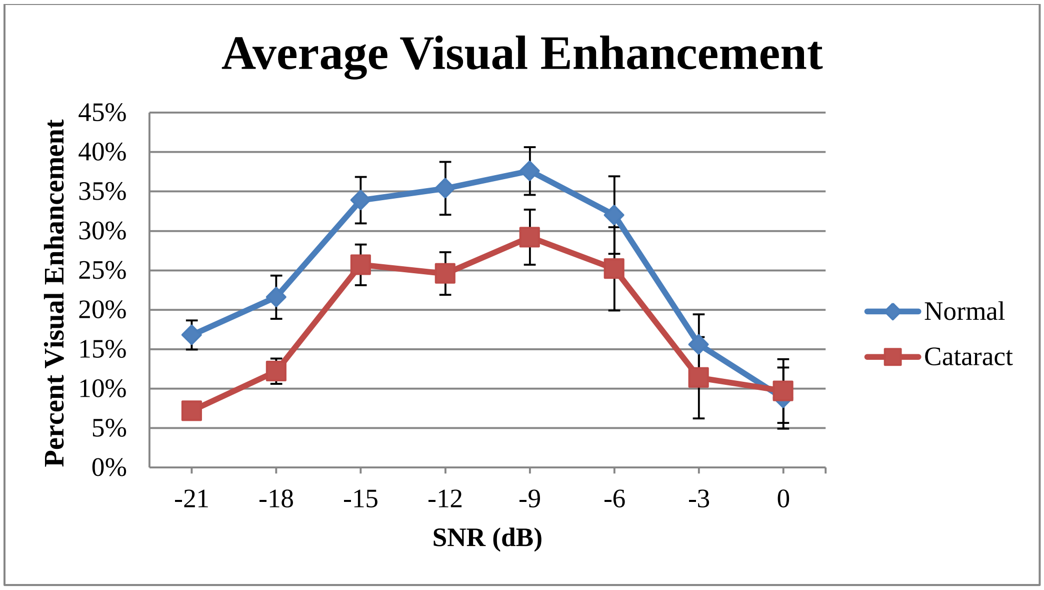

Figure 15. Psychometric functions showing mean VE (N=20) of both normal and simulated cataract viewing conditions as a function of SNR. Error bars in the figure represent standard error.

Paired t-tests were computed for all SNRs between normal visual enhancement and simulated cataract visual enhancement. This analysis was used to test Hypothesis 2d to determine if the largest differences between normal enhancement and simulated cataract visual enhancement occurred at intermediate SNRs. Visual enhancement for recognition of key words in the SIN sentences was significantly poorer ($p < 0.05$) with simulated cataracts than with normal vision at all SNRs except 0 dB. After Bonferroni adjustment, however, only the -12 dB SNR was significant at the 0.006 adjusted *p* level, $t(19) = 2.743$, $p = .006$, Cohen's $d = .69$. The -12 dB SNR, compared to the other SNRs, had the largest difference between normal and simulated cataract VE at 12%. These results support Hypothesis 2d that predicted that the difference in performance between normal visual enhancement and simulated cataract visual enhancement would be most pronounced at intermediate SNRs.

The SNR-50 of each audiovisual condition (auditory-only, cataract, and normal vision) were calculated to determine if the cataract SNR-50 was significantly higher than the normal vision SNR-50 as predicted by Hypothesis 2e. The SNR-50s were computed by plotting a psychometric function of each participant's speech intelligibility scores within a visual condition across all eight SNRs. The psychometric function was fitted using SigmaPlot 11.0™ using a four parameter logistic function. Once the psychometric curve was fitted to the data, the SNR level which supported 50% accuracy was identified and recorded. An example of this process is demonstrated in Figure 16 with the data from participant 3. The data from the psychometric function identified participant 3's SNR-50s as: -6.56 dB for auditory-only, -10.25 dB for cataract audiovisual and -15.44 dB for normal audiovisual. This process was repeated with each participant's speech intelligibility scores to identify the auditory-only, cataract and normal SNR-50 for each participant. Participants' SNR-50 scores are displayed in Table 10.

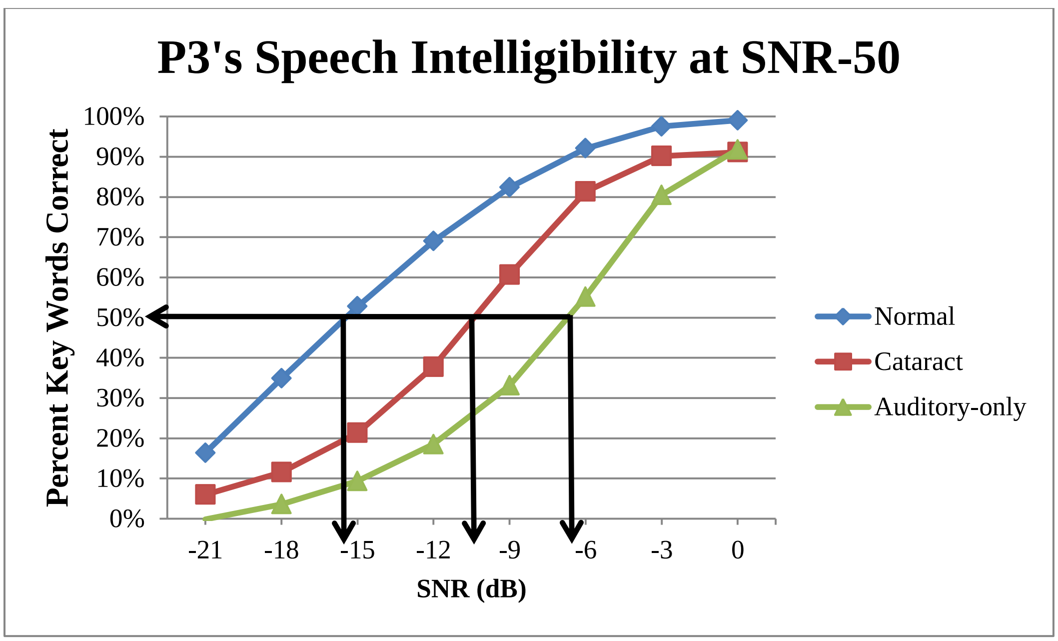

Figure 16. Psychometric functions showing participant 3's (P3) normal and simulated cataract speech intelligibility. Arrows in the figure denote the SNR-50 of each visual condition.

TABLE 10

AUDITORY-ONLY, SIMULATED CATARACT, AND NORMAL SNR-50 VALUES

Participant	Auditory-only	Cataract	Normal
1	-4.83	-8.06	-13.36
2	-8.18	-15.44	-17.05
3	-6.56	-10.25	-15.44
4	-3.68	-14.51	-19.93
5	-11.98	-9.56	-11.86
6	-6.10	-11.06	-9.10
7	-2.76	-7.60	-10.25
8	-9.21	-16.82	-14.17
9	-3.91	-8.98	-10.02
10	-5.87	-9.56	-10.83
11	-6.68	-14.51	-11.75
12	-4.03	-10.37	-10.02
13	-7.48	-11.75	-11.52
14	-7.71	-11.17	-14.51
15	-7.14	-5.64	-8.75
16	-4.95	-11.75	-13.82
17	-2.88	-6.45	-8.06
18	-9.10	-10.71	-21.00
19	-7.71	-13.59	-17.63
20	-7.02	-12.67	-17.05
Average	**-6.39**	**-11.02**	**-13.31**
SD	**2.35**	**2.97**	**3.75**

The average SNR-50 values for cataract vision demonstrate that participants could, on average, detect speech in 5 dB higher noise to detect it equally as well as auditory-only listening conditions. The average SNR-50 values demonstrate that participants with normal vision could, on average, detect speech in noise 7 dB higher and 2 dB higher to detect it equally as well as with auditory-only and cataract vision, respectively. The results of a paired t test revealed that participants' SNR-50 was significantly higher under the cataract audiovisual condition (-11.02 dB) compared to normal audiovisual condition (-13.31 dB), $t(19) = 3.269$, $p = .004$, Cohen's $d = .67$.

The audiovisual scores (cataract and normal vision) at the auditory-only (A)SNR-50 were calculated to determine if speech intelligibility under cataract vision was significantly lower than under normal vision as predicted by Hypothesis 2f. The (A)SNR-50 scores for each participant were computed by plotting a psychometric function of each participant's auditory-only speech intelligibility scores across all eight SNRs. The psychometric functions were fitted using the same procedure described earlier. The psychometric curves were used to estimate the (A)SNR-50 associated with 50% accuracy. The audiovisual speech intelligibility scores for both normal and cataract vision were identified by referencing the psychometric function data points at the (A)SNR-50. An example of this process is demonstrated in Figure 17 with the data from participant 3. The data from the psychometric function identified participant 3's (A)SNR-50 as -6.56 dB and the AV scores at the (A)SNR-50 as 78.23% for cataract vision and 90.56% for normal vision. This process was repeated with each participant's (A)SNR-50 scores to identify AV scores at the (A)SNR-50. Participants' (A)SNR-50 scores and AV scores are displayed in Table 11.

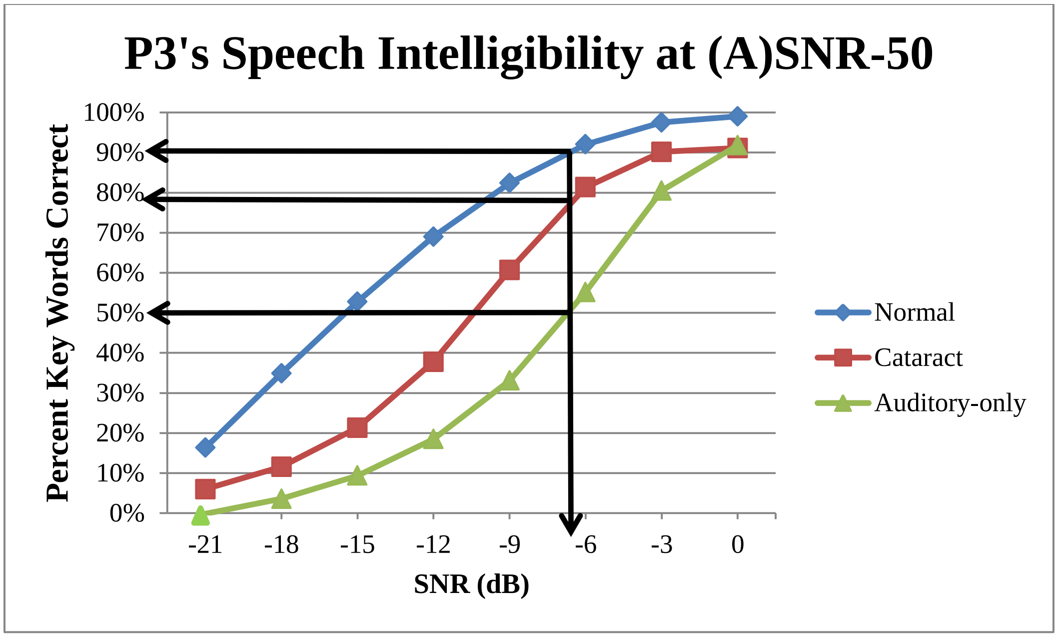

Figure 17. Psychometric functions showing participant 3's (P3) auditory-only, normal and simulated cataract speech intelligibility. Arrows in the figure denote the (A)SNR-50 (-6.56 SNR dB) and the AV scores @ the (A)SNR-50.

TABLE 11

NORMAL AND SIMULATED CATARACT SPEECH INTELLIGIBILITY SCORES AT (A)SNR-50

	(A)SNR-50	Cataract	Normal
1	-4.83	72.57%	92.43%
2	-8.18	83.54%	92.20%
3	-6.56	78.23%	90.56%
4	-3.68	87.84%	83.97%
5	-11.98	39.36%	49.27%
6	-6.10	73.60%	69.14%
7	-2.76	78.80%	92.55%
8	-9.21	84.71%	89.57%
9	-3.91	82.67%	92.54%
10	-5.87	85.97%	69.35%
11	-6.68	86.20%	87.76%
12	-4.03	80.25%	77.96%
13	-7.48	80.69%	69.17%
14	-7.71	81.35%	91.77%
15	-7.14	42.35%	63.99%
16	-4.95	85.76%	87.90%
17	-2.88	63.83%	73.56%
18	-9.10	58.86%	96.00%
19	-7.71	89.01%	87.31%
20	-7.02	71.47%	96.90%
Average	**-6.39**	**75.35%**	**82.70%**
SD	**2.35**	**14.17%**	**12.86%**

The average speech intelligibility scores at the (A)SNR-50 demonstrate that speech intelligibility improved by approximately 33% when participants looked at the talker's face under the normal vision condition, but only improved by ~25% under the cataract vision condition. The results of a paired t test revealed that participants' speech intelligibility was significantly higher under normal audiovisual conditions (82.8%) compared to cataract audiovisual conditions (75.35%), $t(19) = 2.567$, $p = .02$, Cohen's $d = .54$.

A logistic binomial regression was conducted to evaluate how well the visual conditions, SNR manipulations, and screening measures predicted speech intelligibility performance. This was done to test Hypothesis 2b which predicted that participants would have poorer speech intelligibility performance under the simulated cataracts audiovisual conditions compared to the normal audiovisual conditions. The predictors included in the analysis were the three visual conditions (auditory-only, cataract audiovisual and normal audiovisual), SNR, and six screening measures (age, gender, near and far visual acuity (normal and cataract), contrast sensitivity (normal and cataract), and pure tone threshold averages). The model was built using the same forward inclusion and backward exclusion criterion stated in Study 1B. The null deviance of the speech intelligibility scores in this study was 6706.7 (deviance).

The predictors added to the model that met the criterion through forward inclusion were: visual condition, SNR, age, gender, far acuity (normal and cataract) and near acuity (cataract). Contrast sensitivity (normal and cataract), and pure-tone threshold (better and poorer ear) did not meet forward inclusion criterion. Normal near acuity could not be added to the model because of a ceiling effect for all participants which left no variability for predictions (M = 20/25, *SD* = 0). Predictors retained in the model after backward elimination were: visual condition, SNR, age, gender, far acuity (normal and cataract) and near acuity (cataract). No predictors added to the model through forward inclusion met the criterion of backward elimination. The analysis compared performance under the cataract audiovisual and auditory-only conditions to a baseline performance under the normal audiovisual condition. The resulting residual deviance was 1248.0 (residual deviance = 1248.0, null deviance = 6706.7, and AIC = 2552.3.). The results of the regression analysis are displayed in Table 12.

TABLE 12

COEFFICENTS IDENTIFIED AS PREDICTORS OF PERFORMANCE

Coefficients	B weights	Std. Error	z value	p value
(Intercept)	3.52	0.18	19.97	< .001
Auditory-only	-1.65	0.06	-26.98	< .001
Cataract Audiovisual	-0.46	0.06	-8.02	< .001
SNR	0.24	0.00	55.00	< .001
Gender	-0.11	0.05	-2.09	.04
Far Acuity: Normal	-0.09	0.01	-10.54	< .001
Age	-0.03	0.01	-4.88	< .001
Near Acuity: Cataract	0.01	0.00	8.78	< .001
Far Acuity: Cataract	0.01	0.00	3.92	< .001

Notes: Results of the logistic binomial regression analysis. Predictors (coefficients) of speech intelligibility performance are listed on the left.

The visual condition (normal, cataract, and auditory-only) was an important predictor of speech intelligibility performance. Participants performed significantly poorer under the auditory-only condition compared to the normal audiovisual condition ($p < .001$; â = -1.65). Participants were also significantly impaired at the task when their vision was degraded by the cataract simulation lenses ($p < .001$; â = -0.46). The model predicts that speech intelligibility will decline once participants' vision is completely occluded (auditory-only) or partially degraded (simulated cataract vision).

Signal-to-noise ratio was a significant predictor of speech intelligibility performance ($p < 0.001$; â = .24). Participants' performance declined as the SNR declined and the listening task became more difficult. These results are consistent with Hypothesis 2a which predicted that speech intelligibility would change as a function of SNR, with the best performance at high SNRs and the poorest performance at low SNRs.

Gender was found to be a significant predictor of speech intelligibility performance ($p < .001$; â = .68). These results indicate that male participants tended to perform with better accuracy at the speech intelligibility task than female participants. These findings are contrary to those previously observed in Study 1, which found females to outperform males, but had a small sample size of males. There was an equal distribution of males (n=10) and females (n=10) in this study which may better demonstrate a difference in gender if one exists.

Older participants were predicted to have poorer speech intelligibility performance than younger participants ($p < .001$; â = -.03). This finding differs from Study 1B which found older participants tended to outperform younger participants; however, the age range in Study 1B was smaller (18-31 yrs.) and the age range in this study was wider (18-37 yrs.). These results may suggest that speech perception in noise may begin to decline once individuals are in their 30s.

Normal far visual acuity was found to be a significant predictor of performance ($p < .001$; â = -0.09). Better far visual acuity with the simulated cataracts was found to be predictive of more accurate performance on the speech intelligibility task. Cataract far visual acuity and cataract near acuity, however, had the opposite direction of prediction on performance ($p < .001$; â = 0.01; $p < .001$; â = 0.01).   That is, poorer cataract visual acuity was associated with better performance.

Discussion

The results of this study demonstrated that the severe cataract simulation glasses significantly reduced participants' speechreading performance in noisy conditions. The difference between normal and cataract audiovisual performance was most pronounced at an intermediate SNR (i.e. -12 dB). These results are consistent with predictions based on the Ross et al. (2007) study suggesting that -12 dB SNR is the "special zone" in which both vision and audition are maximally utilized. Participants experienced an over 2-fold improvement (54.8% accuracy) in normal audiovisual performance over auditory-only conditions (19.4% accuracy).

Subsequently, this noise level revealed the largest difference between the two visual conditions (normal and simulated cataract).

Despite the drastic reduction in visual acuity and contrast sensitivity caused by the cataract simulation lenses, the magnitude of visual enhancement between cataract and normal vision conditions did not exceed 12%. These results are interesting since the results of Study 1 yielded a similar difference of 7% under cataract visual conditions that were less severe (visual acuity ~20/32). One potential explanation is that the increased brightness of the television screen may have ameliorated some of the impact of the cataract simulations, as discussed earlier. The cataract simulation glasses reduced contrast sensitivity and visual acuity, but the high luminance level of the television may have had some beneficial visual effect. Figure 18 demonstrates the change in contrast reduction and acuity when a picture is viewed from a light reflecting surface versus a light emitting surface. Several participants noted that they could see the televised talker's face more clearly with the cataract simulation glasses than when viewing a real face in the sound booth. Additionally, the power of the study may have been too low since there were only 25 data points for each SNR for each visual condition.

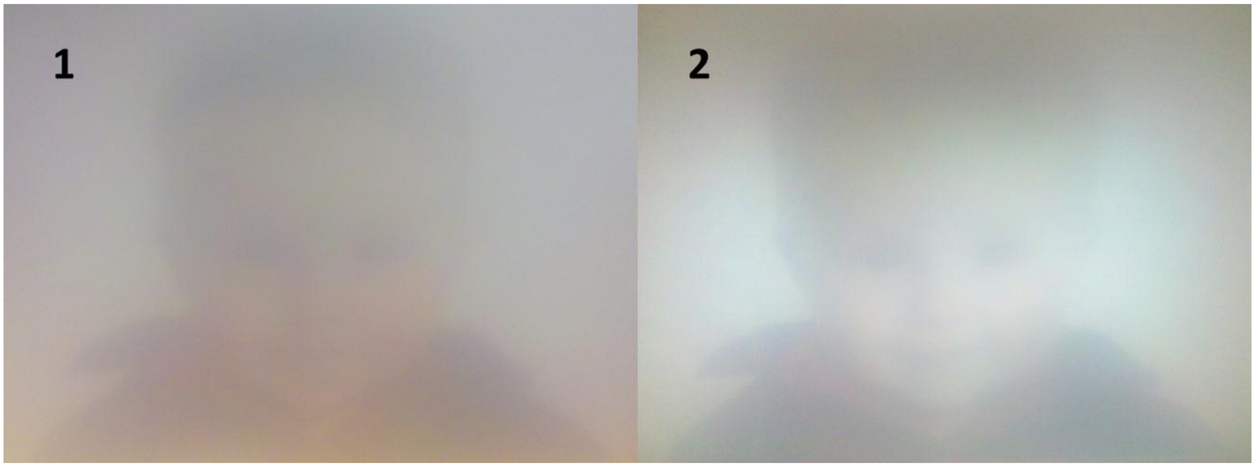

Figure 18. Two versions of the same image. Image 1 was captured from a physical photograph with the two filters used in Study 2 overlaid upon the digital camera's lens. Image 2 is the same image captured from a digital photograph, displayed on a light emitting monitor, with the same two filters overlaid upon the digital camera's lens. The increased luminance allows the facial features of Image 2 to be better resolved than Image 1.

The luminance level of the talker's face in the recording was not only increased by the luminance of the television, but also increased by the bright lighting in the recording studio. Gagne et al. (2006) found that high luminance levels on a light-skinned talker improved speechreading performance. This could also be a potential cause of participants' high performance, despite visual degradation, since the talker in this study was quite fair-skinned. Additionally, the location of lighting source in the recording studio during the taping of the talker was not positioned above the talker's head, but illuminated the talker's face more directly at approximately a 45˚ angle. Previous research has demonstrated that direct lighting or lighting at a 45˚ angle boosted speech perception because the mouth cavity is illuminated (Erber, 1974; Zhou & Boyce, 2001). Similarly, portions of the talker's mouth cavity, particularly her teeth, are illuminated in the recording of the SIN sentences, as shown in Figure 19. The lighting source in Study 1 was from the ceiling of the sound booth. It is less likely that participants could clearly view portions of the talker's mouth cavity in Study 1 and this may have contributed to some of the differences in performance between Study 1 and 2.

Figure 19. A still shot from the WSU recording of the Speech in Noise Sentences. The image demonstrates how the talker's mouth cavity is visible to viewers during the talker's speech.

The SNR-50 scores demonstrated that participants could tolerate increase in background noise an increase of 7 dB with normal vision and an increase of 5 dB with simulated cataracts over auditory only conditions. The 2 dB between the normal and cataract visual conditions was found to be statistically significant. Additionally, the audiovisual scores at (A)SNR-50 differed significantly for the cataract vision performance at (75.3%) and normal vision conditions (82.7%). These results demonstrate that individuals may experience a boost in their auditory-only threshold speech detection attaining levels comparable with normal vision. This is not the case when their vision was degraded by cataracts.

The results of the logistic binomial regression helped to establish which of the participant screening measures predicted speech intelligibility performance. Contrast sensitivity measured with the simulated cataracts was the best predictor of how a participant would perform in the task; however, normal contrast sensitivity was not a predictor in this experiment. There are two likely explanations of this result. First, the increased density of the simulated cataract in Study 2 may have added more predictive variability than the milder simulated cataract in Study 1B. Second, there was little variability in the normal contrast sensitivity scores (i.e. all but one participant had a score ranging from 1.8 to 1.95 on the Pelli-Robson Chart) because most participants were young, with good vision, but there was greater variability in the cataract contrast sensitivity scores (.3 to .6). Visual acuity measured under both normal and cataract conditions predicted speech intelligibility performance, but it accounted for much less variance than cataract contrast sensitivity.

The logistic binomial regression revealed that age was a predictor of speech intelligibility performance despite the restricted age range of our participants (18 to 37 years). The “older” participants had poorer speech intelligibility performance, which is contrary to the findings of Study 1B. However, the age range in Study 1B was even smaller (i.e. 18-31 yrs) than the age range of this study. Pure-tone averages were not significant predictors of performance, so it does not appear that declining hearing function is the cause of older participants’ poorer performance. This may be attributed to declining cognitive function which allows listeners to filter distractor noise and detect target speech. This could suggest that age difference in the ability to detect speech in noise begin much earlier than late adulthood and may begin in individuals’ late 30s.

Study 3:

Effects of Simulated Mild Cataracts on Speech Intelligibility using a Luminance-Controlled Presentation

The results of Study 1 revealed that a mild cataract, which had a moderate effect on acuity (VA= ~20/32; decimal acuity = .667), reduced visual enhancement (VE) by 6.29% compared to a normal viewing condition. Study 2 showed that a more severe simulated cataract further diminished speech intelligibility compared to the mild cataract condition. Visual enhancement was reduced by an average of 12% by the severe cataract which reduced visual acuity to an average of 20/80 (decimal acuity = .25). Thus, changes in visual enhancement scores are not proportional to the changes in acuity produced by the mild and severe cataracts (2 fold change in VE versus a 2.67 fold change in acuity). It is unclear whether the relative tolerance of speech intelligibility to the effects of the simulated cataracts is due to the limited range of visual acuities tested in these experiments or a result of using an LCD display to present the video clips.

The aim of Study 3 was to examine how the luminance of a talker's face affected speech intelligibility performance. We hypothesize that the increased luminance of the television screen may ameliorate some of the effects of the simulated cataracts. A photometer was used to measure the luminance of the middle of the talker's forehead (just above the brow) under the same lighting conditions in Study 1. The luminance of the talker's forehead was measured to be .63 candela per meters squared (cd/m^2) compared to 61.3 cd/m^2 for the video clip presented on the LCD television in Study 2. Neutral density filters were laid over the television screen to reduce the luminance of the LCD display to roughly match the luminance of the live talker in Study 1. The neutral density filters did not alter the color or contrast of the televised talker. The purpose of this study was to examine the effects of simulated mild cataracts on speech intelligibility under controlled luminance levels.

Study 3 Hypotheses

a) Speech intelligibility will vary as a function of SNR, with the best performance at high SNRs and poorest performance at low SNRs.
b) Speech intelligibility will be significantly reduced by the simulated cataracts compared to the normal audiovisual conditions.
c) Visual enhancement will be significantly reduced by the simulated cataracts compared to the normal audiovisual conditions.
d) The difference in visual enhancement between simulated cataract vision and normal vision will be most pronounced at intermediate signal-to-noise ratios.
e) SNR-50 will be significantly higher for participants under the simulated cataract condition compared to normal vision.
f) Participants' speech intelligibility scores at the (A)SNR-50 will be significantly higher under the normal audiovisual condition compared to the cataract audiovisual condition.

Methods

Twenty participants (18-38 yrs, M = 24.9, 5 males and 15 females) with normal or corrected-to-normal vision, no history of hearing loss and who spoke Mainstream American-English were recruited through the online university recruitment site and received course credit for their participation. All participants had normal sensory functioning as determined by standard screening measures of visual (contrast sensitivity and acuity) and auditory functioning (pure tone hearing screening). Participant screening results are shown in Table 13.

TABLE 13

MEAN SCREENING SCORES

	Average	Std. Deviation
Far Acuity- OU		
Normal	20/15	4.60
Cataract	20/32	6.47
Near Acuity- OU		
Normal	20/25	4.91
Cataract	20/40	11.32
Contrast Sensitivity- OU		
Normal	1.8	.09
Cataract	1.2	.07
Pure Tone Average- BE	3.83 dB	2.42
Pure Tone Average- PE	5.75 dB	2.45

Notes: Group mean scores and standard deviation for binocular (OU) near and far visual acuity and contrast sensitivity measured under both normal and simulated cataract conditions. Participants' pure tone average (and standard deviation) hearing thresholds in better ear (BE) and poorer ear (PE).

Procedure

Participants wore one of two pairs of glasses for each of the experimental conditions including frames without lenses for the normal audiovisual and auditory-only conditions (color coded white) and frames with Vistech™ cataract simulation filters for the (mild) cataract audiovisual condition (color coded black). The cataract simulation glasses reduced participants' visual acuity to an average of 20/32 from 20/15 under normal viewing conditions. The simulation glasses reduced contrast sensitivity measured using the Pelli-Robson Contrast Sensitivity Chart from a mean score of 1.8 under normal viewing conditions to a mean score of 1.2 under the cataract simulation condition.

Opaque lenses were used in the previous two studies to prevent the participants from seeing the talker in the auditory-only condition. For this experiment, participants wore frames with the lenses removed and a black piece of opaque fabric was used to occlude the talker's face in the auditory-only condition. Participants were able to prepare for the start and end of each sentence by noting the appearance of several cues including the DVD's menu and a number at the bottom left corner of the television screen denoting the sentence number, displayed in Figure 20. This helped participants write each sentence on the appropriate line of the answer sheet.

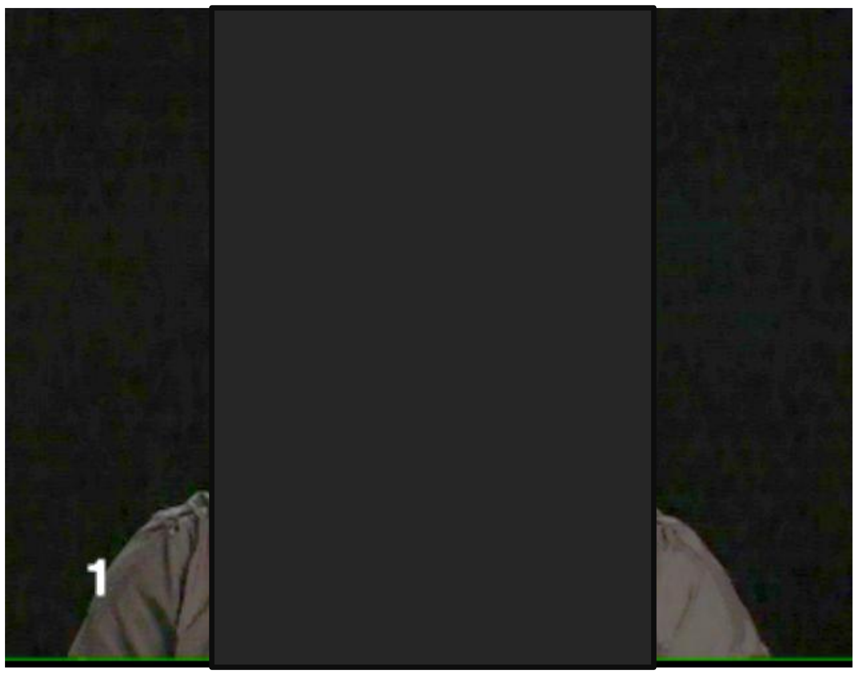

Figure 20. Example of the auditory-only condition in which a black opaque piece of fabric was laid over the televised talker's face. Participants would see the peripheral portions of the screen change from the gray menu of the DVD to the black background and the talker's shoulders. Additionally, the "1" in the bottom left corner of this image would cue the participant that sentence 1 was currently being played.

The experiment took place in the same sound booth described in Study 1. A set of neutral density filters were placed on the 32 inch LCD television to reduce the luminance of the televised talker's face from 61.3 cd/m^2 to the .69 cd/m^2 which approximates the luminance of the live talker's face in Study 1, demonstrated in Figure 21. The set of filters consisted of .15 (½ stop), .3 (1 stop), .9 (2 stop), and 1.2 (3 stop) ND filters (i.e. No. 298, 209, 210, and 299, respectively; Lee Filters, Burbank, CA). The lights of the sound and monitoring booths were turned off to eliminate additional sources of reflection that might produce glare. A desk lamp with a red-tinted 40 watt bulb was used to dimly illuminate the desktop so participants could write their answers without losing dark adaptation. A 10 inch tall, 3 foot wide partition was set on the edge of the writing surface between the desk lamp and television to prevent the red light from reflecting off the filters.

Figure 21. Two digital photographs of the WSU recording of the SIN Sentences shown on the LCD television used in Study 3. Image 1 demonstrates the appearance of the talker's face (61.3 cd/m^2) with no neutral density filters and image 2 demonstrates appearance of the talker's face (.69 cd/m^2) overlaid with the 4 neutral density filters.

Speech intelligibility was tested in the presence of four-person babble which was presented through the same two Grason-Stadler loud speakers as used in previous experiments. The different signal-to-noise ratios (i.e. SNRs) used in the experiments were produced by varying the intensity of the four person babble relative to a sound intensity from the video recording of the talker which was fixed at 65 dB SPL. Participants listened and responded to a recording of SIN Sentences presented on the 32 inch LCD television and the audio track played through the television's loudspeaker. Participants were seated approximately 1.4 meters from the television resulting in a visual angle of 4˚ from pupil to pupil of the talker's eyes, shown in Figure 22. A video camera was used to monitor the participant in the sound booth. Each video track was played once the participants indicated they were ready by placing their pencil down and looking up to the television.

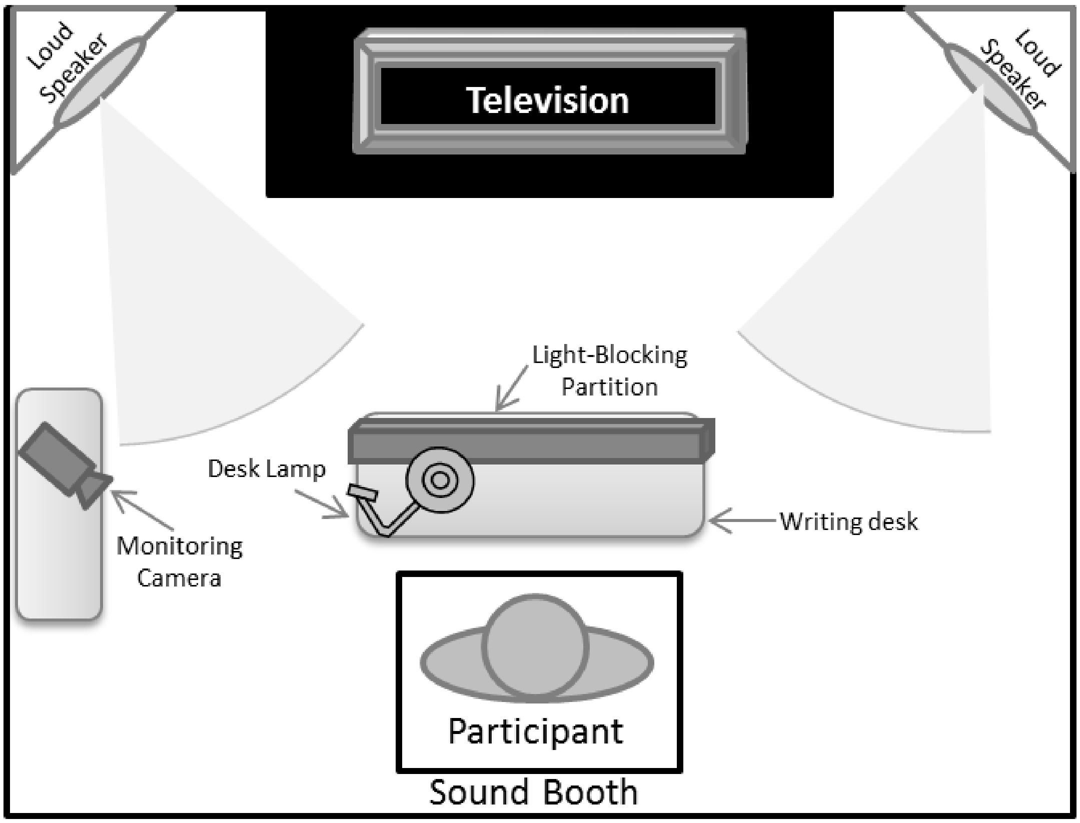

Figure 22. Schematic illustrating the experimental layout of the testing room. Figures depicts the position of the participant as well as the location of the loud speakers, television, writing desk, desk lamp, light-blocking partition, and monitoring camera relative to the participant.

Participants were given instruction to write what they believed the talker to have said, detailed in Appendix E-2. Participants were presented with two practice sentences and instructed to verbally repeat what they heard the talker say. Additionally, a practice list of six sentences, presented in +5 dB SNR of four-person babble, were presented to allow participants to practice listening and writing sentences under the three visual conditions as done in Study 2. Testing was divided into two blocks and speech intelligibility was tested under all three visual conditions in each block. Participants were presented with a two-list set of 20 sentences for each of the three visual conditions, totaling 6 lists in each block. The babble was played into the booth through the loud speakers at one of eight different SNRs: 0, -3, -6, -9, -12, -15, -18, and -21 dB. A different SNR was presented every five sentences. The order of testing at the different SNRs was pseudo-randomized to prevent the four most difficult SNRs from being presented within a two-list set to minimize participant frustration. Instead, the SNRs were divided into two groups: Group A (SNRs 0, -6, -12, and -18 dB) and Group B (SNRs -3, -9, -15, and -21 dB). The SNRs within each group were randomized, demonstrated in Table 14, and the order of group presentation was counterbalanced across all participants. Participants were provided a five minute break in between the two test blocks. The experiment (including screening and practice sessions) lasted approximately one hour and fifteen minutes.

TABLE 14

VISUAL AND AUDITORY CONDITIONS BY EXPERIMENTAL BLOCK

Block 1					
SNR	AO	SNR	Normal	SNR	Cataract
-21 dB	5 sentences	0 dB	5 sentences	-3 dB	5 sentences
-9 dB	5 sentences	-18 dB	5 sentences	-9 dB	5 sentences
-3 dB	5 sentences	-12 dB	5 sentences	-15 dB	5 sentences
-15 dB	5 sentences	-6 dB	5 sentences	-21 dB	5 sentences
Block 2					
SNR	Normal	SNR	Cataract	SNR	AO
-6 dB	5 sentences	-15 dB	5 sentences	-12 dB	5 sentences
-18 dB	5 sentences	-21 dB	5 sentences	-6 dB	5 sentences
-12 dB	5 sentences	-3 dB	5 sentences	0 dB	5 sentences
0 dB	5 sentences	-9 dB	5 sentences	-18 dB	5 sentences

Notes: Experimental testing was divided into two blocks. Each of visual conditions (auditory-only (AO), cataract audiovisual, and normal audiovisual) was presented in each block and randomized. Group A SNRs (-21, -15, -9, & -3 dB) and Group B SNRs (-18, -12, -6, & 0 dB) were randomized in each visual condition and counterbalanced. Five sentences were presented for each visual condition and SNR.

Results

Participants' responses were scored using the aforementioned scoring criterion, described in Study 1, by a second experimenter who was masked to the experimental conditions. Table 15 shows mean speech intelligibility and calculated visual enhancement scores as a function of SNR and visual condition.

TABLE 15

AVERAGE SPEECH INTELLIGIBILITY AND VISUAL ENHANCEMENT BY VISUAL CONDITION AND SNR

SNR	Auditory-only	Cataract Audiovisual	Normal Audiovisual	Cataract VE	Normal VE
0 dB	.76 (.18)	.88 (.11)	.91 (.10)	.12 (.18)	.15 (.17)
-3 dB	.62 (.16)	.75 (.13)	.82 (.17)	.13 (.17)	.20 (.17)
-6 dB	.42 (.18)	.59 (.19)	.67 (.21)	.17 (.24)	.25 (.22)
-9 dB	.21 (.10)	.39 (.17)	.53 (.14)	.18 (.16)	.32 (.14)
-12 dB	.10 (.05)	.22 (.14)	.29 (.17)	.12 (.12)	.19 (.15)
-15 dB	.03 (.03)	.11 (.09)	.22 (.12)	.08 (.10)	.19 (.13)
-18 dB	.02 (.03)	.06 (.06)	.09 (.09)	.04 (.07)	.07 (.10)
-21 dB	.00 (.01)	.04 (.04)	.04 (.05)	.04 (.04)	.04 (.05)

Notes: Participants' speech intelligibility score expressed as mean percent correct and standard deviation (shown in decimal form) for each visual condition and SNR. The last two columns display the calculated visual enhancement (VE) score from Equation 1.

The results indicated that intelligibility, expressed as the percentage of key words correctly reported by participants (shown in Figure 21), improved as the SNR improved and that performance was best under the normal vision relative to the cataract and the auditory only condition (AO) which in turn was worse than the cataract viewing condition. These results also offer support for Hypothesis 3a which predicted that participants would perform best in the best listening condition and performance would decline as the SNR declined.

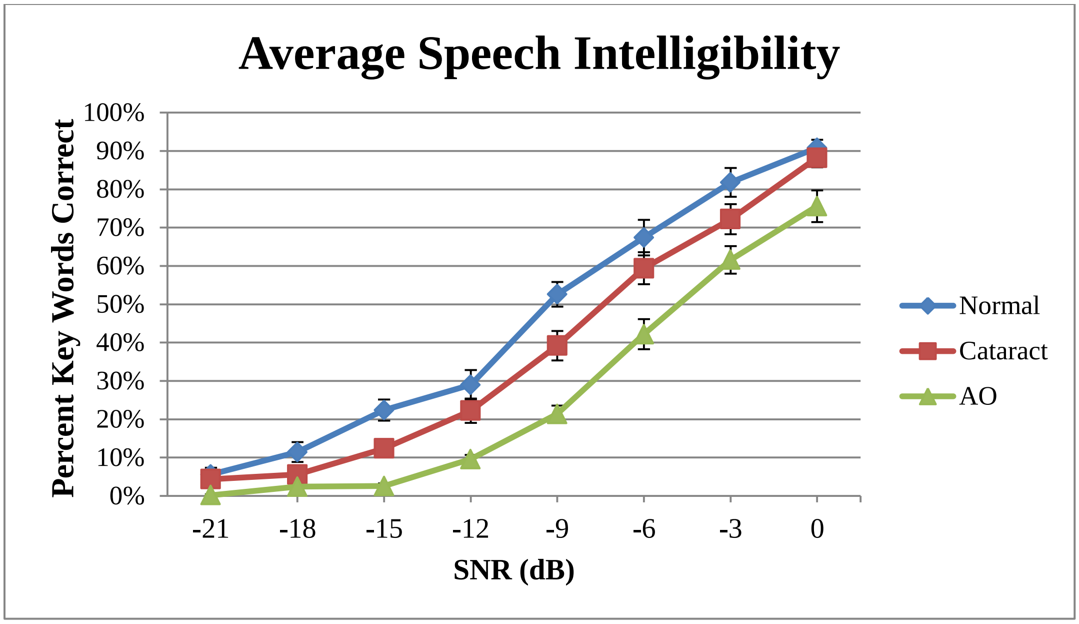

Figure 23. Psychometric functions showing mean speech intelligibility (N=20) for the normal vision, simulated cataract and auditory-only (AO) viewing conditions as a function of SNR. Error bars in the figure represent standard error.

A 2x8 within-subjects analysis of variance (ANOVA) was conducted to evaluate the effect of visual condition and SNR on visual enhancement. This analysis tested Hypothesis 3c to determine if the simulated cataract lenses resulted in significantly less visual enhancement compared to normal vision. Participants' average visual enhancement for each viewing condition and SNR (shown in Figure 24) was calculated using Equation 1: VE= AV-A to demonstrate gross improvement in speech intelligibility. The within-subjects factors were visual condition with two levels (normal vision and simulated cataract vision) and SNR with eight levels (0, -3, -6, -9, -12, -15, -18, and -21 dB). The ANOVA indicated no significant interaction between visual condition and the level of the SNRs, $F(7, 13) = 2.45$, $p = .08$, $\eta_p^2 = .57$, but indicated a significant main effect for visual condition, $F(1, 19) = 20.42$, $p < .01$, $\eta_p^2 = .52$ and a significant main effect for the SNRs, $F(7, 13) = 14.86$, $p < .01$, $\eta_p^2 = .89$. The results offer support for Hypothesis 3c which predicted that listeners would have significantly less visual enhancement under simulated cataracts compared to normal viewing conditions.

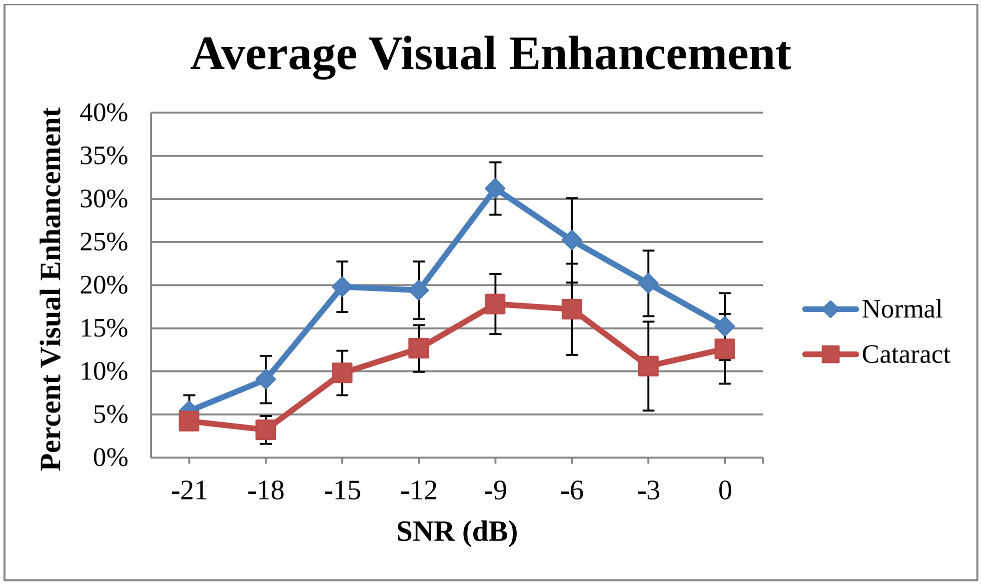

Figure 24. Psychometric functions showing mean VE (N=20) of both normal and simulated cataract viewing conditions as a function of SNR. Error bars in the figure represent standard error.

Paired t-tests were performed comparing VE for the normal and cataract visual conditions at each SNR. Visual enhancement was significantly poorer ($p < .05$) with simulated cataracts than with normal vision at all SNRs except 0 and -21 dB. However, after Bonferroni adjustment ($p \leq 0.006$), significant differences were only found at the -9 dB [$t(19) = 3.74$, $p < .001$, Cohen's $d = 4.10$] and -15 dB [$t(19) = 4.02$, $p < .001$, Cohen's $d = 2.23$] SNRs. The SNR with the largest difference in VE scores (~13.4%) and effect size was -9 dB. These results support Hypothesis 3d that predicted that the difference in performance between normal visual enhancement and simulated cataract visual enhancement would be most pronounced at intermediate SNRs.

The SNR-50 of each audiovisual condition (auditory-only, cataract, and normal vision) were calculated to determine if the cataract SNR-50 was significantly higher than the normal vision SNR-50 as predicted by Hypothesis 3e. The SNR-50s were computed for each participant's speech intelligibility scores within a visual condition across all eight SNRs using the same method described previously. An example of this process is demonstrated in Figure 25 with the data from participant 7. The data from the psychometric function identified participant 14's SNR-50s as: -4.72 dB for auditory-only, -8.87 dB for cataract audiovisual and -10.25 dB for normal audiovisual. Participants' SNR-50 scores are displayed in Table 16.

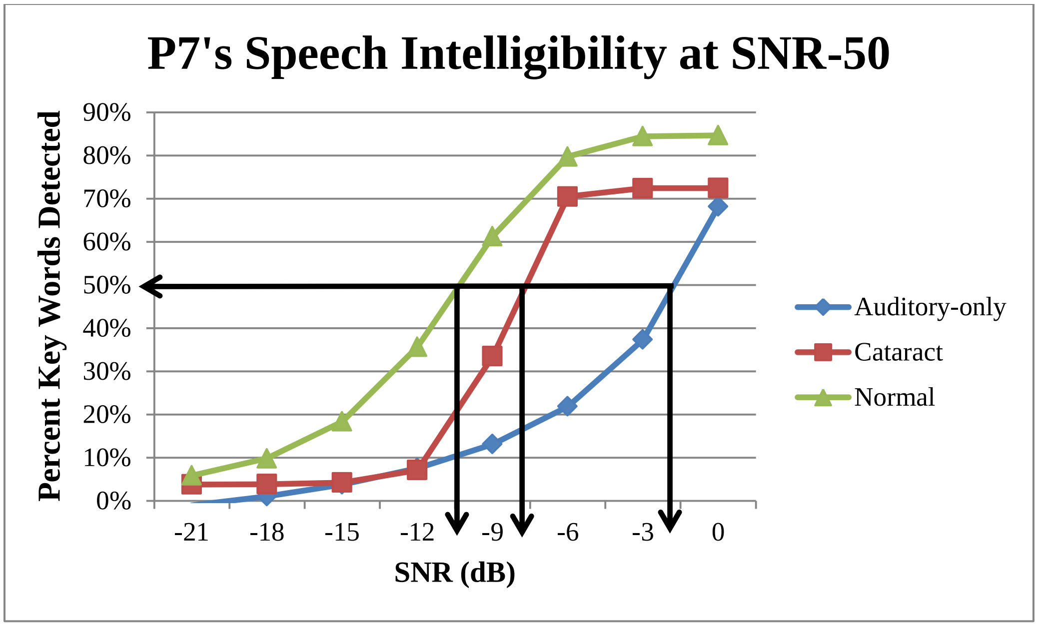

Figure 25. Psychometric functions showing participant 7's normal and simulated cataract speech intelligibility. Arrows in the figure denote the SNR-50 of each visual condition.

TABLE 16

AUDITORY-ONLY, SIMULATED CATARACT, AND NORMAL SNR-50 VALUES

Participant	Auditory-only	Cataract	Normal
1	-4.03	-4.83	-8.98
2	-6.22	-11.86	-10.94
3	-5.53	-6.22	-7.83
4	0.00	-7.02	-8.41
5	-7.95	-7.95	-8.18
6	0.00	-6.45	-5.41
7	-1.49	-8.06	-10.25
8	-4.14	-7.25	-7.02
9	-7.60	-8.06	-10.60
10	-3.34	-7.71	-9.21
11	-5.18	-7.37	-12.90
12	-2.99	-4.37	-6.68
13	-2.30	-1.15	-0.11
14	-4.72	-8.87	-10.25
15	-6.56	-7.48	-11.98
16	-3.45	-9.21	-9.56
17	-5.99	-8.41	-11.06
18	-7.83	-8.52	-8.75
19	-6.45	-7.02	-11.06
20	-4.72	-5.06	-9.10
Average	**-4.52**	**-7.14**	**-8.91**
SD	**2.37**	**2.18**	**2.77**

The average SNR-50 scores demonstrated that participants could, on average, detect speech in an increase of 2.6 dB higher noise under simulated cataract vision to detect it equally as well as auditory-only listening conditions. The average SNR-50 values demonstrated that participants with normal speech intelligibility could, on average, tolerate an increase of noise by4.4 dB compared to auditory-only conditions and an increase 1.8 dB compared to cataract conditions. The results of a paired t test revealed that participants' SNR-50 was significantly higher under cataract audiovisual conditions (-7.14 dB) compared to normal audiovisual conditions (-8.91 dB), $t(19) = 4.02$, $p = .001$, Cohen's $d = .71$.

The audiovisual scores (cataract and normal vision) at the (A)SNR-50 were calculated to determine if speech intelligibility under cataract vision was significantly lower than under normal vision as predicted by Hypothesis 3f. The audiovisual speech intelligibility scores for both normal and cataract vision were identified by referencing the psychometric function data points at the (A)SNR-50. An example of this process is demonstrated in Figure 26 with the data from participant 7. The data from the psychometric function identified participant 7's (A)SNR-50 as -1.49 dB and the AV scores at the (A)SNR-50 as 72.46% for cataract vision and 84.68% for normal vision. Participants' (A)SNR-50 scores and AV scores are displayed in Table 17.

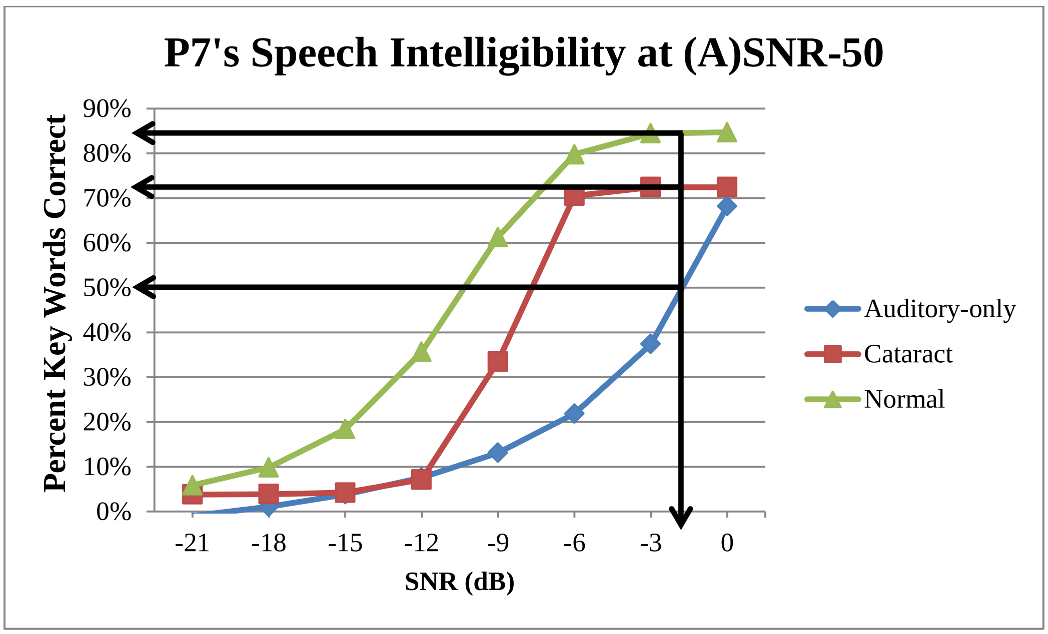

Figure 26. Psychometric functions showing participant 7's auditory-only, normal and simulated cataract speech intelligibility. Arrows in the figure denote the (A)SNR-50 (-1.49 SNR dB) and the AV scores @ the (A)SNR-50.

TABLE 17

NORMAL AND SIMULATED CATARACT SPEECH INTELLIGIBILITY SCORES AT (A)SNR-50

Participant	(A)SNR-50	Cataract	Normal
1	-4.03	58.76%	74.67%
2	-6.22	86.00%	72.48%
3	-5.53	57.03%	75.25%
4	0.00	83.30%	91.42%
5	-7.95	50.15%	51.58%
6	0.00	68.59%	85.99%
7	-1.49	72.46%	84.68%
8	-4.14	80.31%	69.16%
9	-7.60	53.15%	73.72%
10	-3.34	71.05%	73.03%
11	-5.18	64.94%	83.10%
12	-2.99	67.26%	87.68%
13	-2.30	40.36%	24.25%
14	-4.72	86.47%	85.69%
15	-6.56	57.63%	77.54%
16	-3.45	86.66%	79.14%
17	-5.99	77.33%	79.02%
18	-7.83	53.82%	58.54%
19	-6.45	53.33%	82.69%
20	-4.72	51.74%	80.27%
Average	**-4.52**	**66.02%**	**74.50%**
SD	**2.37**	**0.14**	**0.15**

The average speech intelligibility scores at the (A)SNR-50 demonstrate that participants improved their speech intelligibility by looking at the talker's face with normal vision by approximately 24%, but only improved their speech intelligibility by looking at the talker's face with cataract vision by approximately 16%. The results of a paired t test revealed that participants' speech intelligibility was significantly higher under normal audiovisual conditions (74.5%) compared to cataract audiovisual conditions (66.02%), $t(19) = 2.77$, $p = .01$, Cohen's $d = .58$.

A logistic binomial regression was conducted to evaluate how well the visual conditions, SNR manipulations, and screening measures predicted speech intelligibility performance. This was done to test Hypothesis 3b which predicted that participants would have poorer speech intelligibility performance under the simulated cataracts audiovisual conditions than when compared to normal audiovisual conditions. The predictors included in the analysis were the three visual conditions (auditory-only, cataract audiovisual and normal audiovisual), SNR, and six screening measures (age, gender, near and far visual acuity (normal and cataract), contrast sensitivity (normal and cataract), and pure tone threshold averages). The model was built using the same forward inclusion and backward exclusion criterion stated in Study 1B. The null deviance of the speech intelligibility scores in this study was 6681.07 (deviance).

The predictors added to the model that met the criterion through forward inclusion were: visual condition, SNR, age, gender, pure-tone thresholds (better and poorer ear), contrast sensitivity (normal and cataract), far acuity (normal), and near acuity (cataract and normal). Far acuity (cataract) did not meet forward inclusion criterion. Predictors retained in the model after backward elimination were: visual condition, SNR, age, gender, contrast sensitivity (normal), far acuity (normal), and near acuity (cataract and normal). Predictors eliminated from the model through backward exclusion were pure-tone thresholds (better and poorer ear), and contrast sensitivity (cataract). The analysis compared performance under the cataract audiovisual and auditory-only conditions to a baseline performance under the normal audiovisual condition. The resulting residual deviance was 978.45 (residual deviance = 978.45, null deviance = 6681.07, and AIC = 2201.1.). The results of the regression analysis are displayed in Table 18.

TABLE 18

COEFFICENTS IDENTIFIED AS PREDICTORS OF PERFORMANCE

Coefficients	B weights	Std. Error	z value	p value
(Intercept)	5.16	0.58	8.89	< .001
Auditory-only	-1.32	0.06	-20.70	< .001
Cataract Audiovisual	-0.47	0.06	-7.88	< .001
Contrast Sensitivity: Normal	-1.89	0.32	-5.91	< .001
Gender	0.65	0.08	8.05	< .001
SNR	0.27	0.00	54.99	< .001
Near Acuity: Normal	0.05	0.01	7.08	< .001
Far Acuity: Normal	-0.02	0.01	-4.08	< .001
Age	-0.01	0.00	-2.82	< .01
Near Acuity: Cataract	-0.01	0.00	-1.93	0.05

Notes: Results of the logistic binomial regression analysis. Predictors (coefficients) of speech intelligibility performance are listed on the left.

The visual condition (normal, cataract, and auditory-only) was an important predictor of speech intelligibility performance. Participants performed significantly poorer under the auditory-only condition compared to the normal audiovisual condition ($p < .001$; â = -1.32). Participants were also significantly impaired at the task when their vision was degraded by the cataract simulation lenses ($p < .001$; â = -0.47). The model predicts that speech intelligibility will decline once participants' vision is completely occluded (auditory-only) or partially degraded (simulated cataract vision).

Participants' contrast sensitivity score under normal vision was the largest predictor of speech intelligibility performance ($p < .001$; â = -1.89) showing that better contrast sensitivity predicted poorer performance. It is unclear why participants with poorer normal contrast sensitivity are predicted to have better speech intelligibility scores. This may be due to a lack of variability in the normal contrast sensitivity scores of Study 3, since most participants scored between 1.8 and 1.95 on the Pelli-Robson Contrast Sensitivity test.

Gender was found to be a significant predictor of speech intelligibility performance ($p < .001$; â = .65). These results indicate that female participants tended to perform with better accuracy at the speech intelligibility task than male participants. These findings support the gender difference previously observed in Study 1 and 2, which also found females to outperformed males at the task.

Signal-to-noise ratio was a significant predictor of speech intelligibility performance ($p < 0.001$; â = .27). Participants' performance declined as the SNR declined and the listening task became more difficult. These results are consistent with Hypothesis 3a which predicted that speech intelligibility would change as a function of SNR, with the best performance at high SNRs and the poorest performance at low SNRs.

Near visual acuity measured under normal viewing conditions was found to also be predictive of speech intelligibility performance; however, the direction of the prediction is opposite to that found in Study 1. Participants with poorer normal near visual acuity tended to perform more poorly than those with better acuity ($p < .001$; â = 0.05). It is unclear why poorer near visual acuity predicts better speech intelligibility performance, but this may be due to little variance and a ceiling effect within this measure (M = 20/26, *SD* = 4.9). The opposite effect of visual acuity on performance was found with normal far acuity and near visual acuity measured with the simulated cataracts ($p < .001$; â = -0.02; $p = .05$; â = -0.01, respectively). Better normal far acuity and near visual acuity with the simulated cataracts were found to be predictive of more accurate performance on the speech intelligibility task.

Older participants were predicted to have poorer speech intelligibility performance than younger participants ($p = .06$; â = -.01). Age was not found to be a significant predictor (although it is marginally significant), but it was found to contribute to the model based on forward inclusion/backward exclusion criterion. This finding differs from Study 1B which found older participants tended to outperform younger participants, but is consistent with the findings of Study 2.

Discussion

The results of this study demonstrated that the simulated cataracts impaired participants' ability to use visual cues to support speech intelligibility in noise. The wide range of SNR allows us to observe changes in speech intelligibility that varied over almost its entire range (0-90% correct).

Hypothesis 3c was supported by the data which showed that participants had significantly less visual enhancement under the simulated cataracts compared to normal viewing conditions. A SNR of -9 dB produced the greatest difference in visual enhancement (13.4%) between the normal (31.2%) and simulated cataract conditions (17.8%). This is consistent with Hypothesis 3d which predicted that the difference between normal and cataract visual enhancement would be most pronounced at intermediate SNRs. This difference was larger than the difference observed in Study 1B which found only a 6.29% difference between normal and cataract visual enhancements. These studies used the same cataract simulations and were comparable in talker luminance. Study 3 differs in that it used a recorded presentation and it tested participants over a range of SNRs. The recorded presentation added internal reliability to the study by providing consistent speech stimuli. This consistency reduced noise and variance of the data due to talker inconsistency. Additionally, the range of SNRs allowed participants' speech intelligibility to be collected over a wider range to capture the noise level that required the maximal contribution of vision. There may have been some loss to external validity between Study 1B and Study 3 by using a recorded presentation; however, the trade-off between external validity and internal reliability must be evaluated and weighed in every experiment and we consider the gain in internal reliability to be necessary.

The maximum difference between simulated cataract and normal visual enhancement was 13.4% at the -9 dB SNR. This result is consistent with Study 2 despite differences in the density of the two cataract simulations. The density of the simulations in Study 2 degraded participants' vision to an average of 20/80 and the milder simulations in Study 3 only degraded participants' visual acuity to 20/32. It is likely that the decreased luminance of the television is the reason that a similar level of degradation to speech intelligibility, like that of Study 2, was observed with a milder cataract. It is possible, however, that the visual system which supports visual speech perception is robust against further declines of visual acuity and contrast sensitivity and that the magnitude in the difference between the two visual conditions will remain constant regardless of cataract density. The results do not reveal whether participants experience visual enhancement from a more dense cataract, like that used in Study 2, when the audiovisual speech stimuli is presented on a LCD television with the luminance controlled to a naturalistic level of a real talker's face. This was investigated in Study 4.

The SNR-50 scores demonstrated that participants can tolerate a background noise increase of 4.4 dB with normal vision and 2.6 dB with cataract vision over auditory only conditions to be able to detect speech at threshold (i.e. SNR-50). The 1.49 dB increased tolerance to background noise under normal visual conditions compared to cataract visual conditions was found to be statistically significant. Additionally, the audiovisual scores at (A)SNR-50 were shown to significantly differ with cataract vision performance at 66.02% and normal vision performance at 74.05%. These results demonstrate that individuals may only experience a modest increase to speech intelligibility by viewing a talker's face with cataract vision.

The logistic binomial regression demonstrated that the simulated cataracts led to poorer speechreading performance than normal viewing conditions and showed which participant demographic information was predictive of speech intelligibility performance. Visual condition (normal, cataract, or auditory-only) was the best predictor of speech intelligibility performance. The normal audiovisual condition was the most predictive of accurate speech intelligibility, simulated cataract audiovisual conditions was less predictive of good speech intelligibility, and the auditory-only condition was the least predictive of good speech intelligibility performance.

Contrast sensitivity was a significant predictor of speech intelligibility performance. Participants with better contrast sensitivity had higher speech intelligibility scores when they wore the cataract simulation glasses and when their vision was masked. The results of both the contrast sensitivity test and the speech intelligibility test (measured in auditory-only and cataract conditions) demonstrate the importance of detecting small differences in contrast for speechreading. Unlike Study 2, participants' contrast sensitivity scores measured with the simulated cataract were not predictive of speech intelligibility in Study 3. Better near visual acuity measured both under cataract conditions and better normal far acuity was predictive of good speech intelligibility performance, but was not as predictive as contrast sensitivity. The near acuity measure may become more predictive of speech intelligibility in a larger population that has a larger range in near acuities. SNR was also a predictor of speech intelligibility performance. The results demonstrated that participants' performance declined in all three visual conditions (auditory-only, cataract and normal audiovisual) as the background babble increased.

Similar to Study 2, the results of Study 3 showed that participants' age was a predictor of speech intelligibility performance even though the age range was rather small (18 to 38 years). Study 2's older participants did worse than younger participants on the speech intelligibility task. This finding differs from Study 1B which found older participants tended to outperform younger participants, but is consistent with the findings of Study 2. This difference may be due to a wider age range in Study 3 (18-38 yrs, M = 24.9 and *SD* = 7.05) and Study 2 (18-37 yrs, M = 20.45 and *SD* = 4.47) compared to Study 1 (18-31 yrs, M = 22.5 and *SD* = 3.61). These results are consistent with the findings of Grant and Seitz (2000) who found older adults have more difficulty understanding speech in noise. These results are surprising considering the small age range of participants in this study, but consistent with the other studies. The age of the older adults in the Grant and Seitz study do not match the age of the "older" participants in this study; however, these results may show that the continuum of the effect of age on speech intelligibility in noise starts in early adulthood.

Gender was a significant predictor with women performing better than their male counterparts. This is consistent with past studies that have found women to be superior speechreaders to men (Daly et al., 1996; Dancer et al., 1994; Johnson et al., 1988). There was no interaction, however, between gender and visual condition, meaning that men did worse overall at the speech intelligibility task (auditory-only, cataract and normal audiovisual conditions), not simply the conditions that included speechreading. Gender was also found to be a significant predictor of speech intelligibility (i.e. female participants performed more accurately than male participants) in Study 1B.

Study 4:

Effects of Simulated Severe Cataracts on Speech Intelligibility using a Luminance-Controlled Presentation

The results of Study 3 demonstrated that mild cataracts, which degraded visual acuity to an average of 20/32, significantly impaired speechreading. These results are consistent with the results of Study 1, which also found an effect of mild cataracts on speechreading. The results of Study 2 revealed a modest detrimental effect of a severe cataract on performance. This was hypothesized to be due to the LCD television which presented the talker's face nearly 100 times brighter than the talker's real face in Study 1. The luminance controlled television in Study 3 offered some insight regarding the interaction between the effects of simulated cataracts and the brightness of a talker's face on speechreading. The effects of simulated severe cataracts on speechreading were revisited in this study using a controlled luminance LCD television.

The purpose of Study 4 was to examine the effects of simulated severe cataracts on speech intelligibility at a fixed luminance level. The experimental design was identical to Study 3 with the exception of using a denser simulated cataract.

Study 4 Hypotheses

a) Speech intelligibility will vary as a function of SNR, with the best performance at high SNRs and poorest performance at low SNRs.
b) Participants' speech intelligibility scores for the simulated cataract audiovisual conditions and for the auditory-only conditions will not differ.
c) Simulated severe cataracts will significantly reduce visual enhancement compared to the normal vision conditions.

d) The difference in visual enhancement between simulated cataract vision and normal vision will be most pronounced at intermediate signal-to-noise ratios.
e) SNR-50 will be significantly higher for participants under the simulated cataract condition compared to normal vision.
f) SNR-50 will not significantly differ for participants under the simulated cataract condition compared to the auditory-only condition.
g) Participants' speech intelligibility scores at the (A)SNR-50 will be significantly higher under the normal audiovisual condition compared to the cataract audiovisual condition.

Methods

Twenty participants (18-35 yrs, M = 23.5, 10 males and 10 females) with normal or corrected-to-normal vision, no history of hearing loss, and who spoke Mainstream American-English were recruited through the online university recruitment site and received course credit for their participation. All participants had normal sensory functioning as determined by standard screening measures of visual (contrast sensitivity and acuity) and auditory functioning (pure tone hearing screening). Participant screening results are shown in Table 19.

TABLE 19

MEAN SCREENING SCORES

	Average	Std. Deviation
Far Acuity- OU		
Normal	20/15	3.55
Cataract	20/80	24.41
Near Acuity- OU		
Normal	20/25	2.54
Cataract	20/125	26.40
Contrast Sensitivity- OU		
Normal	1.8	.06
Cataract	.45	.11
Pure Tone Average- BE	3.08 dB	2.66
Pure Tone Average- PE	4.83 dB	3.58

Notes: Group mean scores and standard deviation for binocular (OU) near and far visual acuity and contrast sensitivity measured under both normal and simulated cataract conditions. Participants' pure tone average (and standard deviation) hearing thresholds in better ear (BE) and poorer ear (PE).

Procedure

Participants wore one of two pairs of glasses for each of the experimental conditions including: frames without lenses for the normal vision and auditory-only condition (color coded white) and frames with Vistech™ cataract simulation filters with an additional filter (color coded black). A black opaque piece of fabric was used to cover the face of the televised talker in the auditory-only condition. The cataract simulation glasses reduced participants' visual acuity to an average of 20/80 from 20/15 under normal viewing conditions. The simulation glasses reduced contrast sensitivity measured using the Pelli-Robson Contrast Sensitivity Chart from a mean score of 1.85 under normal viewing conditions to a mean score of .45 under the cataract simulation condition. Unless otherwise stated the experimental protocol was as identified in Study 3.

Results

Participants' responses were scored by a second experimenter who was masked to the experimental conditions under which the data were collected using the aforementioned scoring criterion, described in Study 1. Average speech intelligibility and visual enhancement for each visual condition and SNR was calculated across all participants, shown in Table 20.

TABLE 20

AVERAGE SPEECH INTELLIGIBILITY AND VISUAL ENHANCEMENT BY VISUAL CONDITION AND SNR

SNR	Auditory-only	Cataract Audiovisual	Normal Audiovisual	Cataract VE	Normal VE
0 dB	.80 (.17)	.77 (.17)	.86 (.09)	-.03 (.19)	.06 (.13)
-3 dB	.60 (.16)	.70 (.14)	.84 (.13)	.10 (.23)	.24 (.20)
-6 dB	.39 (.17)	.38 (.14)	.76 (.12)	-.01 (.19)	.37 (.18)
-9 dB	.24 (.17)	.25 (.14)	.55 (.23)	.01 (.19)	.31 (.19)
-12 dB	.13 (.08)	.15 (.13)	.36 (.20)	.02 (.14)	.23 (.21)
-15 dB	.05 (.04)	.05 (.04)	.21 (.14)	-.00 (.05)	.16 (.13)
-18 dB	.03 (.05)	.04 (.04)	.14 (.11)	.01 (.06)	.11 (.12)
-21 dB	.01 (.02)	.01 (.01)	.10 (.10)	-.00 (.02)	.09 (.11)

Notes: Participants' speech intelligibility score expressed as mean percent correct and standard deviation (shown in decimal form) for each visual condition and SNR. The last two columns display the calculated visual enhancement (VE) score from Equation 1.

Figure 27 shows the mean intelligibility, expressed as the percentage of key words correctly reported by participants, under the three viewing conditions. Consistent with Hypothesis 4a, performance was best under the highest SNR and showed a systematic decline as the SNR was reduced. Accuracy was highest for the normal audiovisual condition and markedly lower for cataract audiovisual and auditory-only conditions.

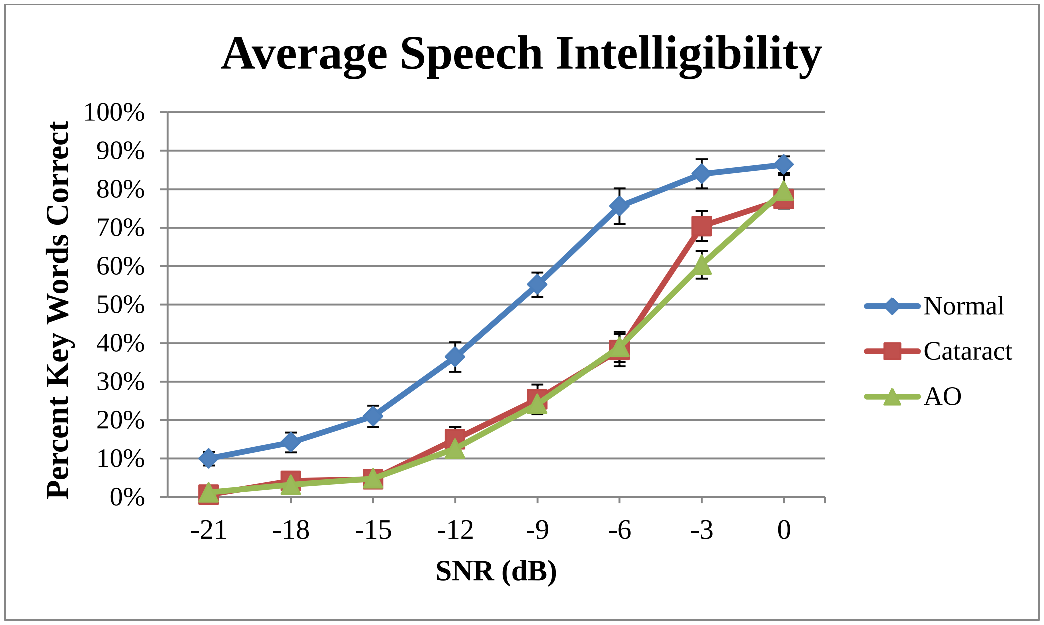

Figure 27. Psychometric functions showing mean speech intelligibility (N=20) for the normal vision simulated cataract and auditory-only (AO) viewing conditions as a function of SNR. Error bars in the figure represent standard error.

A 2x8 within-subjects analysis of variance (ANOVA) was conducted to evaluate the effect of visual condition and SNR. This analysis was used to test Hypothesis 4c to determine if the simulated cataract lenses affected visual enhancement at different SNRs. Participants' average visual enhancement for each viewing condition and SNR was calculated using Equation 1: VE= AV-A (shown in Figure 28) to demonstrate gross improvement in speech intelligibility. The within-subjects factors were visual condition with two levels (normal vision and simulated cataract vision) and SNR with eight levels (0, -3, -6, -9, -12, -15, -18, and -21 dB). The ANOVA indicated a significant interaction between visual condition and the level of the SNRs, $F(7, 13) = 6.14$, $p < .01$, $\eta_p^2 = .77$. The ANOVA also indicated a significant main effect for visual condition, $F(1, 19) = 125.09$, $p < .001$, $\eta_p^2 = .87$ and a significant main effect for the level of the SNRs, $F(7, 13) = 3.72$, $p = .02$, $\eta_p^2 = .67$.

To further investigate the interaction between SNR and visual condition, eight paired t-tests were computed for all SNRs between normal visual enhancement and simulated cataract visual enhancement. Visual enhancement was significantly poorer with simulated cataracts (all $p < .01$) than with normal vision at all SNRs, except 0 dB SNR. These differences remained significant after Bonferroni adjustment ($p \leq .006$) except the 0 dB SNR. The largest difference in VE for normal and simulated cataracts was found at -6 dB [$t(19) = 9.95$, $p < .001$, Cohen's $d = 2.04$] and -9 dB [$t(19) = 6.14$, $p < .001$, Cohen's $d = 1.57$] SNRs, with a difference of 38% and 30%, respectively. These SNR also had the largest effect sizes, compared to other SNRs. These results are consistent with Hypothesis 4d that predicted that the difference in performance between normal visual enhancement and simulated cataract visual enhancement would be most pronounced at intermediate SNRs.

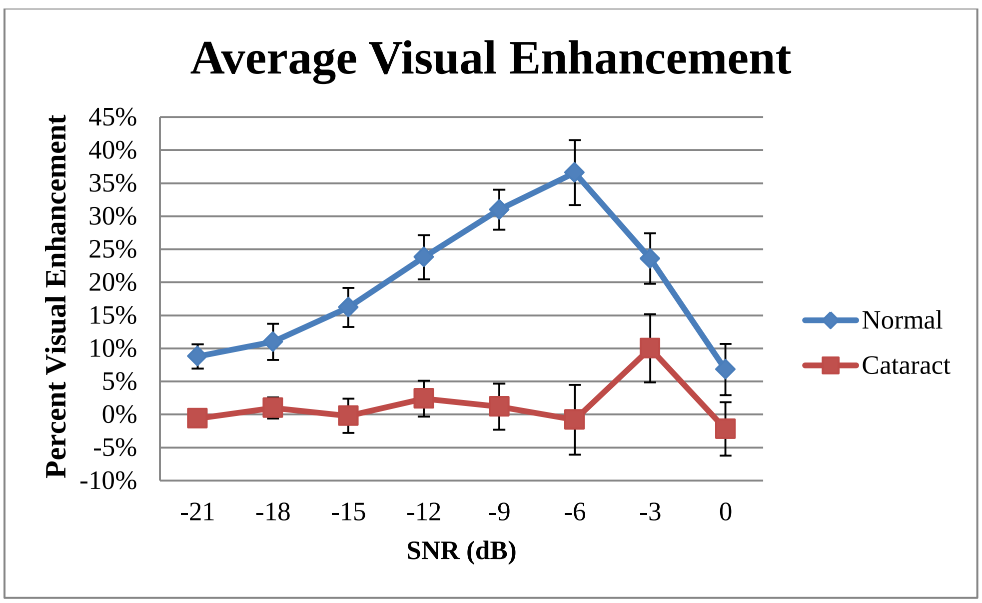

Figure 28. Psychometric functions showing mean VE (N=20) of both normal and simulated severe cataract viewing conditions as a function of SNR. Error bars in the figure represent standard error.

The SNR-50 of each audiovisual condition (auditory-only, cataract, and normal vision) were calculated to determine if the cataract SNR-50 was significantly higher than the normal vision SNR-50 as predicted by Hypothesis 4e. This also helped to determine if the cataract and auditory-only SNR-50s did not significantly differ as predicted by Hypothesis 4f. The SNR-50s were computed as per the procedures described previously. An example of this process is demonstrated in Figure 29 with the data from participant 12. The data from the psychometric function identified participant 12's SNR-50s as: -4.60 dB for auditory-only, -4.71 dB for cataract audiovisual and -10.71 dB for normal audiovisual. Participants' SNR-50 scores are displayed in Table 21.

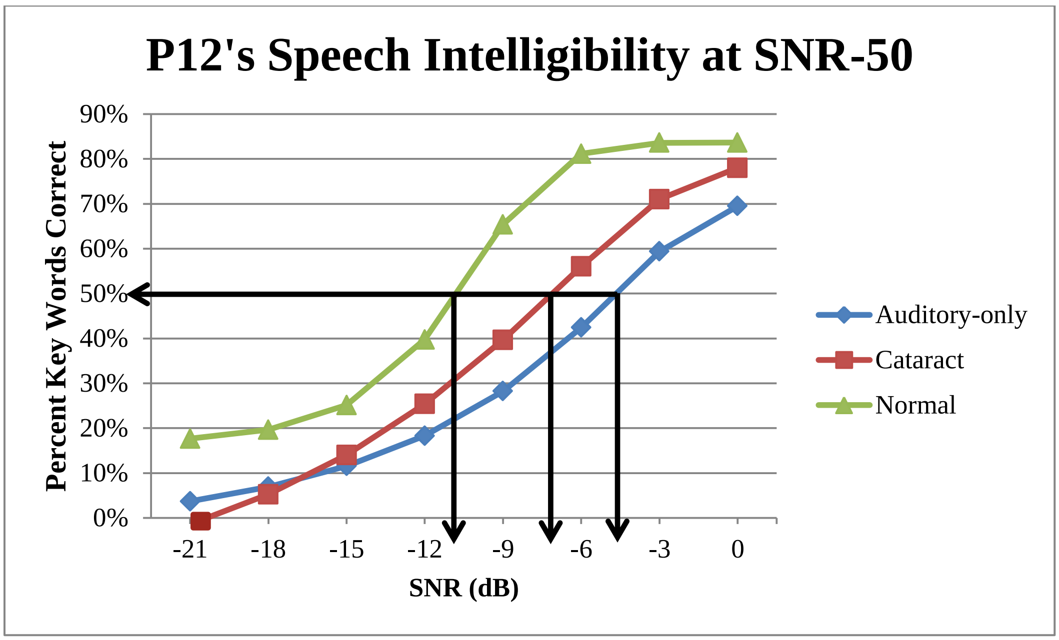

Figure 29. Psychometric functions showing participant 12's normal and simulated cataract speech intelligibility. Arrows in the figure denote the SNR-50 of each visual condition.

TABLE 21

AUDITORY-ONLY, SIMULATED CATARACT, AND NORMAL SNR-50 VALUES

Participant	Auditory-only	Cataract	Normal
1	-2.88	-4.72	-4.03
2	-3.45	-5.53	-9.79
3	-3.80	-2.76	-8.29
4	-7.25	-7.37	-9.90
5	-5.18	-0.11	-9.67
6	-5.99	-2.53	-8.75
7	-4.37	-5.53	-11.63
8	-8.06	-6.68	-15.55
9	-5.29	-4.14	-10.37
10	-0.11	-5.53	-6.22
11	-4.83	-4.72	-9.56
12	-4.60	-7.02	-10.71
13	-8.06	-5.99	-11.29
14	-3.45	-6.68	-9.21
15	-2.07	0.00	-5.76
16	-5.53	-4.83	-10.60
17	-6.22	-6.45	-11.86
18	-4.26	-5.06	-7.25
19	0.00	-6.45	-11.06
20	-2.88	-5.41	-13.02
Average	**-4.41**	**-4.87**	**-9.73**
SD	**2.22**	**2.08**	**2.61**

The average SNR-50 scores demonstrated that participants under cataract conditions could, on average, tolerate an increase in noise of 0.46 dB compared to auditory-only listening conditions. The average SNR-50 scores demonstrated that participants under normal vision could, on average, tolerate an increase in noise of 5.32 dB compared to auditory only conditions and an increase in noise of 4.86 dB compared to cataract vision. The results of a paired t test revealed that participants' SNR-50 was significantly higher under cataract audiovisual conditions (-4.87 dB) compared to normal audiovisual conditions (-9.73 dB), $t(19) = 8.58$, $p < .001$, Cohen's $d = 2.33$, supporting Hypothesis 4e. Additionally, the results of a paired t test revealed that participants' SNR-50 did not significantly differ under cataract audiovisual conditions (-4.87 dB) compared to auditory-only conditions (-4.41 dB), $t(19) = .73$, $p = .47$, Cohen's $d = .21$, supporting Hypothesis 4f.

The audiovisual scores (cataract and normal vision) at the (A)SNR-50 were calculated to determine if speech intelligibility under cataract vision was significantly lower than under normal vision as predicted by Hypothesis 4g. The audiovisual speech intelligibility scores for both normal and cataract vision were identified by referencing the psychometric function data points at the (A)SNR-50. An example of this process is demonstrated in Figure 30 with the data from participant 12. Participant 12's (A)SNR-50 corresponds to a dB value of -4.60. The AV scores at the (A)SNR-50 for cataract vision and for normal vision were 49.27% and 78.28%, respectively. Participants' (A)SNR-50 scores and AV scores are displayed in Table 22.

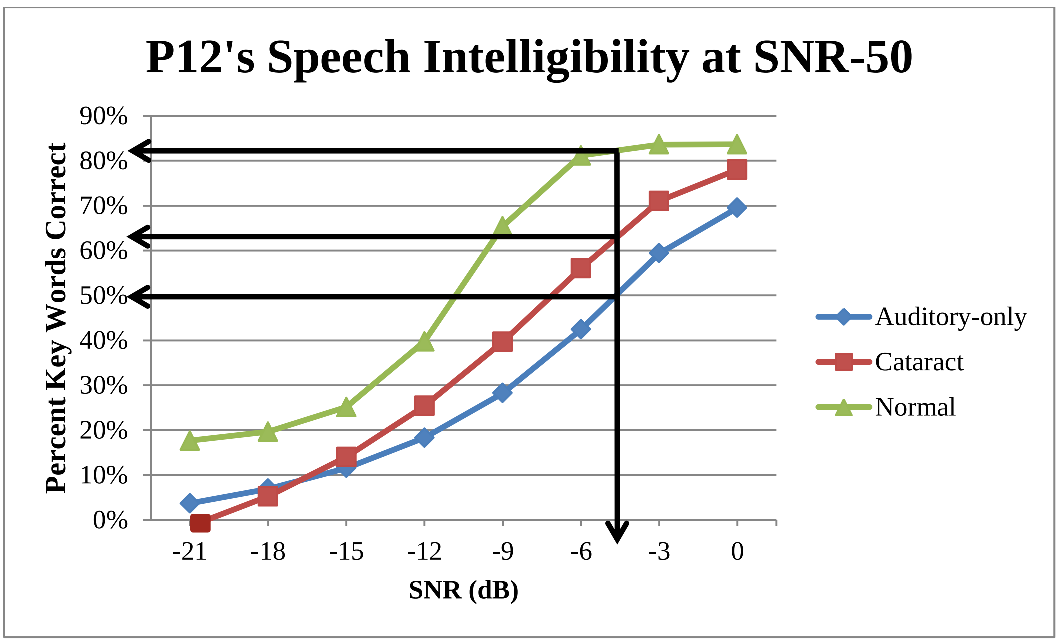

Figure 30. Psychometric functions showing participant 12's auditory-only, normal and simulated cataract speech intelligibility. Arrows in the figure denote the (A)SNR-50 (-4.60 SNR dB) and the AV scores @ the (A)SNR-50.

TABLE 22

NORMAL AND SIMULATED CATARACT SPEECH INTELLIGIBILITY SCORES AT (A)SNR-50

Participant	(A)SNR-50	Cataract	Normal
1	-2.88	69.17%	57.63%
2	-3.45	65.16%	93.39%
3	-3.80	40.82%	76.02%
4	-7.25	52.36%	73.75%
5	-5.18	36.69%	73.83%
6	-5.99	34.24%	76.80%
7	-4.37	64.82%	81.68%
8	-8.06	42.47%	88.70%
9	-5.29	40.19%	78.60%
10	-0.11	78.20%	84.00%
11	-4.83	49.27%	78.28%
12	-4.60	63.52%	83.07%
13	-8.06	40.68%	86.61%
14	-3.45	69.97%	87.54%
15	-2.07	49.53%	72.51%
16	-5.53	42.41%	81.02%
17	-6.22	51.90%	85.02%
18	-4.26	57.54%	69.93%
19	0.00	68.00%	81.43%
20	-2.88	81.73%	97.19%
Average	**-4.41**	**54.93%**	**80.35%**
SD	**2.22**	**14.35%**	**8.80%**

The average speech intelligibility scores at the (A)SNR-50 demonstrate that participants improved their speech intelligibility by looking at the talker's face with normal vision by approximately 30%, but only improved their speech intelligibility by approximately 5% with cataract vision. The results of a paired t test revealed that participants' speech intelligibility was significantly higher under normal audiovisual conditions (80.35%) compared to cataract audiovisual conditions (54.93%), $t(19) = 7.68$, $p < .001$, Cohen's $d = 2.14$.

A logistic binomial regression was conducted to evaluate the predictive power of visual conditions, SNR level, and the screening measures on speech intelligibility performance. This was done to test Hypothesis 4b which predicted that speech intelligibility under the simulated cataracts would not differ significantly from the baseline auditory-only condition. The predictors included in the analysis were the three visual conditions (auditory-only, cataract audiovisual and normal audiovisual), SNR, and six screening measures (age, gender, near and far visual acuity (normal and cataract), contrast sensitivity (normal and cataract), and pure tone threshold averages). The model was built using the same forward inclusion and backward exclusion criterion stated in Study 1B. The null deviance of the speech intelligibility scores in this study was 6453.1 (deviance).

The predictors added to the model that met the criterion through forward inclusion were: visual condition, SNR, age, gender, contrast sensitivity (normal and cataract), far acuity (cataract), and near acuity (cataract). Far acuity (normal), near acuity (normal), and pure-tone thresholds (better and poorer ear) did not meet forward inclusion criterion. Predictors retained in the model after backward elimination were: visual condition, SNR, age, gender, and near acuity (cataract). Predictors eliminated from the model through backward exclusion were: contrast sensitivity (normal and cataract) and far acuity (cataract). To test Hypothesis 4b, the analysis compared performance under the cataract audiovisual and normal audiovisual conditions to a baseline performance in the auditory-only condition. The resulting residual deviance was 1213.7 (residual deviance = 1213.7, null deviance = 6453.1, and AIC = 2436.7). The results of the regression analysis are displayed in Table 23.

TABLE 23

COEFFICENTS IDENTIFIED AS PREDICTORS OF PERFORMANCE

Coefficients	B weights	Std. Error	z value	p value
(Intercept)	-0.21	0.18	-1.18	0.24
Cataract Audiovisual	0.10	0.06	1.65	0.10
Normal Audiovisual	1.38	0.06	22.22	< .001
Gender	0.34	0.05	6.90	< .001
SNR	0.25	0.00	53.46	< .001
Age	0.02	0.00	3.56	< .001
Near Acuity: Cataract	0.01	0.00	6.85	< .001

Notes: Results of the logistic binomial regression analysis. Predictors (coefficients) of speech intelligibility performance are listed on the left.

The visual condition (normal, cataract, and auditory-only) was an important predictor of speech intelligibility performance. The analysis showed that participants performed better under the normal audiovisual condition than under the auditory-only conditions. Additionally, performance under the cataract audiovisual condition and the baseline auditory-only conditions did not differ significantly. Participants performed significantly better in the normal audiovisual condition (p <.001; â = 1.38) compared to the auditory-only condition. There was no significant difference in speech intelligibility performance between the simulated cataract audiovisual conditions and the auditory-only conditions (p =.10; â = .10).

As expected, the SNR was a significant predictor of speech intelligibility performance (p <.001; â = .25). Participants' performance improved as the SNR increased and talker's voice became easier to detect.

Gender was a powerful predictor of speech intelligibility performance (p <.001; â = .322). This result replicates the finding in Study 3 demonstrating that women tended to perform better overall than men. Unlike Study 3, there were an equal number of males (n=10) and females (n=10), which suggests the result of Study 3 was not purely a result of unequal sampling. There was no interaction between gender and visual condition, showing that males and females response similarly to the effect of each visual condition. This suggests that male participants may not have been necessarily worse at speechreading, but they did have poorer performance than females in the speech intelligibility task overall.

Age was again found to be a predictor of speech intelligibility performance ($p < .001$; â = 0.02), but unlike Studies 2 and 3, older participants tended to have better intelligibility performance overall than younger participants, which was consistent across all visual conditions. The age range in this study was slightly more restricted (18-35, M = 23.45, SD = 5.30) than that of Studies 2 and 3. This younger group of participants may not yet exhibit some of the audio-cognitive changes (e.g. auditory sensitivity, susceptibility to distraction, working memory, etc.) that may underlie perception of in speech in noise perception.

Finally, participants' near visual acuity measured under cataract viewing conditions was also a predictor of speech intelligibility performance ($p <.001$; â = 0.01). Participants with poorer cataract near visual acuity tended to have better speech intelligibility overall. This would seem counterintuitive, but this may again be a result a small range and ceiling effect within this measure.

A post-hoc analysis was conducted in order to investigate the effect of talker luminance on speech intelligibility by comparing the scores of Study 4 and Study 2. The two studies were similar except neutral density filters attenuated the luminance of the talker's face. A comparison of the data from each study is shown in Figure 31.

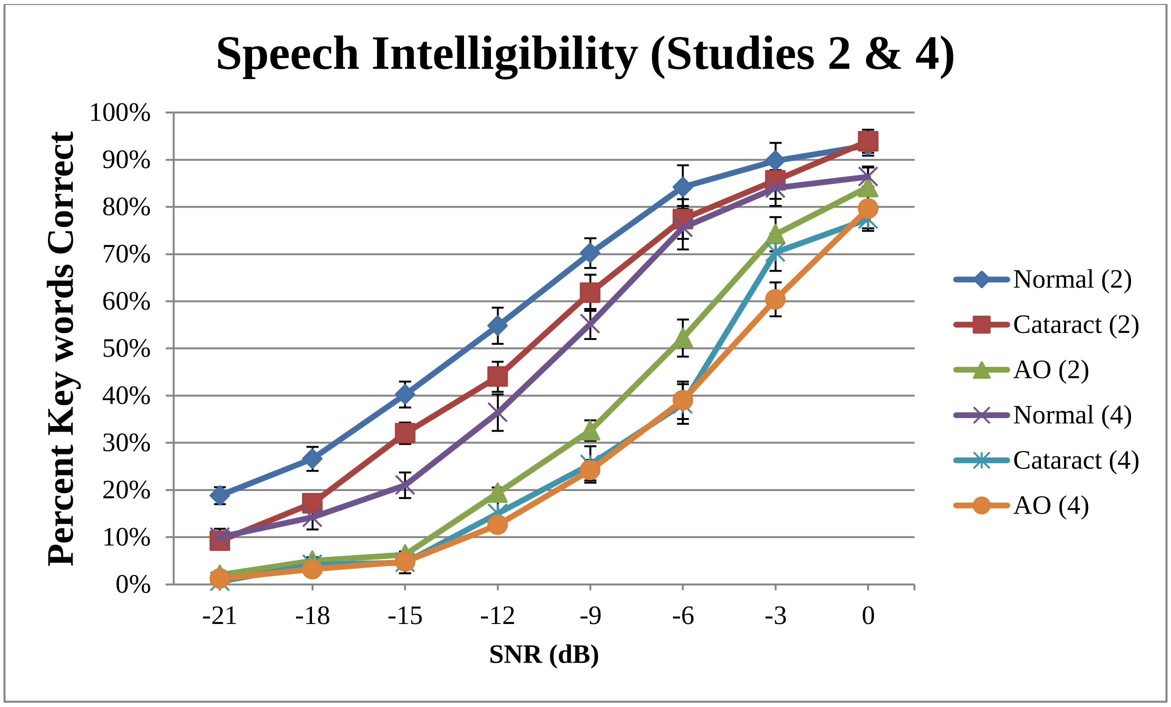

Figure 31. Comparison of average speech intelligibility performance for Study 2 (luminance = 61.3 cd/m^2) and Study 4 (luminance = .69 cd/m^2). Psychometric functions showing mean speech intelligibility for the auditory-only (AO), normal vision, and simulated cataract viewing conditions for Study 2 (N=20) and Study 4 (N=20) as a function of SNR. Error bars in the figure represent standard error.

A logistic binomial regression was conducted on the data for Study 2 and 4 to evaluate how the luminance of the talker's face, the visual conditions, and SNR predicted speech intelligibility performance. Predictors were luminance level (61.3 cd/m^2 for Study 2 and .69 cd/m^2 for Study 4), the three visual conditions (auditory-only, cataract audiovisual and normal audiovisual), and SNR. This was done to determine if speech intelligibility performance, especially that of the simulated cataracts, under controlled luminance was significantly different from baseline unrestricted luminance (Study 2) performance levels. The model was built using the same forward inclusion and backward exclusion criterion stated in Study 1B. The null deviance of the speech intelligibility scores in this study was 13628.8 (deviance).

The predictors added to the model that met the criterion through forward inclusion were: luminance level, visual condition, and SNR. Predictors retained in the model after backward elimination were: luminance level, visual condition, and SNR. No predictors were eliminated from the model through backward exclusion. The analysis compared performance under the auditory-only and cataract audiovisual conditions to a baseline normal audiovisual condition and compared the low luminance level of Study 4 to a baseline high luminance level of Study 2. The resulting residual deviance was 2985.3 (residual deviance = 2985.3, null deviance = 13628.8, and AIC = 5490.6). The results of the regression analysis are displayed in Table 24.

TABLE 24

COEFFICENTS IDENTIFIED AS PREDICTORS OF PERFORMANCE

Coefficients	B weights	Std. Error	z value	p value
(Intercept)	3.20	0.05	63.17	< .001
Auditory-only	-1.49	0.04	-34.67	< .001
Cataract Audiovisual	-0.83	0.04	-20.18	< .001
Luminance (Study 4)	-0.92	0.03	-26.73	< .001
SNR	0.24	0.00	76.77	< .001

Notes: Results of the logistic binomial regression analysis of Study 2 and Study 4. Predictors (coefficients) of speech intelligibility performance are listed on the left.

The results of the regression demonstrated that participants' visual condition was the most predictive of speech intelligibility performance. The analysis established that participants performed poorer under the cataract audiovisual condition (p < .001; â = -0.83) and the auditory-only conditions (p < .001; â = -1.49) compared to the normal audiovisual conditions. The luminance of the televised talker was also related to participants' speech intelligibility performance (p < .001; â = -.92). Participants tended to have poorer performance when the luminance of the talker's face was attenuated with the neutral density filters (i.e. Study 4) compared to the higher luminance television with no filters (i.e. Study 2). The SNR was also a significant predictor of speech intelligibility performance ($p < .001$; â = .269). Performance declined as the SNR declined and the task became more difficult.

Discussion

The results of Study 4 demonstrated that simulated severe cataracts significantly affected participants' ability to use visual cues to support speech perception in noise. The logistic binomial regression and the ANOVA revealed that speech intelligibility and visual enhancement were significantly reduced by the simulated cataract relative to the normal audiovisual condition. The results demonstrated that participants had significantly less visual enhancement with the simulated cataracts than under the normal audiovisual condition at all but one SNR (i.e. 0 dB SNR level). This supports Hypothesis 4c which predicted that participants would have significantly less visual enhancement under cataract conditions than normal viewing conditions. This was seen at nearly all of the SNRs (i.e. except the 0 dB SNR) before the Bonferroni adjustment. The auditory signal at a 0 dB SNR may simply be too easy for this population of young adults to observe any significant differences of visual contributions to speech perception.

Consistent with Hypothesis 4b, we found that the severe cataracts impaired participants' ability to speechread and was comparable to performance under auditory-only conditions. This demonstrates that participants did not benefit from the available visual information seen through the simulated cataracts which degraded their visual acuity to 20/80. This is surprising given that this visual acuity is better than the minimal visual acuity which other authors have argued is necessary to support speech perception. Romano and Berlow (1974) suggested that listeners should be able to benefit from speechreading training as long as their visual acuity were better than 20/200. The decreased luminance of the speech stimuli in Study 4 may have degraded participants visual acuity to be worse than 20/80 under the simulated cataracts. Future research should be conducted to determine participants' visual acuity with the simulated cataracts under the controlled level of luminance used in Study 4.

The SNR-50 scores demonstrated that participants can tolerate a background noise increase of 5.3 dB with normal vision and .5 dB with cataract vision over auditory only conditions to be able to detect speech at threshold (i.e. SNR-50). The 4.85 dB increased tolerance to background noise under normal visual conditions compared to cataract visual conditions was found to be statistically significant, supporting Hypothesis 4e. The small (.5 dB) increase in tolerance to noise observed under the cataract condition compared to the auditory only condition was not found significant, supporting Hypothesis 4f. The results demonstrate that individuals with cataracts may have a similar threshold to speech whether or not they view a talker's face while listening to speech in noise. Additionally, the audiovisual scores at (A)SNR-50 were shown to significantly differ with cataract vision performance at 66.02% and normal vision performance at 74.05%, supporting Hypothesis 4g. These results demonstrate that individuals experience little increase to speech intelligibility by viewing a talker's face with cataract vision.

The regression analysis demonstrated that contrast sensitivity was not predictive of speech intelligibility performance. This may be explained by the fact that luminance conditions of experiment differed from the luminance conditions used to test contrast sensitivity. Additionally, this could stem from a restricted range of the contrast sensitivity scores. It is well known that the contrast sensitivity function changes as function of luminance level, demonstrated in Figure 11. Thus, the contrast sensitivity score measured with the Pelli-Robson Contrast Sensitivity Chart was not a good predictor of the participants' contrast sensitivity under the experimental conditions.

Unlike the previous experiments we found that older participants tended to perform better at the speech intelligibility task than their younger counterparts. This may be a result of differences in the age range of participants across experiments. The age distribution of Study 4 was narrower (M = 23.5, SD = 5.3) than the distribution of Study 3 (M = 24.9, SD = 7.05). The distribution of ages in Study 4 may not have been wide enough to demonstrate the impact of age on speech intelligibility. Gender was again found to be a predictor of speech intelligibility performance, in which females performed better than male participants.

The post-hoc regression analysis demonstrated that the luminance of the televised talker was predictive of speech intelligibility performance and that the simulated severe cataracts were more detrimental to speechreading under the controlled luminance levels of Study 4 than under the high luminance levels of Study 2. The results demonstrated that bright viewing conditions improve individuals' speech intelligibility performance and that individuals with cataracts may experience greater difficulty speechreading under lower luminance conditions.

The results of this study are inconsistent with previous research which had found high levels of blur (i.e. worse than 20/80) had little effect on speechreading performance. Thorn and Thorn (1989) reported that participants' speechreading performance was only modestly degraded by extreme levels of blur (i.e. visual acuity of 20/125 or 4 diopters of blur). This suggests that a severe cataract simulation, which degrades visual acuity to 20/80 should have little impact on speechreading performance. This is consistent with the results of Study 2, which found little impact by severe cataracts on speechreading under high luminance conditions. Similar to Study 2, the results of Thorn and Thorn's study might be dependent on the luminance level of the television used to display the video of the talker. The researchers used a recording of a female talker speaking the CID *Everyday Speech Sentences* presented on a 25-inch color television.

Thorn and Thorn reported that the luminance of an area above the talker's upper lip was 28 cd/m^2. This luminance level is approximately 2 fold lower than the luminance level of the talker's forehead in Study 2 cd/m^2 and considerably brighter than that used in Study 4 (i.e. 0.69 cd/m^2). Two factors may account for their results. First, the higher luminance of their stimulus may counteract the effects of blur. Secondly, Thorn and Thorn used dioptric blur which is known to have less severe effects on vision than the simulated cataract lenses used in this study (Hess & Woo, 1979). It is possible that other studies, which found little effect of blur on speechreading, are also restricted by the televised presentation method of a high luminance television. This should be experimentally examined to determine the degree that viewers are performing well at the audiovisual speech intelligibility tasks under blur because of a tolerance to blur or because of an improvement in vision due to high luminance.

Study 5:

Effects of Simulated Mild Cataracts on Speech Intelligibility at Varying Luminance Levels

The results of Study 3 and Study 4 demonstrated that simulated mild and severe cataracts interfered with participants' speechreading performance at a fixed luminance level of the televised talker. A comparison of the results of Study 2 and Study 4 demonstrated that the higher luminance levels partially ameliorated the effect of the dense simulated cataracts despite their effects on contrast sensitivity and visual acuity. These results are consistent with research demonstrating superior speechreading performance at higher luminance levels (Gagne et al., 2006) and improved sensitivity to contrast differences (De Valois et al., 1974).

The purpose of Study 5 was to investigate how luminance levels affected speechreading performance with a mild cataract. The results of Study 3 showed that simulated mild cataracts significantly reduced participants' ability to perceive visual speech under naturalistic luminance levels; however, previous studies did not test the effects of simulated mild cataracts at higher luminance levels. Mild cataracts were expected to have little effect on speechreading performance at high luminance levels; however, the rate at which speechreading performance (under both normal and mild cataract audiovisual conditions) declines as a function of luminance level had not previously been measured. The aim of this study was to investigate speechreading performance using the simulated mild cataracts at a fixed signal-to-noise ratio (SNR) over a wide luminance range (i.e. 70 cd/m^2 to .004 cd/m^2).

The SNR level (i.e. -9 dB) used in this experiment was carefully chosen to support a baseline of speech intelligibility performance of ~50% thereby minimizing the chance of ceiling or floor effects under the high and low luminance conditions, respectively. As can be seen in Figure 32, at a -9 dB SNR, participants' average auditory-only performance was 32.6% (*SD* =

14%) in Study 2 and 21.4% (*SD* = 10%) in Study 3. The same SNR tested under normal audiovisual conditions resulted in 70.2% (*SD* = 21%) accuracy in Study 2 (high luminance) and 52.6% (*SD* = 14%) accuracy in Study 3 (intermediate luminance).

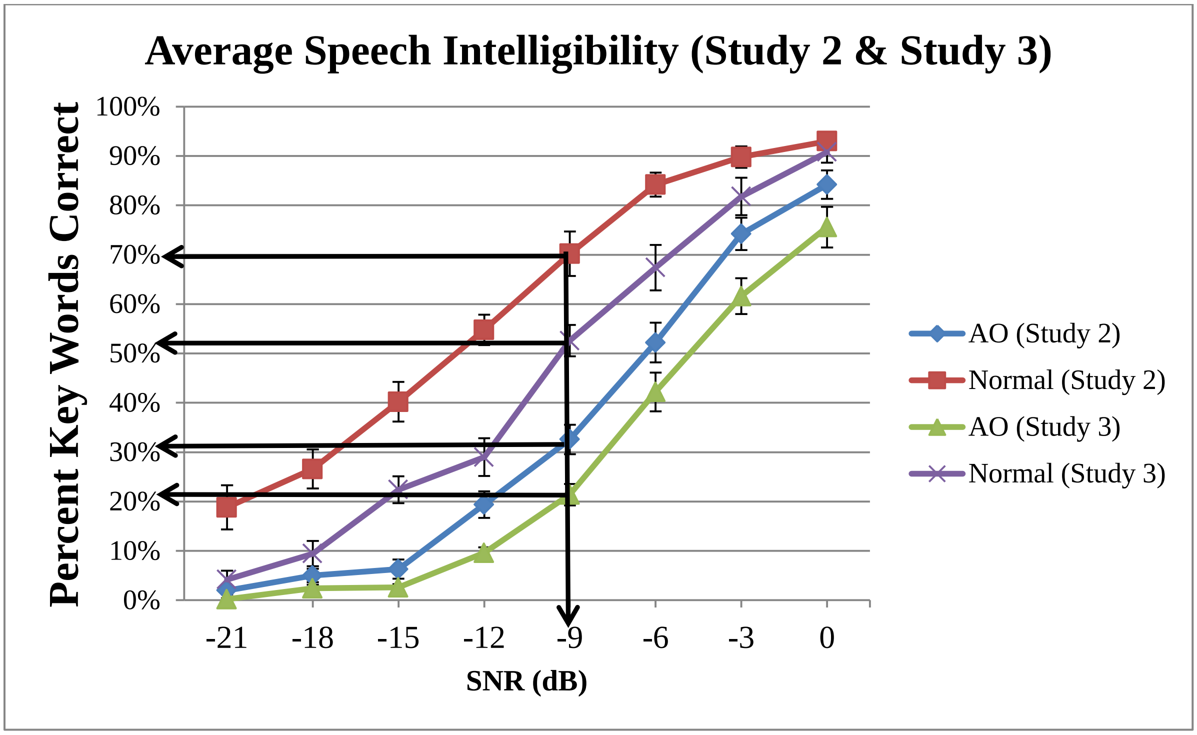

Figure 32. Graph displaying average speech intelligibility performance as a function of SNR from Study 2 (N=20) which was tested under high levels of luminance (61.3 cd/m^2) and Study 3 (N=20) which was tested under lower levels of luminance (.69 cd/m^2) in the auditory-only (AO) and normal audiovisual conditions. The arrows highlight participants' average performance at the -9 dB SNR in each of the four visual conditions.

Study 5 Hypotheses

a) Speech intelligibility will vary as a function of luminance, with better performance at high luminance levels and poorer performance at low luminance levels.

b) Visual enhancement will be significantly reduced by the cataract simulation glasses relative to normal vision.

c) Participants' speech intelligibility scores for normal audiovisual, simulated cataract audiovisual and auditory-only conditions will not differ at low luminance levels.

Methods

Twenty participants (18-40 yrs, *M* = 24.7, 9 males and 11 females) with normal or corrected-to-normal vision, no history of hearing loss and who spoke Mainstream American-English were recruited through the online university recruitment site and received course credit for their participation. All participants had normal sensory functioning as determined by standard screening measures of visual (contrast sensitivity and acuity) and auditory functioning (pure tone hearing screening). Participant screening results are shown in Table 25.

TABLE 25

MEAN SCREENING SCORES

	Average	Std. Deviation
Far Acuity- OU		
Normal	20/15	5.06
Cataract	20/32	9.14
Near Acuity- OU		
Normal	20/25	.52
Cataract	20/40	5.49
Contrast Sensitivity- OU		
Normal	1.85	.06
Cataract	1.25	.11
Pure Tone Average- BE	2.75 dB	2.43
Pure Tone Average- PE	5.25 dB	3.39

Notes: Group mean scores and standard deviation for binocular (OU) near and far visual acuity and contrast sensitivity measured under both normal and simulated cataract conditions. Participants' pure tone average (and standard deviation) hearing thresholds in better ear (BE) and poorer ear (PE).

Procedure

Participants wore one of three sets of glasses for each of the experimental conditions including: frames without lenses for the normal audiovisual condition (color coded white); frames with cataract simulation filters for the cataract audiovisual condition (color coded black) and frames with opaque lenses for the auditory-only condition (color coded brown). The cataract simulation glasses reduced participants' visual acuity to an average of 20/30 from 20/15 under normal viewing conditions. The simulation glasses reduced contrast sensitivity measured using the Pelli-Robson Contrast Sensitivity Chart from a mean score of 1.85 under normal viewing conditions to a mean score of 1.25 under the cataract simulation condition. An extra pair of large opaque glasses was worn by the participant when ND filters were changed. The experimental glasses were arranged on the right side of the writing desk and the protective glasses were laid on the left side of the writing desk to avoid confusion.

This experiment took place in the same sound booth described in Study 1. The layout of the sound booth was the same as described in Study 3. The center of the televised talker's forehead (just above the brow) was measured with a photometer and was found to be approximately 70 cd/m^2. The television under normal conditions (i.e. no neutral density filters) was the highest luminance test condition. The luminance of the television screen was attenuated using neutral density filters producing seven discrete luminance levels. The neutral density filters incrementally reduced the luminance of the television by two log steps (i.e. each additional filter reduced the luminance of the television to a fourth of its previous luminance level). A photometer was used to confirm the effects of the ND filters on the luminance of the screen; however, the luminance level of the two densest filters was calculated because the resulting luminance level was outside the sensitivity range of the photometer. The seven ND filters used and their resulting luminance levels are demonstrated in Figure 33.

The luminance levels of the televised talker used in this study simulated a range of luminance conditions typical of different types of environments. Luminance levels of the real talker's face (used in the video) was measured in several different locations to provide a comparison of the luminance levels used in this study to real world settings, shown in Figure 33. The highest luminance level (70 cd/m^2) is not very representative of normal viewing conditions. Some of the other conditions cover a range of luminance levels ranging from a sunny day to dim restaurant light conditions. The appearance of the televised face at each luminance level is demonstrated in Figure 34.

ND Filters	Luminance Level	Comparison
No Filters	70 cd/m^2	
.6	17.6 cd/m^2	Sunny Day
1.2	4.4 cd/m^2	Office
1.8	1.1 cd/m^2	Home
2.4	.28 cd/m^2	Restaurant
3.0	.07 cd/m^2	Night
3.6	.02 cd/m^2	
4.2	.004 cd/m^2	

Figure 33. The chart demonstrates the eight levels of luminance. The chart shows the neutral density filters (increasing by .6 ND steps), the luminance levels (decreasing by 2 log steps) and a comparison to everyday conversational settings.

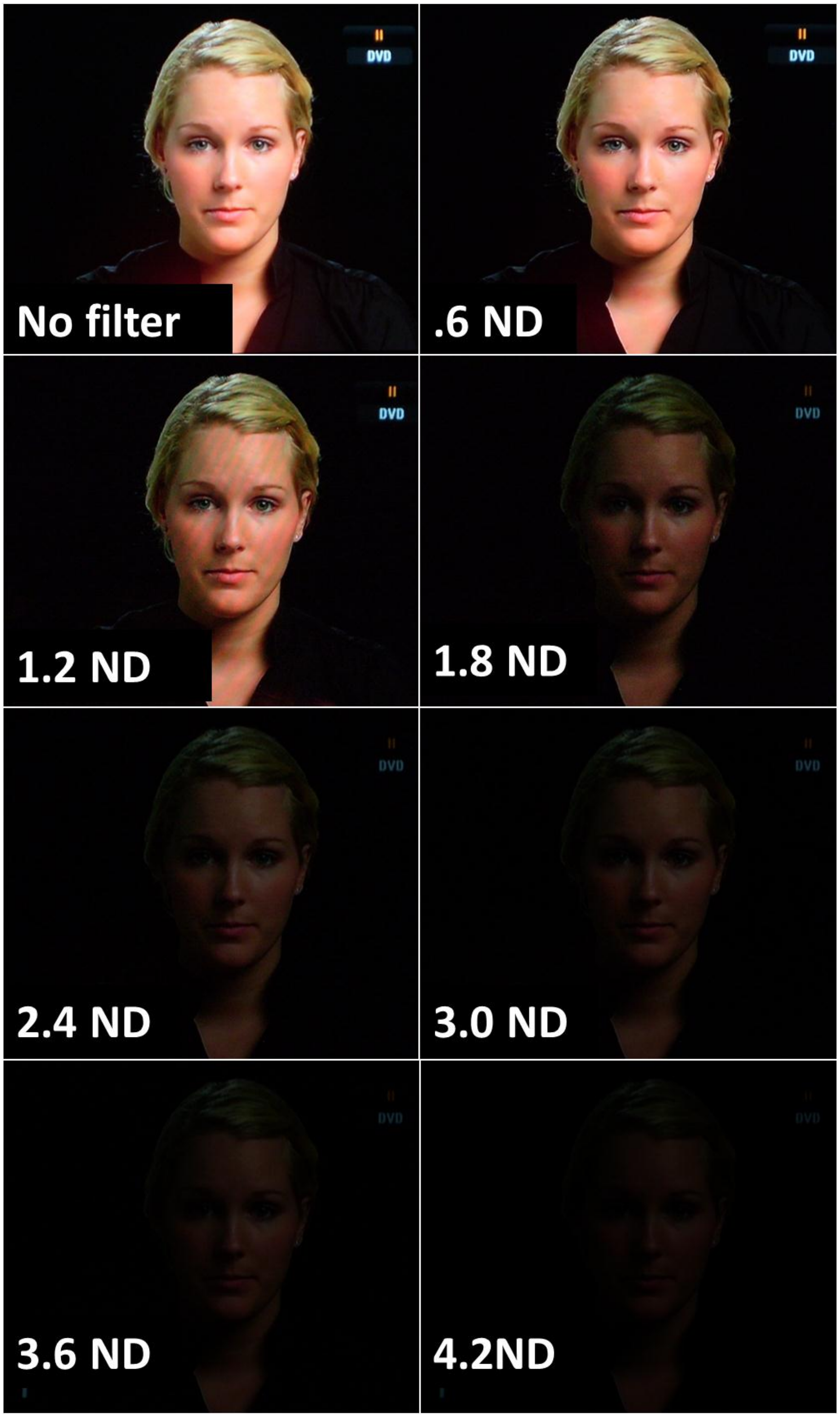

Figure 34. Digital photographs of the WSU recording of the SIN Sentences shown on the LCD television used in Study 5. The images demonstrate the appearance of the televised talker from the highest luminance (No Filter) condition to the lowest luminance (4.2 ND filter) condition.

A set of neutral density filters were stacked upon one another to create the desired density level. The sheets were secured to one another by attaching a ¼ inch square, black, wooden, dowel rod to the top and bottom of each set of sheets and secured with two small black binder clips on each rod. The binder clips were used to hang the filters on two hooks that were fitted at the top of the 32 inch LCD television. When not in use, the filters were hung on the inside walls of the sound booth, each in its own designated place to avoid confusion. The lights of the sound booth and monitoring booth were turned off and the desk lamp with a red-tinted 40 watt bulb and a 10 inch tall, 3 foot long partition were used to prevent light from reflecting off the filters.

Prior to each testing session the participants were dark adapted to the reduced luminance level of the televised talker. The lights of the sound and monitoring booth were turned down to their lowest setting during the hearing screening and when participants were given experiment instructions in order to begin the dark adaptation process (lasting approximately five minutes). The lights of both booths were turned off during the verbal and written practice portions of experimental testing (lasting approximately 10 minutes).

Speech intelligibility was tested while four-person babble was presented through the same two Grason-Stadler loud speakers as used in previous studies. Participants listened and responded to a recording of SIN Sentences presented on a 32 inch LCD television and the audio track played through the television's loudspeaker at 65 dB SPL. Participants were seated approximately 1.4 meters from the television resulting in a visual angle of 4˚ from pupil to pupil of the talker's eyes. A writing desk was placed in front of the participant to allow them to write the sentences. Experimenters monitored participants through a video camera streaming to a television in the monitoring booth outside of the testing booth. Each televised video track was played once the participants indicated they were ready by placing their pencil down and looking up to the television.

Participants were provided instructions, detailed in Appendix E-3, regarding what to expect with the neutral density filters and how to write what they thought the talker said. Participants were presented with two practice sentences and instructed to verbally repeat what they heard the talker say. Additionally, a practice list of six sentences, presented in +5 dB SNR of four-person babble, were presented to allow participants to practice listening and writing sentences under the three visual conditions. The television screen was covered with the 1.8 ND filter during the verbal and written practice sessions. Testing was divided into two blocks. Participants' speech intelligibility under all three visual conditions was tested in each block and four-person babble was played into the booth through the loud speakers at -9 dB SNR. Participants were presented with a 15 sentence set of SIN sentences for each of the luminance levels, totaling eight sets or 120 sentences. Each 15 sentence set was divided into three groups of five sentences each for the three visual conditions (i.e. five sentences for each visual condition). The order of the luminance levels was pseudo-randomized preventing the dimmest and bright luminance level from following one another thereby minimizing the visual discomfort or requiring prolonged adaptation. The luminance levels were divided into two groups: Group A (70, 17.7, 4.4, and 1.1 cd/m^2) and Group B (.28, .07, .02, and .004 cd/m^2). The luminance levels within each group were randomized and the order of group presentation was alternated and counterbalanced across all participants and is demonstrated in Table 26.

TABLE 26

VISUAL AND AUDITORY CONDITIONS BY EXPERIMENTAL BLOCK

Block 1							
Vision	70 cd/m^2	Vision	17.7 cd/m^2	Vision	1.1 cd/m^2	Vision	4.4 cd/m^2
AO	5 sentences	CAT	5 sentences	Norm	5 sentences	CAT	5 sentences
CAT	5 sentences	AO	5 sentences	CAT	5 sentences	NORM	5 sentences
Norm	5 sentences	Norm	5 sentences	AO	5 sentences	AO	5 sentences
Block 2							
Vision	.004 cd/m^2	Vision	.28 cd/m^2	Vision	.07 cd/m^2	Vision	.02 cd/m^2
Norm	5 sentences	AO	5 sentences	CAT	5 sentences	Norm	5 sentences
AO	5 sentences	Norm	5 sentences	Norm	5 sentences	CAT	5 sentences
CAT	5 sentences	CAT	5 sentences	AO	5 sentences	AO	5 sentences

Notes: Experimental testing was divided into two blocks. One of the group luminance levels, i.e. Group A (70, 17.7, 4.4, and 1.1 cd/m^2) and Group B (.28, .07, .02, and .004 cd/m^2) were presented in each block and counterbalanced. Each of visual conditions (auditory-only (AO), cataract audiovisual, and normal audiovisual) was presented under a single luminance level and randomized. Five sentences were presented for each luminance level and visual condition.

Participants were allowed 3-5 minutes to adapt to the new luminance level once a new filter was applied to the television. More time was allotted (i.e. up to 10 minutes) in instances in which the randomization required the luminance to increase by four or more log unit steps in the Group A luminance range (e.g. 1.1 to 70 cd/m^2). Participants were provided a five minute break in between the two test blocks; however, the break took place within the sound booth to maintain the participants' dark adaptation. Participants were told prior to the start of the experiment that the break would take place within the sound booth to maintain dark adaptation and were encouraged to use the restroom or get a drink from the water fountain before they entered the booth. The experiment (including screening and practice sessions) lasted approximately one hour and fifteen minutes.

Results

Participants' responses were scored by a second experimenter who was masked to the experimental conditions under which the data were collected using the aforementioned scoring criterion, described in Study 1. Average speech intelligibility and visual enhancement for each visual condition and luminance level was calculated across all participants, shown in Table 27.

TABLE 27

AVERAGE SPEECH INTELLIGIBILITY AND VISUAL ENHANCEMENT BY VISUAL CONDITION AND LUMINANCE LEVEL

Luminance	Auditory-only	Cataract Audiovisual	Normal Audiovisual	Cataract VE	Normal VE
70 cd/m^2	.22 (.16)	.55 (.19)	.62 (.19)	.33 (.16)	.40 (.22)
17.7 cd/m^2	.20 (.15)	.52 (.23)	.59 (.21)	.32 (.23)	.39 (.21)
4.4 cd/m^2	.25 (.13)	.58 (.20)	.58 (.18)	.33 (.21)	.33 (.16)
1.1 cd/m^2	.21 (.17)	.46 (.16)	.51 (.19)	.25 (.19)	.30 (.15)
.28 cd/m^2	.20 (.16)	.35 (.14)	.45 (.20)	.15 (.13)	.25 (.19)
.07 cd/m^2	.20 (.12)	.22 (.12)	.41 (.14)	.02 (.11)	.21 (.14)
.02 cd/m^2	.23 (.17)	.24 (.17)	.29 (.15)	.01 (.16)	.06 (.19)
.004 cd/m^2	.22 (.14)	.18 (.11)	.19 (.15)	-.04 (.15)	-.03 (.14)

Notes: Participants' speech intelligibility score expressed as mean percent correct and standard deviation (shown in decimal form) for each visual condition and SNR. The last two columns display the calculated visual enhancement (VE) score from Equation 1.

The mean intelligibility, expressed as the percentage of key words correctly reported by participants, under the three viewing conditions is displayed in Figure 35. Participants had the best performance in the normal and cataract audiovisual conditions at the highest luminance levels and performance declined as luminance declined, which supports Hypothesis 5a. Participants' performance under auditory-only conditions averaged about 20% independent of luminance levels. Performance at the high luminance levels was comparable for the normal audiovisual and cataract condition but diverged at intermediate luminance levels before converging again at the lowest luminance levels (i.e. 0.004 cd/m^2). This is consistent with

Hypothesis 5c which predicted that performance would be the same for all three visual conditions at the lowest luminance level.

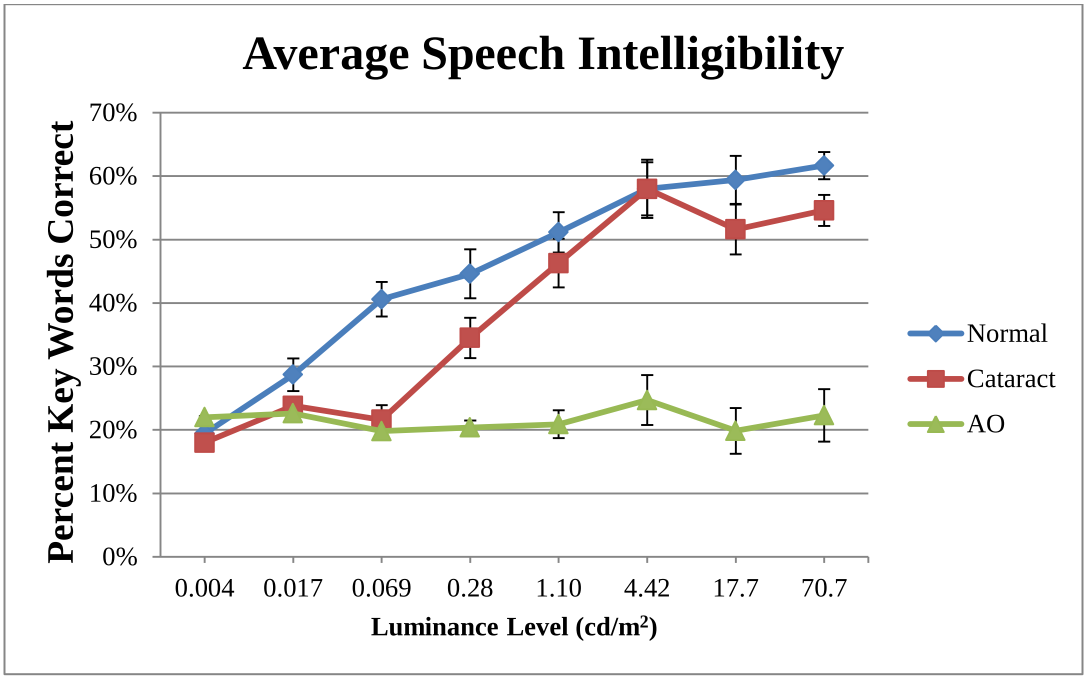

Figure 35. Psychometric functions showing mean speech intelligibility (N=20) for the auditory-only (AO), normal vision, and simulated cataract viewing conditions as a function of luminance level. Error bars in the figure represent standard error.

A 2x8 within-subjects analysis of variance (ANOVA) was conducted to evaluate the effect of visual condition and luminance level. This analysis was used to test Hypothesis 5b to determine if the simulated cataract lenses significantly reduced visual enhancement as luminance declined. Participants' average visual enhancement for each viewing condition and luminance level was calculated using Equation 1: VE= AV-A (shown in Figure 36) to estimate gross improvement in speech intelligibility. The within-subjects factors were visual condition with two levels (normal vision and simulated cataract vision) and luminance with eight levels (70 to 0.004 cd/m^2). The ANOVA indicated a significant interaction between visual condition and luminance level, $F(7, 13) = 3.38$, $p = .03$, $\eta_p^2 = .65$. The ANOVA also indicated a significant main effect for visual condition, $F(1, 19) = 29.19$, $p < .001$, $\eta_p^2 = .61$ and a significant main effect for luminance level, $F(7, 13) = 12.55$, $p < .001$, $\eta_p^2 = .87$.

To further investigate the interaction between the luminance and visual condition on visual enhancement, eight paired t-tests were computed for each luminance level between normal and simulated cataract visual conditions. Visual enhancement did not differ significantly between the simulated cataract and normal vision conditions at the four highest luminance levels (70, 17.7, 4.42, and 1.1 cd/m^2), with the exception of the 17.7 cd/m^2 level, $t(19) = 2.37$, $p = .03$, Cohen's $d = .52$. Large differences were observed between the normal and cataract vision at the four lowest luminance levels (0.28, 0.069, 0.017, and 0.004 cd/m^2). The 0.28 and .068 cd/m^2 luminance levels were found to yield significant differences between participants' normal and cataract visual enhancement, $t(19) = 2.806$, $p = .01$, Cohen's $d = .73$ and $t(19) = 6.722$, $p < .001$, Cohen's $d = 1.54$, respectively. These results are consistent with the Hypothesis 5c which predicted that participants would have less visual enhancement while donning the cataract simulation glasses at intermediate levels of luminance than when donning the control or normal vision lenses and this difference will be significant. The difference with the largest effect size was the .069 cd/m^2 luminance level.

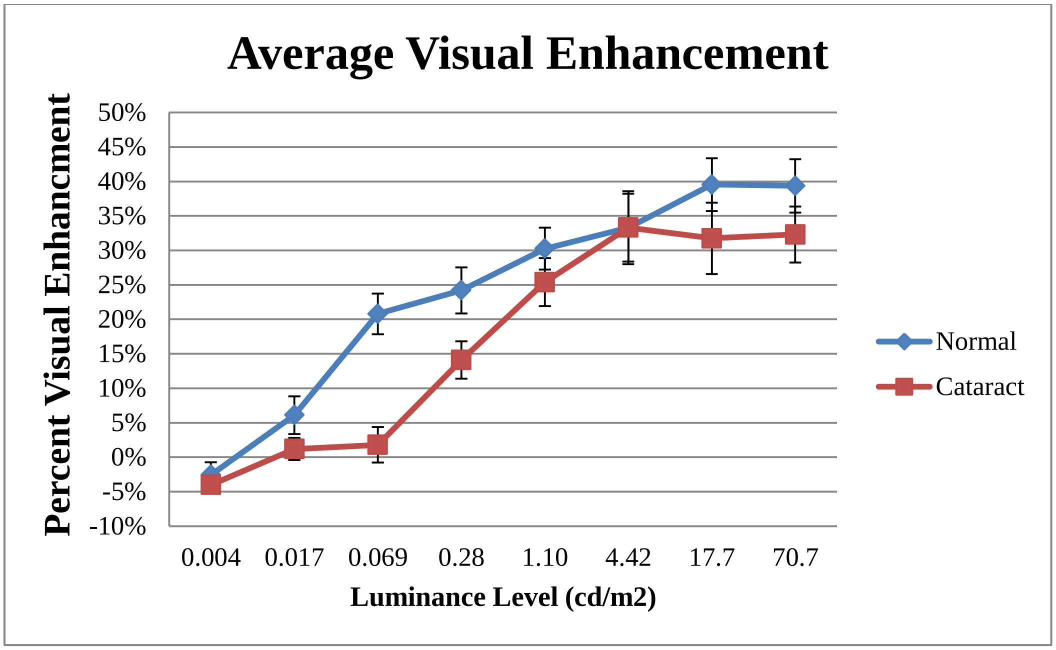

Figure 36. Psychometric functions showing mean VE (N=20) for both normal and simulated severe cataract viewing conditions as a function of luminance level. Error bars in the figure represent standard error.

A logistic binomial regression was conducted to evaluate the predictive power of visual conditions, luminance level, and the screening measures on speech intelligibility performance. This was done to test Hypothesis 5b which predicted that speech intelligibility under the simulated cataracts would significantly differ from the normal vision condition. The predictors included in the analysis were the three visual conditions (auditory-only, cataract audiovisual and normal audiovisual), luminance level, and six screening measures (age, gender, near and far visual acuity (normal and cataract), contrast sensitivity (normal and cataract), and pure tone threshold averages). The model was built using the same forward inclusion and backward exclusion criterion stated in Study 1B. The null deviance of the speech intelligibility scores in this study was 2920.6 (deviance).

The predictors added to the model that met the criterion through forward inclusion were: visual condition, luminance, age, gender, contrast sensitivity (cataract), and pure-tone thresholds (better and poorer ear). Far acuity (normal and cataract), near acuity (normal and cataract), and contrast sensitivity (normal) did not meet forward inclusion criterion. Predictors retained in the model after backward elimination were: visual condition, luminance, age, gender, contrast sensitivity (cataract), and pure-tone thresholds (better). Predictors eliminated from the model through backward exclusion were: pure-tone thresholds (poorer). To test Hypothesis 5b, the analysis compared performance under the auditory-only and cataract audiovisual conditions to a baseline performance in the normal audiovisual condition. The resulting residual deviance was 2088.8 (residual deviance = 2088.8, null deviance = 2920.6, and AIC = 3655.1). The results of the regression analysis are displayed in Table 28.

TABLE 28

COEFFICENTS IDENTIFIED AS PREDICTORS OF PERFORMANCE

Coefficients	B weights	Std. Error	z value	p value
(Intercept)	-5.05	0.73	-6.94	< .001
Auditory-only	-1.13	0.05	-22.42	< .001
Cataract Audiovisual	-0.29	0.05	-6.31	< .001
Contrast Sensitivity: Normal	1.94	0.48	4.10	< .001
Contrast Sensitivity: Cataract	0.58	0.29	2.04	0.04
Gender	-0.28	0.04	-7.08	< .001
Age	0.02	0.00	6.06	< .001
Pure Tone Average: BE	-0.03	0.01	-3.12	.002
Luminance	0.01	0.00	12.41	< .011

Notes: Results of the logistic binomial regression analysis. Predictors (coefficients) of speech intelligibility performance are listed on the left.

The analysis compared performance under the auditory-only and cataract audiovisual conditions to a baseline performance in the normal audiovisual condition. This helped determine if speech intelligibility performance under the simulated cataracts was significantly different from baseline normal audiovisual performance levels. The analysis was conducted to test

Hypothesis 5b to determine if participants' cataract audiovisual speech intelligibility performance was disproportionally affected by decreasing luminance levels.

The analysis showed that participants performed better in the speech intelligibility task under the normal audiovisual condition than under the cataract audiovisual and auditory-only conditions. The visual condition (i.e. normal, cataract, and auditory-only) was the best predictor of speech intelligibility performance. Participants performed the best in the normal audiovisual condition. Participants' performance declined significantly in the auditory-only condition (p <.001; â = -1.13) and the cataract audiovisual condition (p <.001; â = -0.29) when compared to the normal audiovisual conditions.

Contrast sensitivity, under both normal and cataract viewing conditions was found to be a significant predictor of speech intelligibility performance. Better contrast sensitivity under both normal and cataract viewing conditions were found to negatively affect performance (p < .001; â = 1.94 and p = .04; â = 0.58, respectively). These results demonstrated that participants with better contrast sensitivity had superior speech intelligibility performance.

Gender was the next best predictor of speech intelligibility performance (p <.001; â = -.28). These results, contrary to previous studies, show that female participants had poorer performance than the male participants. These results are interesting given that previous studies have consistently demonstrated females to be better at recognizing the target words. Participant age was also a predictor of performance showing that older participants tended to have better performance compared to younger participants (p <.001; â = 0.02).

As expected, the luminance level was a significant predictor of intelligibility (p <.001; â = 0.01). Participants' performance declined as the luminance level declined and the talker became more difficult to see.

Participants' pure tone average (PTA) in their better ear (BE) was a predictor of speech intelligibility ($p < .01$; â = -0.03). Participants with higher pure tone thresholds (poorer hearing) in their better ear tended to perform better. Participants' poorer ear PTAs were not found to contribute to predicting speech intelligibility performance and were not included in the regression equation.

Discussion

The results of Study 5 demonstrated that speech intelligibility varies with luminance levels and that any visual benefit to speech perception disappears at the lowest luminance levels (i.e. 0.004 cd/m^2). The simulated mild cataracts significantly reduced speech intelligibility compared to the normal audiovisual conditions and the difference in performance was more pronounced at intermediate levels. This supports Hypothesis 5b which predicted that participants' performance would decline at a disproportional rate compared to normal audiovisual conditions as the luminance of the televised talker declined.

The slope of normal audiovisual speech intelligibility performance as a function of luminance was similar to that reported by Erber (1974). Erber found similar declines in spondees (two syllable words with equal emphasis on each syllable), trochees (two syllable words with emphasis on the first syllable), and monosyllabic word recognition performed at eight different levels of luminance ranging from 30 to .01 foot lamberts (FL) (i.e. 102.7 to 0.034 cd/m^2). Erber's data and data collected in the normal audiovisual condition of Study 5 have been plotted in Figure 37. The graph clearly shows that performance initially improves as luminance level increases and asymptote at luminance levels of between approximately .28 and 1.1 cd/m^2. The differences in performance observed in the different data sets may stem from differences in speech stimuli (i.e. the sentence stimuli are more complex than individual words) and in the participants recruited for the two studies. Erber's participant group consisted of deaf children who are more skilled at speechreading than participants with normal hearing.

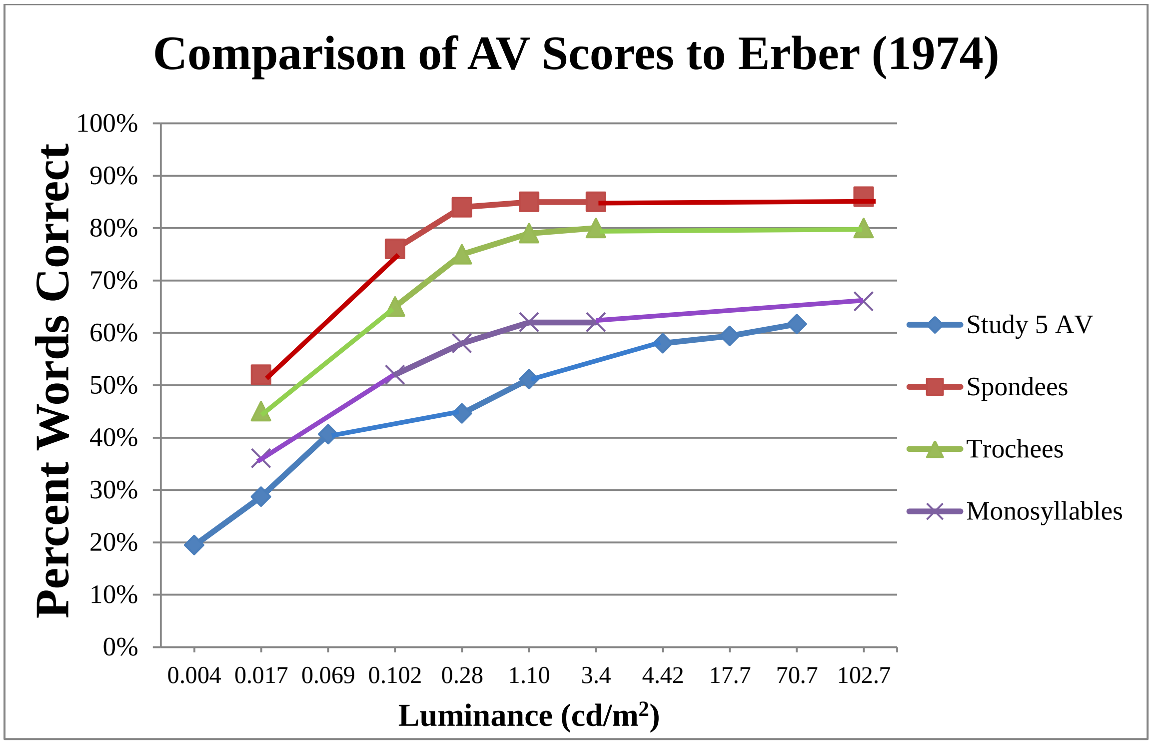

Figure 37. Psychometric functions showing mean speech intelligibility under normal audiovisual viewing conditions for Study 5 (Study 5 AV) as a function of luminance level. The results of Erber (1974) who measured speech intelligibility using spondees, trochees, and monosyllabic words are also shown for comparison.

It is interesting to note that the simulated cataract has no effect on intelligibility performance at the higher levels of luminance. This result suggests that the luminance level used in Study 3 and 4 (i.e. 0.69 cd/m^2) may be the ideal luminance level for revealing the effects of simulated mild cataracts on speechreading. This is supported by the results of the statistical analyses comparing VE for the normal and simulated cataract vision conditions (VE) at 1.1 cd/m^2 and .28 cd/m^2 luminance levels.   No difference was found in VE between the conditions at higher luminance levels (e.g. 1.1 cd/m^2) than used in Study 2 and 3. However, significant differences in VE were obtained at the lower .28 cd/m^2 luminance level. This suggests that common conversational settings with dim lighting, such as in a home or at a restaurant, may affect speech perception.

Speech intelligibility was more variable in this study compared to previous studies. The logistic binomial regression revealed that visual condition, luminance, and participant screening scores were less predictive of participants' performance. However, the earlier studies primarily manipulated SNR whose effects may be relatively less complex than those associated with changes in luminance level. Changes in luminance level produced concomitant changes in acuity, contrast sensitivity, accommodative response, the size of the pupil which affects retinal illumination of the optics of the eye, and a shift from cone to rod mediated vision. Perhaps it is not surprising that predictor variables account for less variance under these conditions. Also, it is important to note that the visual screening measures were obtained at photopic illumination levels and this may not be a reliable predictor of performance at mesopic or high scotopic luminance conditions like those tested in this experiment. Low pure tone averages for the right ear (i.e. better hearing) was one of the few screening measures that was found to be predictive of better performance.

Gender was predictive of speech intelligibility performance showing that males tended to outperform females. Unlike previous experiments, the SNR level was fixed in this study and the luminance levels were varied. Thus, the tolerance of females to speech in noise, may have offered little benefit under conditions where luminance is the primarily independent variable.

Study 6:

Effects of Simulated Severe Cataracts on Speech Intelligibility at Varying Levels of Luminance

The results of Study 5 demonstrated that the effects of simulated mild cataracts on speechreading are moderated by changes in luminance level. The results show that the effects of cataracts on speech perception are ameliorated at high luminance levels. These results suggest that the luminance level used in Study 3 was likely the highest luminance level at which the effects of simulated mild cataract on speechreading performance would be observed. We do not know if this is also true for the simulated severe cataract lenses.

The purpose of Study 6 was to document the effects of luminance level on speechreading with simulated severe cataracts. The experimental protocol was identical to that used in Study 5 with the exception that the density of the simulated cataract was increased to that used in Studies 2 and 4.

Study 6 Hypotheses

a) Speech intelligibility in the normal and cataract audiovisual conditions will vary as a function of luminance, with the best performance at high luminance levels and poorest performance at low luminance levels.

b) Visual enhancement will be significantly reduced by the simulated severe cataracts relative to the normal vision condition.

c) Participants' speech intelligibility scores for normal audiovisual, simulated cataract audiovisual and auditory-only conditions will not differ at the lowest luminance level.

Methods

Twenty participants (18-35 yrs, *M* = 26.7, 8 males and 12 females) with normal or corrected-to-normal vision, no history of hearing loss and who spoke Mainstream American-English were recruited through the online university recruitment site and received course credit for their participation. All participants had normal sensory functioning as determined by standard screening measures of visual (contrast sensitivity and acuity) and auditory functioning (pure tone hearing screening). Participant screening results are shown in Table 29.

TABLE 29

MEAN SCREENING SCORES

	Average	Std. Deviation
Far Acuity- OU		
Normal	20/15	3.67
Cataract	20/100	35.82
Near Acuity- OU		
Normal	20/25	.31
Cataract	20/100	49.26
Contrast Sensitivity- OU		
Normal	1.9	.06
Cataract	.40	.09
Pure Tone Average- BE	3.00 dB	2.74
Pure Tone Average- PE	5.58 dB	3.17

Notes: Group mean scores and standard deviation for binocular (OU) near and far visual acuity and contrast sensitivity measured under both normal and simulated cataract conditions. Participants' pure tone average (and standard deviation) hearing thresholds in their better ear (BE) and poorer ear (PE).

Procedure

Participants wore one of three pairs of glasses for each of the experimental conditions including: frames without lenses for the normal vision condition (color coded white); frames with Vistech™ cataract simulation filters with an added filter (color coded black); and frames with opaque lenses for the auditory-only condition (color coded brown). The cataract simulation glasses reduced participants' visual acuity to an average of 20/100 from 20/15 under normal viewing conditions. The simulation glasses reduced contrast sensitivity measured using the Pelli-Robson Contrast Sensitivity Chart from a mean score of 1.9 under normal viewing conditions to a mean score of .4 under the cataract simulation condition. An extra pair of large, opaque glasses was provided to the participant to wear while the neutral density filters were being changed to protect the participants' eyes from the bright television during filter transitional stages. Unless otherwise stated, the experimental protocol was as identified in Study 5.

Results

Participants' responses were scored by a second experimenter who was masked to the experimental conditions under which the data were collected using the aforementioned scoring criterion, described in Study 1. Average speech intelligibility and visual enhancement for each visual condition and luminance level was calculated across all participants, shown in Table 30.

TABLE 30

AVERAGE SPEECH INTELLIGIBILITY AND VISUAL ENHANCEMENT BY VISUAL CONDITION AND LUMINANCE LEVEL

Luminance	Auditory-only	Cataract Audiovisual	Normal Audiovisual	Cataract VE	Normal VE
70 cd/m^2	.24 (.15)	.51 (.13)	.63 (.17)	.27 (.17)	.39 (.20)
17.7 cd/m^2	.16 (.09)	.47 (.16)	.65 (.17)	.31 (.18)	.49 (.19)
4.4 cd/m^2	.22 (.10)	.36 (.14)	.52 (.19)	.14 (.14)	.30 (.20)
1.1 cd/m^2	.22 (.09)	.29 (.14)	.52 (.24)	.07 (.16)	.30 (.23)
.28 cd/m^2	.22 (.11)	.15 (.08)	.50 (.17)	-.07 (.13)	.29 (.20)
.07 cd/m^2	.19 (.11)	.14 (.09)	.35 (.19)	-.05 (.14)	.16 (.18)
.02 cd/m^2	.20 (.09)	.23 (.13)	.25 (.12)	.02 (.14)	.04 (.15)
.004 cd/m^2	.19 (.10)	.23 (.13)	.19 (.13)	.03 (.13)	.00 (.12)

Notes: Participants' speech intelligibility score expressed as mean percent correct and standard deviation (shown in decimal form) for each visual condition and luminance level. The last two columns display the calculated visual enhancement (VE) score from Equation 1.

Mean intelligibility scores, expressed as the percentage of key words correctly reported by participants under the three viewing conditions and eight luminance levels, are shown in Figure 38. Participants had the best performance in the normal and cataract audiovisual conditions at the highest luminance levels and gradually had poorer performance as luminance declined, which supports Hypothesis 6a. Similar to Study 5, participants' average accuracy was approximately 20% independent of luminance levels. Cataract audiovisual performance was poorer than normal audiovisual performance at high luminance levels and this difference became greater at intermediate-to-low luminance levels. Participants had comparable performance in the auditory-only, cataract audiovisual and normal audiovisual conditions at the lowest luminance level (i.e. .004 cd/m^2). This is consistent with Hypothesis 6c which predicted that performance would be comparable for all three visual conditions at the lowest luminance level.

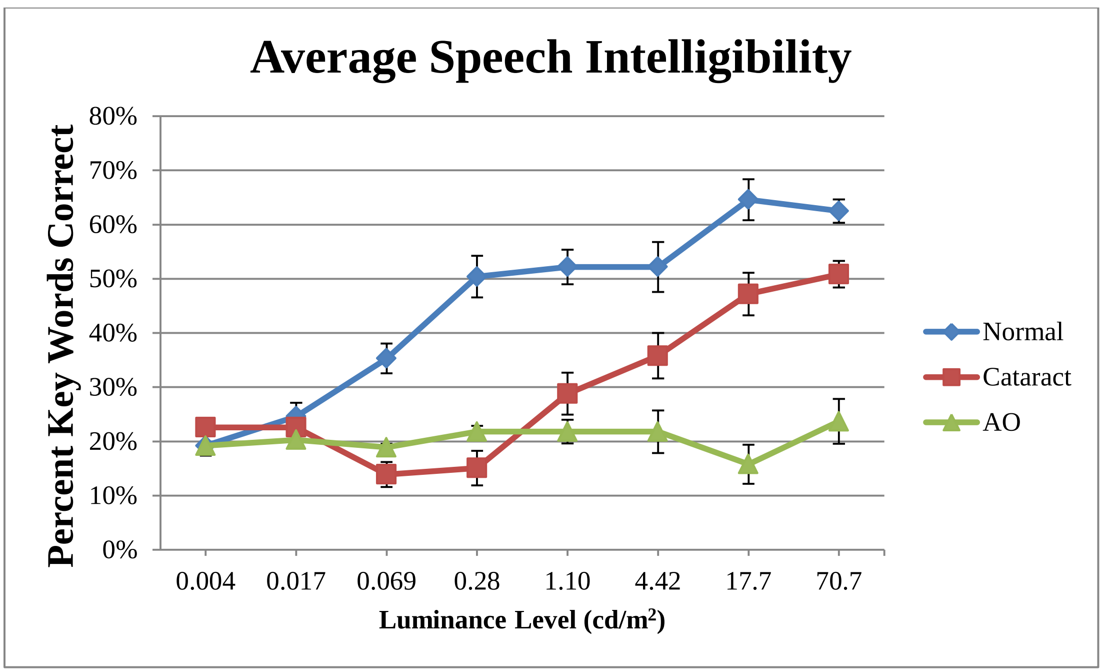

Figure 38. Psychometric functions showing mean speech intelligibility (N=20) for the auditory-only (AO), normal vision, and simulated cataract viewing conditions as a function of luminance level. Error bars in the figure represent standard error.

A 2x8 within-subjects analysis of variance (ANOVA) was conducted to evaluate the effect of visual condition and luminance level. This analysis was used to test Hypothesis 6b to determine if the simulated cataract lenses significantly reduced visual enhancement. Participants' average visual enhancement for each viewing condition and luminance level was calculated using Equation 1: VE= AV-A (shown in Figure 39) to demonstrate gross improvement in speech intelligibility. The within-subjects factors were visual condition with two levels (normal vision and simulated cataract vision) and luminance with eight levels (70 to 0.004 cd/m^2). The ANOVA also indicated a significant main effect for visual condition, $F(1, 19) = 59.59$, $p < .001$, $\eta_p^2 = .76$ and a significant main effect for luminance level, $F(7, 13) = 22.64$, $p < .001$, $\eta_p^2 = .92$. The ANOVA also indicated a significant interaction between visual condition and luminance level, $F(7, 13) = 12.80$, $p < .001$, $\eta_p^2 = .87$.

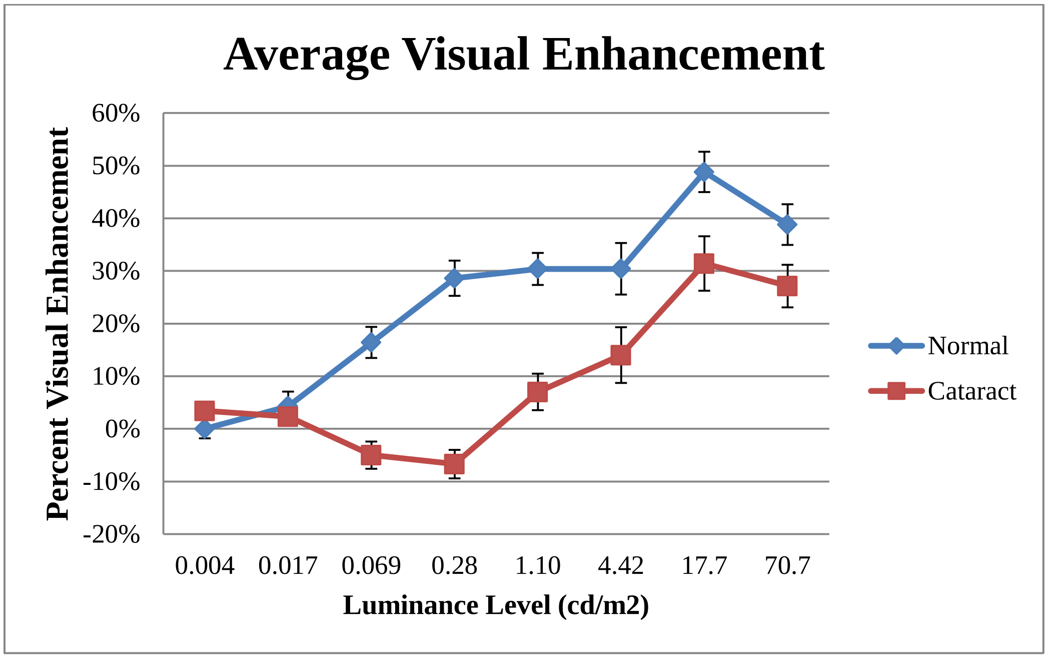

Figure 39. Psychometric functions showing mean VE (N=20) of both normal and simulated severe cataract viewing conditions as a function of luminance level. Error bars in the figure represent standard error.

To further investigate the interaction between the luminance of the talker and visual condition, eight paired t-tests were computed for all luminance levels between normal visual enhancement and simulated cataract visual enhancement. Visual enhancement was significantly poorer with simulated cataracts than with normal vision at the six highest luminance levels (70, 17.7, 4.42, 1.1, 0.28, and 0.069 cd/m^2). However, after Bonferroni adjustment ($p \leq .006$), only the three of these met the stricter p value. These luminance levels were 1.1 cd/m^2 [$t(19) = 4.44$, $p < .001$, Cohen's $d = 5.29$], 0.28 cd/m^2 [$t(19) = 10.718$, $p < .001$, Cohen's $d = 9.36$], and 0.069 cd/m^2 [$t(19) = 9.198$, $p < .001$, Cohen's $d = 6.03$].

A post-hoc analysis was conducted to investigate the luminance levels in which participants' speech intelligibility performance under simulated severe cataracts was poorer than their baseline auditory-only performance. The boxed area in Figure 40, indicated the two luminance levels, 0.069 and 0.28 cd/m^2, that yielded significantly poorer cataract audiovisual performance than auditory-only performance on the speech intelligibility task.

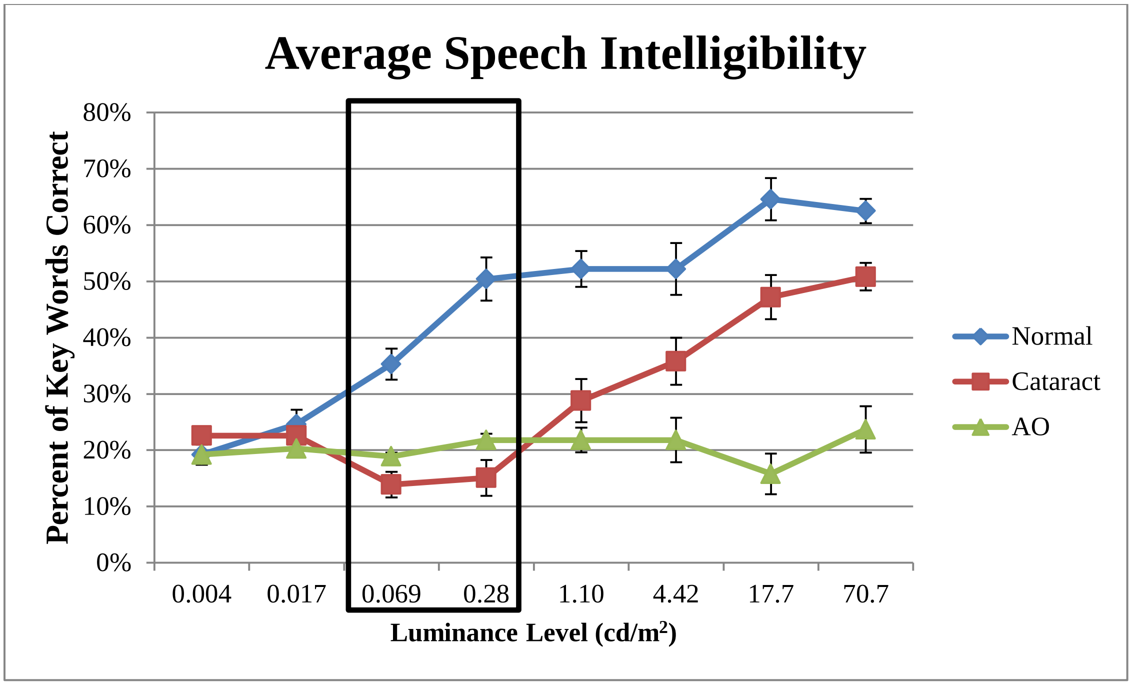

Figure 40. Psychometric functions showing mean speech intelligibility (N=20) of auditory-only (AO), normal vision, and simulated cataract viewing conditions as a function of luminance level. The box highlights luminance levels where auditory-only speech intelligibility was better than simulated severe cataract intelligibility. Error bars in the figure represent standard error.

Two paired t-tests were computed between simulated cataract and auditory-only speech intelligibility scores. The difference in speech intelligibility at the 0.28 cd/m^2 luminance level was found to be statistically significant, $t(19) = 2.39$, $p = .028$, Cohen's $d = 3.0$. While, the difference in speech intelligibility at the 0.069 cd/m^2 luminance level was not found to be statistically significant, $t(19) = 1.62$, $p = .122$, Cohen's $d = 2.25$.

A logistic binomial regression was conducted to evaluate the predictive power of visual conditions, luminance level, and the screening measures on speech intelligibility performance. This was done to test Hypothesis 6b which predicted that speech intelligibility under the simulated cataracts would significantly differ from the normal vision condition. The predictors included in the analysis were the three visual conditions (auditory-only, cataract audiovisual and normal audiovisual), luminance level, and six screening measures (age, gender, near and far visual acuity (normal and cataract), contrast sensitivity (normal and cataract), and pure tone threshold averages). The model was built using the same forward inclusion and backward exclusion criterion stated in Study 1B. The null deviance of the speech intelligibility scores in this study was 2454.2 (deviance).

The predictors added to the model that met the criterion through forward inclusion were: visual condition, luminance, age, gender, contrast sensitivity (cataract), and far acuity (normal). Far acuity (cataract), near acuity (normal and cataract), pure-tone thresholds (better and poorer ear), and contrast sensitivity (normal) did not meet forward inclusion criterion. Predictors retained in the model after backward elimination were: visual condition, luminance, age, gender, contrast sensitivity (cataract), and far acuity (normal). No predictor met the requirements for backward exclusion. To test Hypothesis 6b, the analysis compared performance under the auditory-only and cataract audiovisual conditions to a baseline performance in the normal audiovisual condition. The resulting residual deviance was 1452 (residual deviance = 1452, null deviance = 2454.2, and AIC = 3020.6). The results of the regression analysis are displayed in Table 31.

TABLE 31

COEFFICENTS IDENTIFIED AS PREDICTORS OF PERFORMANCE

Coefficients	B weights	Std. Error	z value	p value
(Intercept)	-1.50	0.17	-8.76	< .001
Auditory-only	-1.20	0.05	-23.43	< .001
Cataract Audiovisual	-0.70	0.05	-14.54	< .001
Contrast Sensitivity: Cataract	0.92	0.24	3.82	< .001
Gender	0.32	0.05	6.81	< .001
Age	0.04	0.00	9.98	< .001
Far Acuity: Normal	-0.03	0.01	-5.04	< .001
Luminance	0.01	0.00	15.80	< .001

Notes: Results of the logistic binomial regression analysis. Predictors (coefficients) of speech intelligibility performance are listed on the left.

The analysis compared performance under the auditory-only and cataract audiovisual conditions to a baseline performance in the normal audiovisual condition. This helped to determine if speech intelligibility performance under the simulated cataracts was significantly different from baseline normal audiovisual performance levels. The analysis was conducted to test Hypothesis 6b to determine if participants' cataract audiovisual speech intelligibility performance was disproportionally affected by decreasing levels of luminance.

The analysis demonstrated that participants performed better in the speech intelligibility task under the normal audiovisual condition than under cataract audiovisual and auditory-only conditions. Visual condition (normal, cataract, and auditory-only) was also found to be an important predictor of speech intelligibility performance. Participants performance was significantly worse under the auditory-only condition ($p < .001$; â = -1.20) and the cataract audiovisual condition ($p < .001$; â = -.70) compared to normal audiovisual conditions.

The results of the regression showed that participants' simulated cataract contrast sensitivity scores were the best predictors of speech intelligibility performance ($p < .001$; â = .92). Participants with better contrast sensitivity under cataract viewing conditions had better performance. An additional predictor of speech intelligibility performance was normal far acuity (p < .001; â = -0.03). These results show that participants with better visual acuity under both viewing conditions had better speech intelligibility.

Gender was also a predictor of speech intelligibility performance (p =.001; â = .32). These results show that female participants tended to perform better task than male participants. These results are contrary to the results of Study 5, but consistent with prior studies, providing support to the evidence that women may have superior verbal processing and verbal memory.

The age of the participant was found to be a predictor of speech intelligibility performance showing that older participants tended to have better speech intelligibility performance (p < .001; â = 0.04). These results are consistent with previous studies which have found older participants to outperform younger participants.

The luminance level was a significant predictor of speech intelligibility performance (p <.001; â = .01). Participants' speech intelligibility performance declined as the luminance level declined and talker became more difficult to see. These findings support Hypothesis 6a which predicted that speech intelligibility would be negatively affected by decreasing levels of luminance.

An additional post-hoc analysis was conducted to compare participants' performance in Study 5 and Study 6 in order to investigate the effect of cataract density on speech intelligibility as a function of luminance. The two studies were similar except that the cataract simulation in Study 6 was modified to increase its severity. A comparison of the data from each study is shown in Figure 41.

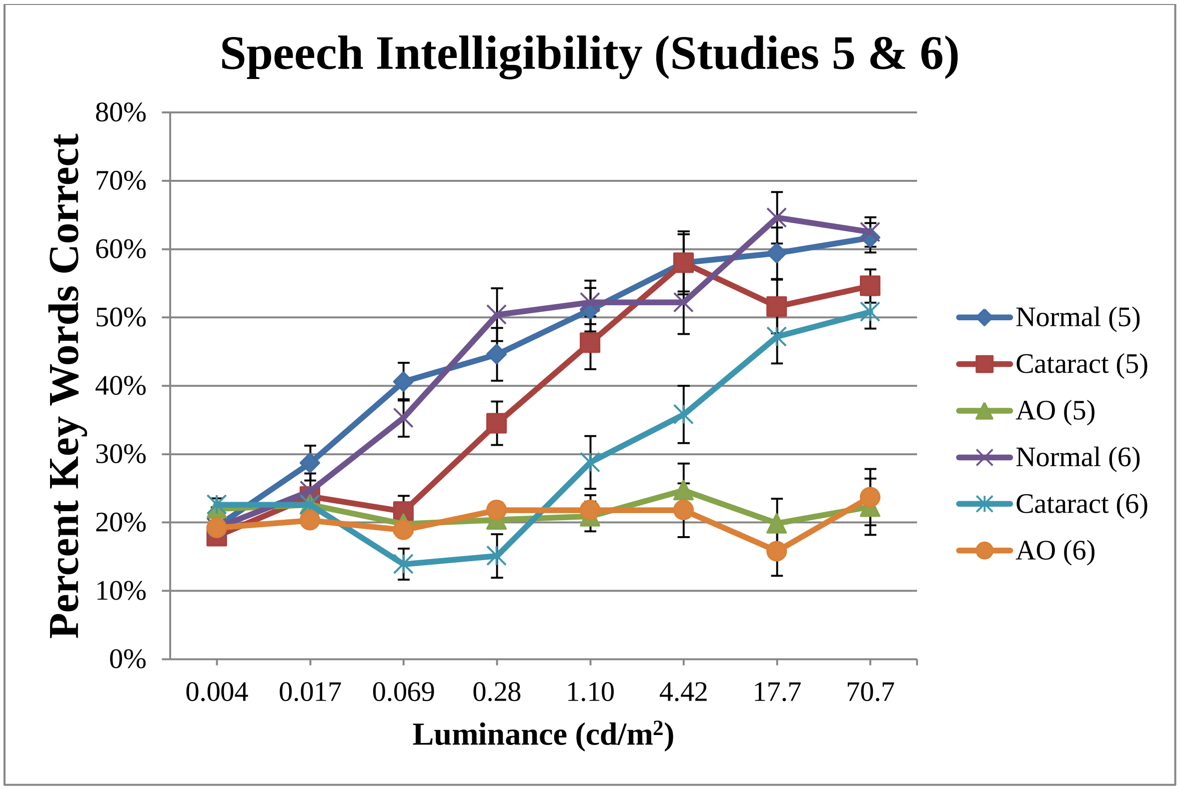

Figure 41. Comparison of average speech intelligibility performance for Study 5 (mild cataract) and Study 6 (severe cataract). Psychometric functions showing mean speech intelligibility for the auditory-only (AO), normal vision, and simulated cataract viewing conditions for Study 5 (N=20) and Study 6 (N=20) as a function of luminance. Error bars in the figure represent standard error.

A logistic binomial regression was conducted on the data for Study 5 and 6 to evaluate how the density of the simulated cataract, the visual conditions, and luminance level predicted speech intelligibility performance. Predictors were cataract density (mild for Study 5 and severe for Study 6), the three visual conditions (auditory-only, cataract audiovisual and normal audiovisual), and eight luminance levels. This was done to determine if speech intelligibility performance under simulated severe cataracts was significantly different from baseline simulated mild simulated cataract conditions. The model was built using the same forward inclusion and backward exclusion criterion stated in Study 1B. The null deviance of the speech intelligibility scores in this study was 5405.7 (deviance).

The predictors added to the model that met the criterion through forward inclusion were: cataract density, visual condition, and luminance level. Predictors retained in the model after backward elimination were: cataract density, visual condition, and luminance level. No predictors were eliminated from the model through backward exclusion. The analysis compared performance under the auditory-only and cataract audiovisual conditions to a baseline normal audiovisual condition and compared the simulated severe cataract of Study 6 to a baseline simulated mild cataract of Study 5. The resulting residual deviance was 3085.3 (residual deviance = 3085.3, null deviance = 5405.7, and AIC = 7014.6). The results of the regression analysis are displayed in Table 32.

TABLE 32

COEFFICENTS IDENTIFIED AS PREDICTORS OF PERFORMANCE

Coefficients	B weights	Std. Error	z value	p value
(Intercept)	-0.24	0.03	-8.78	< .001
Auditory-only	-1.16	0.04	-32.25	< .001
Cataract Audiovisual	-0.48	0.03	-14.57	< .001
Cataract type: Severe	-0.17	0.03	-5.88	< .001
Luminance	0.01	0.00	19.61	< .001

Notes: Results of the logistic binomial regression analysis of Study 5 and Study 6. Predictors (coefficients) of speech intelligibility performance are listed on the left.

The results of the regression demonstrated that participants' visual condition was the most predictive of speech intelligibility performance. The analysis established that participants performed poorer under the cataract audiovisual condition (*p* < .001; â = -0.48) and the auditory-only conditions (*p* < .001; â = -1.16) compared to the normal audiovisual conditions. The luminance level of the televised talker was also related to participants' speech intelligibility performance (*p* < .001; â = .01). Participants tended to have better performance when the luminance of the talker's face was increased. Additionally, the density of the simulated cataract was also a significant predictor of speech intelligibility performance ($p < .001$; â = -0.17). Performance was significantly lower when participants wore a denser cataract in Study 6 than when they wore a milder simulated cataract in Study 5.

Discussion

The results of Study 6 show that normal audiovisual speech intelligibility is impaired at lower luminance levels. These results are consistent to those from Study 5 which showed that participants' derived no benefit of vision under the normal vision condition at the lowest luminance level (.004 cd/m^2) for the normal vision condition. Thus, the available visual information was so degraded it could not aid speech perception. Participants' cataract audiovisual speech intelligibility was shown to be poorer than their normal audiovisual speech intelligibility and was shown to decline at a faster rate with the luminance level.

The simulated severe cataracts degraded participants' speechreading abilities at the highest six luminance levels. The three highest of these levels showed a significant difference between the normal and cataract visual enhancement; however, they did not yield large enough differences between the two VEs to meet the conservative significance level (all $p \leq .006$) set by the Bonferroni adjustment. The remaining three luminance levels had differences large enough to meet the strict significance level. The two lowest luminance levels examined with *t* tests revealed no significant difference in VE between the normal and simulated severe cataract vision. This is because the luminance had declined to a level in which participants under all three visual conditions had similar accuracy (i.e. near 20%). These results demonstrate that differences in VE are best observed at intermediate luminance levels.

The results of Study 4 showed that the simulated severe cataracts eliminated any visual benefit of vision to speech perception at a fixed luminance level, .69 cd/m^2. It was unclear if the

.69 cd/m^2 luminance was the maximal level of luminance that could be used to demonstrate the same effect of the simulated cataracts on speech intelligibility observed in Study 4. The results of this study demonstrate that participants could gain some support to speech perception under the severe cataracts at the 1.1 cd/m2 luminance level, but their performance fell below auditory-only performance at the .28 cd/m^2 luminance level. In fact, Figure 40 shows that participants' cataract audiovisual speech intelligibility crosses their auditory-only performance exactly between the .28 and 1.1 cd/m^2 luminance levels which is the exact luminance level used in Study 4 (i.e. .69 cd/m^2). This suggests that higher levels of luminance can be used to demonstrate differences between normal and severe cataract audiovisual speech intelligibility, but that the effect of eliminating a visual contribution to speech perception by severe cataracts may not be able to be observed at luminance levels higher than .69 cd/m^2.

The absence of visual support to speech perception at .69 cd/m^2 and lower luminance levels demonstrates the difficulty that individuals with advanced cataracts may have in detecting audiovisual speech in noise under reduced illumination levels. These individuals may derive no benefit from seeing a speakers' face under dim levels of illumination.

The post-hoc analysis comparing auditory-only and cataract audiovisual speech intelligibility offers a fascinating insight into the integration processes of degraded multisensory information. Previous research has shown that listeners benefit from looking at a talker's face even when the face is degraded beyond recognition (Thorn & Thorn, 1989). The results of Study 4 and 6 counter this research by showing that not only does severe visual enhancement reduce the visual enhancement to speech perception in noise, but it can eliminate it entirely. However, it was not anticipated that a severely degraded visual image (i.e. through simulated cataracts and low luminance) would have such a severe effect that their performance was worse than their baseline auditory only performance. Thus, it was worse to “listen” and “view” a speaker than it was to “listen” to their voice under these conditions. This suggests that participants would have been better off closing their eyes and simply listening to the speech signal rather than attempting to integrate the degraded visual signal into the degraded auditory signal. In fact, multiple participants in this study reported that they “liked the brown (auditory-only) glasses better than the black (simulated cataracts) glasses” under the lower luminance conditions. On a few occasions, participants were observed attempting to close their eyes during the low luminance cataract conditions but were instructed by the experimenters to keep their eyes open. This behavior may demonstrate that participants intuitively knew that their performance was worsened by attempting to resolve the visual signal than simply reducing their sensory input to only hearing. Another explanation is that participants found it too difficult to “listen” and “view” than simply “listen” under the dim illuminations.

A potential explanation for the effect of severely degraded vision on performance is that demands associated with attending to and integrating the multimodal signal (visual and audition) exceeds the participants’ attentional resources. Perhaps, attempting to extract a speech signal embedded in the four-person babble and the visual signal, which was degraded by blur, in a stimulus that is low contrast, low luminance, and blurred places a demand that is too great. This interpretation is consistent with previous research (Tiippana et al., 2004; Anderson et al., 2009; Alsius et al., 2005) which has shown that audiovisual speech integration is an effortful process that is modulated by attentional load.

The regression analysis of Study 6 demonstrated less residual deviance of the speech intelligibility scores by the independent variables and screening measures than previously found in Study 5. However, the result of the regression analyses in this study showed that the predictor variables accounted for less of the variance in performance than previous studies which predicted speech intelligibility as a function of SNR.

The logistic binomial regression demonstrated that contrast sensitivity measured while viewing through the cataract simulation was a predictor of better performance. Visual acuity was also found to be predictive of performance. This suggests that an individual's contrast sensitivity and visual acuity should be measured when considering the likelihood that they can support speech perception through visual enhancement.

The results of this study, contrary to Study 5, showed that female participants had better performance than males. This trend was seen across nearly all the studies suggesting that females are superior to males in perceiving speech under degraded auditory and visual conditions which may be attributed to superior verbal processing and memory (Bolla-Wilson & Bleeker, 1986; Daly et al., 1996). The interaction between age and speech intelligibility was another trend that was observed in this study. Older participants consistently have difficulty understanding speech in noise and in cataract conditions, but benefit under normal audiovisual conditions.

The logistic regression results across Study 5 and 6 showed that the severe cataracts have more acute effects on performance. Additionally, we observed performance benefits at high luminance levels for severe cataracts that were less observed for mild cataracts. This suggests that highly illuminated environments are especially important for good face-to-face conversations for older individuals as their cataracts mature. A surprising result of the post-hoc regression analysis was that older participants had better performance under the simulated severe cataract than their younger counterparts compared to the mild cataracts. Despite the older participants' susceptibility to noise and visual degradation, they may have been more motivated to perform well under the more dense cataracts than were the younger participants. It should be noted that this comparison came from two different populations and there may simply be sampling or chance differences between the two age groups in their responses to the cataract density.

CHAPTER 5

GENERAL DISCUSSION

The findings of the six studies support the hypothesis that simulated cataracts interfere with a listener's ability to utilize visual information for speech intelligibility. Many factors were found to influence participants' ability to understand speech while wearing the simulated cataracts. The major factors included: signal-to-noise ratio, age, luminance, contrast sensitivity, visual acuity, cataract density, and attentional resources.

Past research has demonstrated that listeners with normal hearing will only benefit from visual speech cues when the speech signal is degraded by extraneous noise (Ross et al., 2006; Sumby & Pollack, 1956). This was supported by the results of these studies. Participants performed significantly better at high SNRs (i.e. 0 dB SNR). Relatively little visual enhancement was found at the 0 dB SNR because the participants could discern the speech signal by relying on the auditory channel. Consequently, the simulated cataracts did not affect performance at high SNRs. The simulated cataracts affected visual enhancement most at intermediate SNRs, where the visual contribution to speech was largest. Intermediate SNRs, such as -9 and -12 dB, were also where the largest differences in visual enhancement were obtained for the normal and cataract vision conditions. This is consistent with the findings of Ross et al. that found evidence showing that a -12 dB SNR constituted a "special zone" where auditory and visual speech signals are maximally integrated.

The noise used in these studies consisted of four-person babble composed of two female and two male voices. This babble was selected over cafeteria-style babble (i.e. a roar of voices) because it made the speech detection task more difficult given that each of the four voices in the babble could be segregated from the others. The four-person babble served as an effective masker because it is meaningful babble, which is known to affect both young and older participants' speech intelligibility (Tun et al., 2002; Tun & Wingfield, 1999; Schneider et al., 2002). Many participants commented that the babble was "annoying" and were particularly frustrated with one of the female voices in the audio track. One participant even went so far as to write "WINTER IS THE HARSHEST TIME" angrily on his answer sheet, which was not one of the SIN sentences, but was a recurring phrase from this particular female in the babble. It is hypothesized that the reason that participants were frustrated with this particular female voice was because her voice had similar acoustic qualities to the target talker. This would make the "annoying" females' voice a more effective mask of the target talker's voice, which would in turn make the speech detection task more difficult. Future research should examine speech intelligibility performance using a different four-person babble to determine if performance shifts up because a less effective masker of the target female's voice is used.

It was somewhat surprising that age was often found to be a significant predictor of performance across the six studies given the limited age range of the participants. The use of younger participants was motivated in part to minimize the potential confounding effects of age-related changes in speech perception. It is possible that even over this limited age range that changes have occurred that impact speech perception. Age was a recurring predictor of speech intelligibility demonstrating at times that older participants tended to perform more poorly than younger participants at the speech intelligibility task and other times demonstrating they performed better. The results of studies 2 and 3 both demonstrated that older participants had poorer performance than younger participants and both studies had a wide range of participant ages (18-37 yrs. and 18-38 yrs., respectively). The results of studies 1B and 4 both demonstrated that older participants had better performance than younger participants and both studies had a smaller age range of participants (18-31 yrs. and 18-35 yrs., respectively). These results demonstrate that “younger-young” adults (e.g. ~18-25 years old) may be less impacted by competing noise while perceiving speech and “older-young” adults (e.g. ~26-40) may be more impacted.

The effects of the simulated cataracts on speechreading reported in these studies with younger-young adults and older-young adults suggest that the effect of cataracts on speech intelligibility would be larger if tested in a group of older adults (i.e. 40 years old and above). Age-related changes in cognitive abilities may exacerbate the effects of simulated cataracts on speech perception. Older adults may rely more on visual cues due to hearing loss, changes in higher cognitive processing that compromise speech intelligibility (Grant & Seitz, 2000) or increased susceptibility to distraction from competing speech sounds (Tun et al., 2002). Sommers et al., (2005) found that older listeners were able to integrate visual and auditory cues just as well as younger listeners, but appear to have diminished speechreading performance. It is possible that this diminished performance is a result of age-related changes in vision and visual processing.

Older adults with real cataracts, however, may have adapted to their visual conditions and have become adept at using other visual cues that are still available. Additionally, the development of cataracts is a gradual process, in most instances, which may allow for a gradual adaptation to the visual impairment. The young adults in these studies only experienced the simulated cataracts for approximately one hour and may not have been able to overcome their effects during that time. The effect of contrast reductions have been demonstrated to lessen with exposure (Vitkovitch & Barber, 1996) and viewers have been demonstrated to quickly overcome the effects of small amounts of blur (Thorn & Thorn, 1989). Finally, the Vistech simulators have been tested and demonstrated to simulate the effects of light-scatter and reduction in contrast sensitivity (Elliot et al., 1996); however, they may not simulate all of the visual effects that an adult with age-related cataracts experiences.

Luminance level moderated the effects of cataracts on speechreading performance. The contribution of vision to speech perception has been shown to decline as the luminance level declines (Erber, 1974; Gagne et al., 2006). High levels of luminance have also been demonstrated to improve speechreading performance, especially when using a light-skinned talker (Gagne et al., 2006). The results of Study 5 and Study 6 offered further support by demonstrating that speech intelligibility under normal vision declined to auditory-only levels of performance at very low luminance levels (i.e. .004 cd/m^2). The effect of the simulated cataracts on speechreading was modulated by the luminance of the talker. The results of Study 1, using a live talker, demonstrated that simulated mild cataracts degraded participants' speechreading. The simulated severe cataracts were hypothesized to degrade speechreading to a much larger extent than seen in Study 1; however, the high luminance LCD display used in Study 2 counteracted the effects of severe cataracts. The decline in speechreading by the simulated severe cataracts was amplified once the LCD television was restricted to a luminance level comparable to that of the live talker in Study 1. The impact of the severe cataracts on speechreading under this level was so large that nearly all evidence of visual enhancement was eliminated. Study 5 and Study 6 investigated the impact of mild and severe cataracts on speechreading as a function of luminance level, high to low. The results of these studies revealed that there may be an optimal luminance level that best reveals the impact of visual impairment on speechreading. There were few differences in visual enhancement found between normal and cataract conditions at both high luminance levels (i.e. 70 cd/m^2) and low luminance levels (i.e. 0.004 cd/m^2). Intermediate luminance levels (i.e. 0.28 and 0.069 cd/m^2) at a SNR of -9 dB, however, produced the largest differences between normal and cataract visual enhancements for both simulated mild and severe cataracts. Similar to the findings of Ross et al. (2006), these results suggest that a luminance level of 0.28 or 0.69 cd/m^2 may constitute a "special zone" for revealing the effects of luminance on speechreading performance. Additionally, high luminance, directional lighting, which illuminated the oral cavity in the video recording of the SIN sentences, was believed to help improve speechreading performance.

Contrast sensitivity was a predictor of speech intelligibility performance, demonstrating that individuals with better contrast sensitivity scores tended to perform better than those with lower scores. Near and far acuity also predicted performance, however, acuity was not a consistent predictor and accounted for less variance compared to contrast sensitivity. These results are consistent with the view that mid-to-low range spatial frequencies are critical to speechreading but that high spatial frequencies may support discrimination of some visemes. The combined loss of both high and mid-to-low range spatial frequencies may account for the greater effect of cataracts on speechreading. This could explain the discrepancy between the results of these studies and previous research which has shown little effect of blur on speechreading. Perhaps viewers can compensate for the high spatial frequency losses (i.e. those caused by blur) by simply relying more on the mid-to-low range spatial frequencies. Individuals with cataracts may have difficulty detecting both low spatial frequency facial characteristics that help to distinguish vowels (i.e. through lip rounding) and high spatial frequency characteristics that help to distinguish fricative consonants (e.g. tongue against the teeth). This is particularly problematic, as stated by Erber (2002) for older adults who have high auditory frequency hearing loss and cannot rely on visual cues to improve their detection of fricative sounds. The distance between the talker and listener may impact the relationship between visual impairment and spatial frequencies because lower spatial frequencies will shift up and high spatial frequency may be attenuated as the distance between a viewer and talker increases (Munhall, Kroos, et al., 2004). Individuals with cataracts may benefit more from speechreading at a near distance because a wide range of the spatial frequencies are available.

Both simulated mild and severe cataracts were found to significantly impair participants' speechreading performance. The results of the studies 1, 3, and 5 suggest that individuals with mild cataracts are likely to experience poorer speechreading performance than their peers with normal vision; however, they will still be able to use vision to partially support speech perception. The results of studies 2, 4, and 6 suggest that individual with severe cataracts will be more dramatically affected by their visual impairment and may be particularly disadvantaged by poor lighting conditions. In light of these findings, it recommended that individuals with severe cataract impairment seek environments that are well lit during face-to-face interactions to partially overcome their visual impairment to speechreading. These findings do not take into consideration other age-related cognitive declines that an older adult with real cataracts may experience, which may exacerbate cataracts' effects on speechreading. It is possible that even mild cataracts paired with cognitive and other sensory declines may be sufficient to restrict any visual enhancement to speech perception.

Attentional resources were hypothesized to be an important factor in considering the effect of simulated cataracts on speechreading. A great deal of attention was required from the participants in these studies because the listening tasks were designed to be difficult in order to make vision necessary for speech perception. Additionally, the experimental durations were quite long to allow for sufficient data collection. Participants were provided a break to prevent fatigue; however, some participants reported being fatigued toward the end of the experiment. These factors may have reduced participants' ability to perceive the auditory and visual information and ultimately may have led to less than optimal integration of the dual speech signals. Several participants reported feeling frustrated, having trouble focusing on the target speech, and experiencing trouble filtering the background babble. Similar complaints are reported by older listeners who struggle to listen to speech in noise (Pichora-Fuller et al., 1995; Tun et al., 2002).

Age-related attentional declines may have been accentuated by the simulated cataracts, especially at low luminance levels, which may have required more cognitive effort to resolve the degraded visual image. This was best demonstrated in Study 6 which revealed that simulated severe cataract performance was worse than auditory-only performance at two luminance levels. The combination of a low SNR and a dark image degraded by severe cataracts may have depleted attentional resources to prevent full auditory processing and auditory-visual integration processes. Individuals with hearing loss have been shown to have less auditory-visual integration and this effect is hypothesized to be due to depleted attentional resources from demands on limited attentional resources (Musacchia et al., 2009). This suggests that there may be an interaction between bottom-up and top-down processes that determine how well older adults with age-related cognitive and sensory losses can perceive audiovisual speech. The results of Study 6 suggest that individuals with severe cataracts under dim illuminations may actually show a performance decline when attempting to resolve the degraded visual image and may improve performance by looking away from or attempting to ignore the visual signal and focusing their attentional resources on the auditory signal.

In summary, the results of these studies demonstrated that a cataract simulation, even one that has little concomitant effects on visual acuity, significantly affects speechreading performance. These results support anecdotal comments and professional recommendations that cataracts interfere with older adults' ability to speechread. This suggests that individuals with cataracts may show improved audiovisual speech perception following cataract surgery. This additional benefit may add immeasurable improvements to individuals' quality of life.

Future Research

Future research should investigate the effect of simulated cataracts on speechreading with middle-aged and older adult populations. Age was found to be a predictor of participants' speech intelligibility performance as well as the degree to which the cataracts impaired speechreading. This was surprising given the limited age range (i.e. 18-40 years old). Older adults may demonstrate larger declines in speechreading from the simulated cataracts compared to younger participants, similar to the findings of Gordon and Allen (2005). Participants in these studies were screened to ensure they had normal hearing; however, future studies should include populations with hearing loss to investigate any strategies that they may have adopted or any differences in speechreading skills that may exist due to learning effects.

Eye tracking technology has been used to determine where individuals look during speechreading and which facial features and movements contribute the most to visual speech perception (Everdell et al., 2007; Lansing & McConkie, 1994; Paré et al., 2003). Future research should use eye tracking technologies to examine individuals with cataracts to determine if they have adopted any new gaze patterns or strategies as a result of their visual impairment.

Most importantly, future research should examine individuals' speechreading performance pre- and post-cataract removal surgery to determine if any improvement to visual enhancement has occurred. Additionally, these individuals' speechreading could be tested under similar amounts of blur to simulate their visual acuity, but not contrast sensitivity, prior to cataract removal surgery. This research may help to isolate the effect of diffusive blur and contrast sensitivity reduction on speechreading performance.

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APPENDICES

APPENDIX A-1

CONSENT FORM: STUDY 1

PURPOSE OF THE STUDY: The study involves a number of components. We will evaluate your vision, hearing, and speech perception. This study will provide information about the effect of age-related changes in visual, hearing and cognitive skills related to speech perception.

INVITATION TO PARTICIPATE: You have been invited to participate in this study because you are one of 30 students who represent the group of students that we are interested in studying. In order to decide whether or not you should agree to be part of this research study, you should understand enough about the risks and benefits to make an informed judgment. This process is known as informed consent. This consent form gives detailed information about the research study which the investigator will discuss with you. Once you understand the study, you will be asked to sign this form if you wish to participate.

EXPLANATION OF PROCEDURES: This study involves a number of components. We will evaluate your vision, hearing and speech perception using standard tests. This will be completed in a series of tests. Some tests will be administered by the experimenter by which your ears and hearing sensitivity will be examined as well as a simple vision screening, the other will be a short survey of your demographic information, such as age and education. The session will take approximately an hour and a half.

RISKS AND DISCOMFORTS: There are no anticipated risks to your health from participating in this experiment. You may experience a modest degree of fatigue from the concentration required during the performance of the task.

Wichita State University does not provide medical treatment or other forms of reimbursement to persons injured as a result of or in connection with participation in research activities conducted by Wichita State University or its faculty, staff or students. If you believe that you have been injured as a result of participating in the research covered by this consent form, you can contact the Office of Research Administration, Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

BENEFITS: Although the results of this specific experiment will not provide a direct benefit to you, it could have substantial impact on understanding the factors that affect speech perception.

FINANCIAL COMPENSATION: You will receive course credit for your participation in this study.

CONFIDENTIALITY: Any information in this study in which you can be identified will remain confidential and will be disclosed only with your permission. At the beginning of your participation you will be assigned a participant number under which your data will be recorded. Your name will not be directly associated with any of the data collected.

VOLUNTARY PARTICIPATION: Participation in this study is entirely voluntary. Your decision whether or not to participate will not affect your future relations with Wichita State University. If you agree to participate in this study, you are free to withdraw from the study at any time free from penalty.

OFFER TO ANSWER QUESTIONS: If you have any questions about the instructions or would like any information clarified do not hesitate to ask the experimenter. If later you have additional questions, contact: Dr. Alex Chaparro at Wichita State University, 978-3038. If you have questions pertaining to your rights as a research participant, or about research-related injury, you can contact the Office of Research Administration at Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

INFORMED CONSENT REQUIREMENTS: If you wish, you may have a copy of this consent form. You are making a decision about whether or not to participate in this study. Your signature indicates that you have read the information provided above and have voluntarily decided to participate.

____________________________________ ____________________
Signature of Subject Date

____________________________________ ____________________
Signature of Primary Investigator Date

APPENDIX A-2

CONSENT FORM: STUDY 2

PURPOSE: This study involves a number of components. As a participant, we will evaluate your hearing, vision, and speech perception. This study hopes to provide information about the effect of age-related changes in visual, hearing and cognitive skills related to speech perception.

INVITATION TO PARTICIPATE: Since you are 18 years of age or older, you are invited to participate in a study investigating speech perception. We need 20 participants for this study. You were selected as a possible participant in this study because you fit the criteria of the population we are interested in studying (namely you are a college student at WSU). In order to decide whether or not you should agree to be part of this research study, you should understand enough about the risks and benefits to make an informed judgment. This process is known as informed consent. This consent form gives detailed information about the research study which the investigator will discuss with you. Once you understand the study, you will be asked to sign this form if you wish to participate.

EXPLANATION OF PROCEDURES: If you decide to participate, we will than begin by asking you a few questions regarding your demographics, such as age and education. This study involves several components, and we will be testing your vision, hearing, and speech perception using various tests. Your hearing will be tested by the experimenter whereby your ears and hearing capabilities will be tested. Simple vision testing will also be performed. This session will take approximately an hour and a half, with intermittent breaks.

CONFIDENTIALITY: Any information obtained in this study in which you can be identified will remain confidential and will be disclosed only with your permission. At the beginning of your participation, you will be given a participant number. This number will be used to keep track of your data, so your name will not be associated with any of the data collected.

RISKS AND DISCOMFORTS: There are no anticipated risks to your health from participating in this experiment. You may experience a modest degree of fatigue from the concentration required during the performance of the task.

Wichita State University does not provide medical treatment or other forms of reimbursement to persons injured as a result of or in connection with participation in research activities conducted by Wichita State

University or its faculty, staff or students. If you believe that you have been injured as a result of participating in the research covered by this consent form, you can contact the Office of Research Administration, Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

BENEFITS: Although the results of this specific experiment will not provide a direct benefit to you, it could have substantial impact on understanding the factors that affect speech perception.

FINANCIAL COMPENSATION: You will receive course credit for your participation in this study.

VOLUNTARY PARTICIPATION: Participation is entirely voluntary. Your decision whether or not to participate will not affect your future relations with Wichita State University. If you decide to participate, you may withdraw from the study at any time without affecting your status with Wichita State University.

OFFER TO ANSWER QUESTIONS: If you have any questions about the instructions or would like any information clarified do not hesitate to ask the experimenter. If later you have additional questions, contact: Dr. Alex Chaparro at Wichita State University, 978-3038. If you have questions pertaining to your rights as a research participant, or about research-related injury, you can contact the Office of Research Administration at Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

If you wish, you may have a copy of this consent form. You are making a decision whether or not to participate. Your signature indicates that you have read the information provided above and have voluntarily decided to participate.

______________________________________ ________________________

Signature of Participant Date

______________________________________ ________________________

Signature of Investigator Date

APPENDIX A-3

CONSENT FORM: STUDIES 3-6

Purpose: You are invited to participate in a study of the effects of vision on speech perception. We will evaluate your vision, hearing, and speech perception. This study will provide information about the effect of age-related changes in visual, hearing and cognitive skills related to speech perception

.

Participant Selection: You have been invited to participate in this study because you are one of 80 subjects who represent a group of students that we are interested in studying. You have been chosen because you fit the age requirements (ages 18-40), you speak Mainstream American English as a first language, have no history of hearing loss, visual impairment or cognitive impairment.

Explanation of Procedures: In order to decide whether or not you should agree to be part of this research study, you should understand enough about the risks and benefits to make an informed judgment. This process is known as informed consent. This consent form gives detailed information about the research study which the investigator will discuss with you. Once you understand the study, you will be asked to sign this form if you wish to participate. This experiment will last approximately one hour to one and a half hours.

This study involves a number of components. We will evaluate your vision, hearing and speech perception using standard tests. This will be completed in a series of tests. Some tests will be administered by the experimenter in which your ear and hearing sensitivity will be examined as well as a simple vision test, the other will be a survey on the computer. Your vision and hearing must be corrected to normal. If you do not meet the requirements of vision or hearing, you will be excluded from the experiment, but will still receive full credit for your participation. In this case of exclusion, the experimenter will refer you to your vision or hearing specialist to fully examine your vision or hearing. If you do not already have a vision or hearing specialist, the experimenter will provide you with information to see a licensed vision or hearing specialist.

You will proceed in the experiment if your vision and hearing is found to be normal. You will be required to watch a video of a person speaking everyday speech sentences and you will be required report the sentences that you have heard. During this time you will be required to wear different glasses simulating different visual conditions, one of which will change the quality of your vision only while wearing them. The experimenter will provide feedback to you about the experiment and how your participation contributed to it once your session has been completed.

Discomforts/Risks: There are no anticipated risks to your health from participating in this experiment. You may experience a modest degree of fatigue from the concentration required during the performance of the task. You may feel fatigued or frustrated by the noisy conditions at times while listening to the videos. However, you will be provided a break from the speech testing section of the experiment to allow you to rest.

Benefits: Although the results of this specific experiment will not provide a direct benefit to you, it could have substantial impact on understanding the factors that affect speech perception.

Confidentiality: Any information in this study in which you can be identified will remain confidential and will be disclosed only with your permission. At the beginning of your participation you will be assigned a participant number under which your data will be recorded. Your name will not be directly associated with any of the data collected.

Compensation or treatment: There is no financial compensation for this study. Wichita State University does not provide medical treatment or other forms of reimbursement to persons injured as a result of or in connection with participation in research activities conducted by Wichita State University or its faculty, staff, or students. If you believe that you have been injured as a result of participating in the research covered by this consent form, you can contact the Office of Research Administration, Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

Refusal/Withdrawal: Participation in this study is entirely voluntary. Your decision whether or not to participate will not affect your future relations with Wichita State University. If you agree to participate in this study, you are free to withdraw from the study at any time free from penalty.

Contact: If you have any questions about the instructions or would like any information clarified do not hesitate to ask the experimenter. If later you have additional questions, contact: Dr. Alex Chaparro at Wichita State University, 978-3038. If you have questions pertaining to your rights as a research participant, or about research-related injury, you can contact the Office of Research Administration at Wichita State University, Wichita, KS 67260-0007, telephone (316) 978-3285.

You are under no obligation to participate in this study. You are making a decision about whether or not to participate in this study. Your signature indicates that you have read the information provided above and have voluntarily decided to participate.

________________________________ __________________
Signature of Subject Date

________________________________ __________________
Signature of Primary Investigator Date

APPENDIX B-1
DISTANCE VISUAL ACUITY TEST

The participant stood four meters from the Snellen eye chart with the center of the chart at eye level of the participant. The experimenter verbally instructed the participant as follows: "Stand on the marked line and read down the row of letters on the chart when I point to it. As you read down, each row of letters will reduce in size. If you cannot make out the letter, please guess the letter. As you read the letters, keep your eyes fully open and do not squint. Do you understand? Do you have any questions?"

APPENDIX B-2
NEAR VISUAL ACUITY TEST

The participant stood at a table where a Snellen near acuity eye chart was laid. Participants was handed a string attached to the chart and was asked to position their head over the chart at the same distance as the length of the string. The experimenter verbally instructed the participant as follows: "Please hold this string in between your eyes to position your head the same distance as the length of the string. Once you have your head at that distance, you can release the string but keep your head stationary. As you read down, each row of letters will reduce in size. If you cannot make out the letter, please guess the letter. As you read the letters, keep your eyes fully open and do not squint. Do you understand? Do you have any questions?"

APPENDIX B-3
CONTRAST SENSITIVITY TEST

The participant stood one meter from the Peli-Robson Contrast Sensitivity Chart. The instructions for this test were as follows: “Stand on this marked line. Read the groups of three letters from left to right when I point to it. As you read down each group, the letters will reduce in contrast. If you cannot make out the letters, please guess the letter. As you read the letters, keep your eyes open, do not squint or lean forward. Do you understand? Do you have any questions?”

APPENDIX B-4
COLOR BLINDNESS SCREENING

Participants was handed a book containing the Ishihara Color Plates. Participants were asked to identify the numbers within the color plates or to trace the pattern in the color plate with their finger. The instructions for this test were as follows: “Please read the numbers in each of the colored circles as I turn the page. Please trace your finger over the pattern, without touching the paper, on the color plates that you see a curved line. Do you understand? Do you have any questions?”

APPENDIX B-5
HEARING TEST

The participant responded to the presence of a pure tone signal presented through headphones during the screening test. The instructions for the participants were as follows: “You are going to hear some tones. Some of the tones will be very soft. When you hear the tones, raise your hand and put it back down. Please raise your hand even if you only think you heard the tone. Do you understand? Do you have any questions?”

APPENDIX C
PARTICIPANT'S INSTRUCTIONS FOR *EVERYDAY SPEECH SENTENCES*: Live-Voice

Brief Instructions (Given by Nichole: Talker):

Thank you for participating in our experiment. Today we will be examining speech comprehension which will involve you listening to me say everyday sentences under different conditions. Before we can begin, we must screen your vision and hearing to determine if it is within normal levels to proceed.

Full Instructions (Given by Experimenter):

In the experiment, you will hear Nichole saying everyday speech sentences while you are in one of 5 conditions. You will be asked to wear three different color coded glasses. You will sit across from Nichole and listen to her speak. Please keep your head straight and look right at her. The conditions that you will be under will be written will be on top of each answer sheet. Once Nichole puts on her glasses, you may then pick up yours. Nichole cannot be aware of which condition you are in, if you have a question please turn toward the window and signal me to come in and answer it. Please keep your answer sheet out of Nichole's view until she has on her glasses. You will be cued by Nichole with a bell chime just before a sentences is spoken and just after, please be ready. Once you hear the sentence you will write it on the sheet of paper in front of you. Please write the sentence as clearly as you can. You should write exactly what you heard her say. There will, at times, be contractions in the sentences. It is okay to write them if it is what you think you heard. Please to do not use any abbreviations. It is okay to leave omissions within the sentences for places you missed, but please try to write something for each of the sentences. Some of the different conditions you are under may make it difficult to see what and where you are writing, so once Nichole has completed the sentence, you may remove your glasses to write what you heard. Once you place the glasses back on, I will know you are prepared for the next sentence. If you completely could not make out anything in the sentence write N/A and then skip to the next line for the next sentence. Each page has lines for 10 sentences. Each group of 10 sentences will be considered one list. After each list, there will be a pause in the background noise which will signify to you to go to the next answer sheet and appropriately change your glasses according to the instructions on the answer sheet. Once we complete 3 lists, we will take a break. After the break, we will repeat the 3 conditions on 3 new lists. Then we will explain the purpose of your participation and you will be free to go. Do you have any questions??

APPENDIX D
CID *EVERYDAY SPEECH SENTENCES*

Note: Underlined words denote scoreable items.

List 1

1. Walking's my favorite exercise.
2. Here's a nice quiet place to rest.
3. Our Janitor sweeps the floors every night.
4. It would be much easier if everyone would help.
5. Good morning.
6. Open your windows before you go to bed.
7. Do you think that she should stay out so late?
8. How do you feel about changing the time when we begin work?
9. Here we go.
10. Move out of the way!

List 2

1. The water's too cold for swimming.
2. Why should I get up so early in the morning?
3. Here are your shoes.
4. It's raining.
5. Where are you going?
6. Come here when I call you!
7. Don't try to get out of it this time.
8. Should we let little children go to the movies by themselves?
9. There isn't enough paint to finish the room.
10. Do you want an egg for breakfast?

List 3

1. Everybody should brush his teeth after meals.
2. Everything's all right.
3. Don't use up all the paper when you write your letter.
4. That's right.
5. People ought to see a doctor once a year.
6. Those windows are so dirty I can't see anything outside.
7. Pass the bread and butter please!
8. Don't forget to pay your bill before the first of the month.
9. Don't let the dog out of the house.
10. There's a good ballgame this afternoon.

APPENDIX D (continued)

List 4

1. It’s time to go.
2. If you don’t want those old magazines, throw them out.
3. Do you want to wash up?
4. It’s a real dark night so watch your driving.
5. I’ll carry the package for you.
6. Did you forget to shut off the water?
7. Fishing in a mountain stream is my idea of a good time.
8. Fathers spend more time with their children than they used to.
9. Be careful not to break your glasses!
10. I’m sorry.

List 5

1. You can catch the bus across the street.
2. Call her on the phone and tell her the news.
3. I’ll catch up with you later.
4. I’ll think it over.
5. I don’t want to go to the movies tonight.
6. If you tooth hurts that much you ought to see a dentist.
7. Put that cookie back in the box!
8. Stop fooling around!
9. Time’s up.
10. How do you spell your name?

List 6

1. Music always cheers me up.
2. My brother’s in town for a short while on business.
3. We live a few miles from the main road.
4. This suit needs to go to the cleaners.
5. They ate enough green apples to make them sick for a week.
6. Where have you been all this time?
7. Have you been working hard lately?
8. There’s not enough room in the kitchen for a new table.
9. Where is he?
10. Look out!

APPENDIX D (continued)

List 7

1. I’ll see you right after lunch.
2. See you later.
3. While shoes are awful to keep clean.
4. Stand there and don’t move until I tell you!
5. There’s a big piece of cake left over from dinner.
6. Wait for me at the corner in front of the drugstores.
7. It’s no trouble at all.
8. Hurry up!
9. The morning paper didn’t say anything about rain this afternoon or tonight.
10. The phone call’s for you.

List 8

1. Believe me!
2. Let’s get a cup of coffee.
3. Let’s get out of here before it’s too late.
4. I hate driving at night.
5. There was water in the cellar after that heavy rain yesterday.
6. She’ll only be gone a few minutes.
7. How do you know?
8. If we don’t get rain soon, we’ll have no grass.
9. They’re not listed in the new phone book.

List 9

1. Where can I find a place to park?
2. I like those big red apples we always get in the fall.
3. You’ll get fat eating candy.
4. The show’s over.
5. Why don’t they paint their walls some other color?
6. What’s new?
7. What are you hiding under your coat?
8. How come I should always be the one to go first?
9. I’ll take sugar and cream in my coffee.
10. Wait just a minute!

APPENDIX D (continued)

List 10

1. Breakfast is ready.
2. I don’t know what’s wrong with the car, but it won’t start.
3. It sure takes a sharp knife to cut this meat.
4. I haven’t read a newspaper since we bought a television set.
5. Weeds are spoiling the yard.
6. Call me a little later!
7. Do you have change for a five –dollar bill?
8. How are you?
9. I’d like some ice cream with my pie.
10. I don’t think I’ll have any dessert.

APPENDIX E-1

PARTICIPANT'S INSTRUCTIONS FOR SIN SENTENCES: STUDY 2

Thank You for participating in our experiment today. In the experiment you will hear Nichole saying everyday speech sentences while you are in one of three conditions. You will record what you heard on the answer sheet I have provided you. You will be asked to wear three different color coded glasses, Brown, Black, or White.

Nichole will be on the television saying the sentences, when she is, make sure you are staring straight at her even if it is difficult to see.

While you are listening to Nichole, there will be a lot of distracting noise, just try your best to make out the sentences. Now, on the top of your sheet it will tell you which glasses to wear. Please write the sentence as clearly as you can, large and in print. Write exactly what you heard her say. Do not abbreviate, and write possible contractions how you think Nichole said them. If you think she said cannot, write cannot, if you think she said can't, write can't. It is okay to leave omissions within the sentence for places you missed, but please try to write something for each sentence. If you heard, "The dog (blank) the house", write The Dog ---- the house. Some of the conditions you are under will make it difficult to see so when you go to write the sentence feel free to remove or lift up the glasses in order to write. If you slide them onto your head this will go quicker than if you take them completely off. If you completely could not make anything out in the sentence write N/A and then skip to the next line for the next sentence.

We will do a verbal practice before we start. On the television, Nichole will say two sentences and you will just verbally repeat what she said back. We will then start the experiment.

Practice:

Each page of 10 sentences is considered a list. After each list there will be a pause in background noise which will signify you to go to the next page in the answer sheet and appropriately change your glasses according to the instructions on the answer sheet. Once we have completed 6 lists we will take a break and let the booth cool down, you can get some fresh air, or walk around. After the break we will repeat the three conditions on 6 new lists, and then take another break before we finish up with the last set of three lists. When we have completed the experiment we will explain the purpose of your participation and you will be free to go. Do you have any questions?

APPENDIX E-2

PARTICIPANT'S INSTRUCTIONS FOR SIN SENTENCES: LUMINANCE CONTROLLED: STUDY 3-4

Thank You for participating in our experiment today. In the experiment you will hear Nichole saying everyday speech sentences while you are in one of three conditions. You will record what you heard on the answer sheet I have provided you. You will be asked to wear two different color coded glasses, Black or White.

Nichole will be on the television saying the sentences, when she is, make sure you are staring straight at her even if it is difficult to see.

While you are listening to Nichole, there will be a lot of distracting noise, just try your best to make out the sentences. Now, on the top of your sheet it will tell you which glasses to wear. Please write the sentence as clearly as you can, large and in print. Write exactly what you heard her say. Do not abbreviate, and write possible contractions how you think Nichole said them. If you think she said cannot, write cannot, if you think she said can't, write can't. It is okay to leave omissions within the sentence for places you missed, but please try to write something for each sentence. If you heard, "The dog (blank) the house", write The Dog ---- the house. Some of the conditions you are under will make it difficult to see so when you go to write the sentence feel free to remove or lift up the glasses in order to write. If you slide them onto your head this will go quicker than if you take them completely off. If you completely could not make anything out in the sentence write N/A and then skip to the next line for the next sentence.

We will do a verbal practice before we start. On the television, Nichole will say two sentences and you will just verbally repeat what she said back. We will then start the experiment.

Each page of 10 sentences is considered a list. After each list there will be a pause in background noise which will signify you to go to the next page in the answer sheet and appropriately change your glasses according to the instructions on the answer sheet. Once we have completed 6 lists we will take a break and let the booth cool down, you can get some fresh air, or walk around. After the break we will repeat the three conditions on 6 new lists. When we have completed the experiment we will explain the purpose of your participation and you will be free to go. Do you have any questions?

APPENDIX E-3

PARTICIPANT'S INSTRUCTIONS FOR SIN SENTENCES:

LUMINANCE VARIABLE: STUDY 5-6

Thank You for participating in our experiment today. In the experiment you will hear Nichole saying everyday speech sentences while you are in one of three conditions. You will record what you heard on the answer sheet I have provided you. You will be asked to wear three different color coded glasses, Black, Brown, or White.

Nichole will be on the television saying the sentences, when she is, make sure you are staring straight at her even if it is difficult to see.

While you are listening to Nichole, there will be a lot of distracting noise, just try your best to make out the sentences. Now, on the top of your sheet it will tell you which glasses to wear. Please write the sentence as clearly as you can, large and in print. Write exactly what you heard her say. Do not abbreviate, and write possible contractions how you think Nichole said them. If you think she said cannot, write cannot, if you think she said can't, write can't. It is okay to leave omissions within the sentence for places you missed, but please try to write something for each sentence. If you heard, "The dog (blank) the house", write The Dog ---- the house. Some of the conditions you are under will make it difficult to see so when you go to write the sentence feel free to remove or lift up the glasses in order to write. If you slide them onto your head this will go quicker than if you take them completely off. If you completely could not make anything out in the sentence write N/A and then skip to the next line for the next sentence.

Throughout the experiment, we will be changing the filters hanging on the front of the television. These filters are designed to restrict the light flow of the television. Once we remove a filter, you will experience the very bright television behind it. This will be uncomfortable for your eyes because they will be dark adapted. To prevent any discomfort and to ensure your eyes stay dark adapted, please put on the large black glasses provided to you on the left side of your writing desk. We will refer to these glasses as the “big black glasses”. When we come into the booth to change a filter, please put on the big black glasses and close your eyes. Once I have added the new filter, I will let you know that it is safe to open your eyes and remove the glasses.

We will do a verbal practice before we start. On the television, Nichole will say two sentences and you will just verbally repeat what she said back. We will then start the experiment.

Each page of 15 sentences is considered a list. After each list there will be a pause in background noise which will signify you to go to the next page in the answer sheet and appropriately change your glasses according to the instructions on the answer sheet. Once we have completed 4 lists we will take a break. However, the break must take place within the sound booth to keep your eye dark adapted for the second half of the experiment. After the break we will repeat the three conditions on 4 new lists. When we have completed the experiment we will explain the purpose of your participation and you will be free to go. Do you have any questions?

APPENDIX F

SPEECH IN NOISE (SIN) SENTENCES

Note: Underlined words denote scoreable items.

Block 1 (list 1-4)
List 1

1. The *birch* *canoe* *slid* on the *smooth* *planks*.

2. *Glue* the *sheet* to the *dark* *blue* *background*.

3. *It's* *easy* to *tell* the *depth* of a *well*.

4. These *days* a *chicken* *leg* is a *rare* *dish*.

5. *Rice* is *often* *served* in *round* *bowls*.

6. The *juice* of *lemons* *makes* *fine* *punch*.

7. The *box* was *thrown* *beside* the *parked* *truck*.

8. The *hogs* were *fed* *chopped* *corn* and *garbage*.

9. *Four* *hours* of *steady* *work* *faced* us.

10. A *large* *size* in *stockings* is *hard* to *sell*.

List 2

1. The *boy* was *there* *when* the *sun* *rose*.

2. A *rod* is *used* to *catch* *pink* *salmon*.

3. The *source* of the *huge* *river* is the *clear* *spring*.

4. *Kick* the *ball* *straight* and *follow* *through*.

5. *Help* the *woman* *get* *back* to her *feet*.

6. A *pot* of *tea* *helps* to *pass* the *evening*.

7. *Smokey* *fires* *lack* *flame* and *heat*.

8. The *soft* *cushion* *broke* the *man's* *fall*.

9. The *salt* *breeze* *came* *across* from the *sea*.

10. The *girl* at the *booth* *sold* *fifty* *bonds*.

APPENDIX F (CONTINUED)

List 3

1. The *small* *pup* *gnawed* a *hole* in the *sock*.
2. The *fish* *twisted* and *turned* on the *bent* *hook*.
3. *Press* the *pants* and *sew* a *button* on the *vest*.
4. The *swan* *dive* was *far* *short* of *perfect*.
5. The *beauty* of the *view* *stunned* the *young* *boy*.
6. *Two* *blue* *fish* *swam* in the *tank*.
7. *Her* *purse* was *full* of *useless* *trash*.
8. The *colt* *reared* and *threw* the *tall* *rider*.
9. It *snowed*, *rained*, and *hailed* the *same* *morning*.
10. *Read* *verse* *out* *loud* for *pleasure*.

List 4

1. *Hoist* the *load* to *your* *left* *shoulder*.
2. *Take* the *winding* *path* to *reach* the *lake*.
3. *Note* *closely* the *size* of the *gas* *tank*.
4. *Wipe* the *grease* *off* his *dirty* *face*.
5. *Mend* the *coat* *before* you *go* *out*.
6. The *wrist* was *badly* *strained* and *hung* *limp*.
7. The *stray* *cat* *gave* *birth* to *kittens*.
8. The *young* *girl* *gave* no *clear* *response*.
9. The *meal* was *cooked* *before* the *bell* *rang*.
10. *What* *joy* *there* *is* in *living*.

Block 2 (list 5-8)

List 5

1. A *king* *ruled* the *state* in the *early* *days*.
2. The *ship* was *torn* *apart* on the *sharp* *reef*.
3. *Sickness* *kept* him *home* the *third* *week*.
4. The *wide* *road* *shimmered* in the *hot* *sun*.
5. The *lazy* *cow* *lay* in the *cool* *grass*.
6. *Lift* the *square* *stone* *over* the *fence*.
7. The *rope* will *bind* the *seven* *books* at *once*.
8. *Hop* *over* the *fence* and *plunge* *in*.
9. The *friendly* *gang* *left* the *drug* *store*.
10. *Mesh* *wire* *keeps* *chicks* *inside*.

List 6

1. The *frosty* *air* *passed* *through* the *coat*.
2. The *crooked* *maze* *failed* to *fool* the *mouse*.
3. *Adding* *fast* *leads* to *wrong* *sums*.
4. The *show* was a *flop* *from* the *very* *start*.
5. A *saw* is a *tool* *used* for *making* *boards*.
6. The *wagon* *moved* on *well* *oiled* *wheels*.
7. *March* the *soldiers* past the *next* *hill*.
8. A *cup* of *sugar* *makes* *sweet* *fudge*.
9. *Place* a *rosebush* *near* the *porch* *steps*.
10. *Both* *lost* their *lives* in the *raging* *storm*.

List 7

1. *We* *talked* of the *side* *show* in the *circus*.

2. *Use* a *pencil* to *write* the *first* *draft*.

3. He *ran* *half* *way* to the *hardware* *store*.

4. The *clock* *struck* to *mark* the *third* *period*.

5. A *small* *creek* *cut* *across* the *field*.

6. *Cars* and *busses* *stalled* in *snow* *drifts*.

7. The *set* of *china* *hit* the *floor* with a *crash*.

8. This is a *grand* *season* for *hikes* *on* the *road*.

9. The *dune* *rose* *from* the *edge* of the *water*.

10. *Those* *words* were the *cue* for the *actor* to *leave*.

List 8

1. A *yacht* *slid* *around* the *point* into the *bay*.

2. The *two* *met* *while* *playing* on the *sand*.

3. The *ink* *stain* *dried* on the *finished* *page*.

4. The *walled* *town* was *seized* *without* a *fight*.

5. The *lease* *ran* *out* in *sixteen* *weeks*.

6. A *tame* *squirrel* *makes* a *nice* *pet*.

7. The *horn* of the *car* *woke* the *sleeping* *cop*.

8. The *heart* *beat* *strongly* and with *firm* *strokes*.

9. The *pearl* was *worn* in a *thin* *silver* *ring*.

10. The *fruit* *peel* was *cut* in *thick* *slices*.

Block 3 (list 9-12)

List 9

1. The *navy* *attacked* the *big* *task* *force*.
2. *See* the *cat* *glaring* at the *scared* *mouse*.
3. *There* are *more* than *two* *factors* *here*.
4. The *hat* *brim* was *wide* and *too* *droopy*.
5. The *lawyer* *tried* to *lose* *his* *case*.
6. The *grass* *curled* *around* the *fence* *post*.
7. *Cut* the *pie* *into* *large* *parts*.
8. *Men* *strive* but *seldom* *get* *rich*.
9. *Always* *close* the *barn* *door* *tight*.
10. He *lay* *prone* and *hardly* *moved* a *limb*.

List 10

1. The *slush* *lay* *deep* *along* the *street*.
2. A *wisp* of *cloud* *hung* in the *blue* *air*.
3. A *pound* of *sugar* *costs* *more* than *eggs*.
4. The *fin* was *sharp* and *cut* the *clear* *water*.
5. The *play* *seems* *dull* and *quite* *stupid*.
6. *Bail* the *boat* to *stop* it *from* *sinking*.
7. The *term* *ended* in *late* *June* that *year*.
8. A *tusk* is *used* to *make* *costly* *gifts*.
9. *Ten* *pins* were *set* *in* *order*.
10. The *bill* was *paid* *every* *third* *week*.

List 11

1. *Oak* is *strong* and *also* *gives* *shade*.
2. *Cats* and *dogs* *each* *hate* the *other*.
3. The *pipe* *began* to *rust* *while* *new*.
4. *Open* the *crate* but *don't* *break* the *glass*.
5. *Add* the *sum* to the *product* of *these* *three*.
6. *Thieves* who *rob* *friends* *deserve* *jail*.
7. The *ripe* *taste* of *cheese* *improves* with *age*.
8. *Act* on *these* *orders* with *great* *speed*.
9. The *hog* *crawled* *under* the *high* *fence*.
10. *Move* the *vat* *over* the *hot* *fire*.

List 12

1. The *bark* of the *pine* *tree* was *shiny* and *dark*.
2. *Leaves* *turn* *brown* and *yellow* in the *fall*.
3. The *pennant* *waved* *when* the *wind* *blew*.
4. *Split* the *log* with a *quick* *sharp* *blow*.
5. *Burn* *peat* *after* the *logs* are *out*.
6. He *ordered* *peach* *pie* with *icecream*.
7. *Weave* the *carpet* on the *right* *hand* *side*.
8. *Hemp* is a *weed* *found* in *parts* of the *tropics*.
9. A *lame* *back* *kept* his *score* *low*.
10. *We* *find* *joy* in the *simplest* *things*.

Block 9 (list 33-36)

List 33

1. *Fill* the *ink* *jar* with *sticky* *glue*.
2. He *smokes* a *big* *pipe* with *strong* *contents*.
3. We *need* *grain* to *keep* our *mules* *healthy*.
4. *Pack* the *records* in a *neat* *thin* *case*.
5. The *crunch* of *feet* in the *snow* was the *only* *sound*.
6. The *copper* *bowl* *shone* in the *sun's* *rays*.
7. *Boards* will *warp* *unless* *kept* *dry*.
8. The *plush* *chair* *leaned* *against* the *wall*.
9. *Glass* will *clink* when *struck* *by* *metal*.
10. *Bathe* and *relax* in the *cool* *green* *grass*.

List 34

1. *Nine* *rows* of *soldiers* *stood* in *line*.
2. The *beach* is *dry* and *shallow* at *low* *tide*.
3. The *idea* is to *sew* *both* *edges* *straight*.
4. The *kitten* *chased* the *dog* *down* the *street*.
5. *Pages* *bound* in *cloth* *make* a *book*.
6. *Try* to *trace* the *fine* *lines* of the *painting*.
7. *Women* *form* *less* than *half* of the *group*.
8. The *zones* *merge* in the *central* *part* of *town*.
9. A *gem* in the *rough* *needs* *work* to *polish*.
10. *Code* is *used* *when* *secrets* are *sent*.

List 35

1. *Most* of the *news* is *easy* for *us* to *hear*.
2. He *used* the *lathe* to *make* *brass* *objects*.
3. The *vane* on *top* of the *pole* *revolved* in the *wind*.
4. *Mince* *pie* is a *dish* *served* to *children*.
5. The *clan* *gathered* on *each* *dull* *night*.
6. *Let* it *burn*, it *gives* us *warmth* and *comfort*.
7. A *castle* *built* from *sand* *fails* to *endure*.
8. A *child's* *wit* *saved* the *day* for *us*.
9. *Tack* the *strip* of *carpet* to the *worn* *floor*.
10. *Next* *Tuesday* *we* *must* *vote*.

List 36

1. *Pour* the *stew* from the *pot* *into* the *plate*.
2. *Each* *penny* *shone* *like* new.
3. The *man* *went* to the *woods* to *gather* *sticks*.
4. The *dirt* *piles* were *lined* *along* the *road*.
5. The *logs* *fell* and *tumbled* into the *clear* *stream*.
6. *Just* *hoist* it *up* and *take* it *away*.
7. A *ripe* *plum* is *fit* for a *king's* *palate*.
8. *Our* *plans* *right* *now* are *hazy*.
9. *Brass* *rings* are *sold* by *these* *natives*.
10. It *takes* a *good* *trap* to *capture* a *bear*.

APPENDIX G-1
RESPONSE SHEET: NORMAL VISION (STUDY 1-4)
AND AUDITORY-ONLY: (STUDY 3-4)

(Put on the **WHITE** Glasses)
Please print sentences clearly.

Code ________

1. ____

2. ____

3. ____

4. ____

5. ____

6. ____

7. ____

8. ____

9. ____

10. ____

APPENDIX G-2

RESPONSE SHEET: SIMULATED CATARACT VISION (STUDY 1-4)

(Put on the **BLACK** Glasses)
Please print sentences clearly.

Code ________

1. ____

2. ____

3. ____

4. ____

5. ____

6. ____

7. ____

8. ____

9. ____

10. ____

APPENDIX G-3

RESPONSE SHEET: AUDITORY-ONLY (STUDY 1-3)

(Put on the **BROWN** Glasses)
Please print sentences clearly. Code ________

1. ____

2. ____

3. ____

4. ____

5. ____

6. ____

7. ____

8. ____

9. ____

10. ____

APPENDIX G-4

RESPONSE SHEET: AUDITORY-ONLY, NORMAL VISION AND SIMULATED

CATARACT VISION (STUDY 5-6)

(Put on the **WHITE** Glasses)

1.____

2.____

3.____

4.____

5.____

(Put on the **BROWN** Glasses)

1.____

2.____

3.____

4.____

5.____

(Put on the **BLACK** Glasses)

1.____

2.____

3.____

4.____

5.____