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Effects of Simulated Cataracts on Speech Intelligibility

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ABSTRACT

Limited research is available on how well visual cues integrate with auditory cues to improve speech intelligibility in persons with visual impairments, such as cataracts. We investigated whether simulated cataracts interfered with participants' ability to use visual cues to help disambiguate a spoken message in the presence of spoken background noise. We tested 21 young adults with normal visual acuity and hearing sensitivity. Speech intelligibility was tested under three conditions: auditory only with no visual input, auditory-visual with normal viewing, and auditory-visual with simulated cataracts. Central Institute for the Deaf (CID) *Everyday Speech Sentences* were spoken by a live talker, mimicking a pre-recorded audio track, in the presence of pre-recorded four-person background babble at a signal-to-noise ratio (SNR) of -13 dB. The talker was masked to the experimental conditions to control for experimenter bias. Relative to the normal vision condition, speech intelligibility was significantly poorer, [t (20) = 4.17, $p < .01$, Cohen's d =1.0], in the simulated cataract condition. These results suggest that cataracts can interfere with speech perception, which may occur through a reduction in visual cues, less effective integration or a combination of the two effects. These novel findings contribute to our understanding of the association between two common sensory problems in adults: reduced contrast sensitivity associated with cataracts and reduced face-to-face communication in noise.

1. INTRODUCTION

Cataracts represent the most common cause of visual impairment worldwide (Attebo, Mitchell, & Smith, 1996). In a recent study, 72% of adults aged 49 years and older had cataracts or had undergone cataract surgery over a 10 year follow-up period (Kanthan et al., 2008). Importantly, as the population continues to age, the number of older adults with cataracts will increase further, given that the prevalence of cataracts increases significantly with increasing age (Congdon et al., 2004). Visual impairment resulting from cataracts may hinder a person's independence in daily functions like walking, reading and driving. Less obvious is the suggestion, made by professionals in the speech and hearing sciences, that cataracts and other forms of visual impairment may hinder speech reading (Erber & Scherer, 1999; Karp, 1988; Tye-Murray, 2009). Importantly, little research is available on how well visual cues are integrated with auditory cues to improve speech intelligibility in persons with cataracts.

Persons 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 the television (Massaro & Cohen, 1995). Anecdotal comments from patients suggest that visual degradation can interfere with the acquisition of visual cues associated with speech that facilitate verbal communication. A growing body of evidence supports patients' insights regarding 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 a spoken message is masked by background noise. They tested speech intelligibility of adults with and without view of the talker's facial and lip movements under different signal-to-noise ratios (SNR). Viewing the talker's face significantly improved participants' intelligibility when the noise had rendered speech unintelligible (Sumby & Pollack, (1954). Other findings have shown that viewing a talker's face improves detection of speech in noise (Grant, 2001; Grant & Seitz, 2000) and speech intelligibility

(Schwartz, Berthommier, & Savariaux, 2004). Visual cues can bias the perception of speech even under optimal listening and viewing conditions (McGurk & MacDonald, 1976). When participants hear an audio clip of a talker voicing /ba/ paired with a video clip showing the talker voicing /ga/ they report hearing /da/ not /ba/. This phenomenon, known as the McGurk effect, illustrates how visual and auditory cues are integrated by processes involved in speech perception (Cosatto & Graf, 1998, June; Munhall, Jones, Callan, Kuratate, & Vatikiotis-Bateson, 2004; Rosenblum, Johnson, & Saldaña, 1996).

The visual requirements of auditory-visual speech perception appear to be relatively modest as observers derive visual enhancement of speech even when visual acuity is reduced (Campbell, Zihl, Massaro, Munhall, & Cohen, 1997; Erber, 1979; Thomas & Jordan, 2002), when the mouth is viewed using peripheral vision (Paré, Richler, ten Hove, & Munhall, 2003), or when the image is made very small (Jordan & Sergeant, 2000; Munhall, Kroos, Jozan, & Vatikiotis-Bateson, 2004; Neely, 1956). A study using spatially filtered video clips (Munhall, Kroos, et al., 2004) indicates that information supporting speech recognition exists over a range of spatial frequencies, except at very low spatial frequencies (i.e., <1.8 cycles/face); though a mid-to-low band of spatial frequencies (~11 cycles/face) enhance audiovisual performance the most. The strength of the McGurk effect was diminished slightly at lower spatial frequencies suggesting that observers can derive useful information from large image features (Munhall, Kroos, et al., 2004). Listeners may use a variety of visual cues including the shape and movements of the lips and tongue, as well as features of the upper face including eye brows and movements of the head synchronized with speech (Rosenblum, Johnson, & Saldana, 1996; Cosatto & Graf, 1998; Munhall, Jones, Callan, Kuratate, & Vatiliotis-Bateson, 2004).

Despite evidence demonstrating the importance of visual information to speech perception, there have been only a limited number of studies that have explored the effects of true visual impairment on speech perception – other than reductions in visual acuity. Osborn, Erber and Galleti (2000) reported that patients with age-related macular degeneration with best-eye visual acuities of 20/200-20/3200, identified significantly fewer test words or phrases than age-matched normal observers. Wilson, Wilson, ten Hove, Paré, & Munhall (2008) tested patients with unilateral macular holes and reported that the McGurk effect was largely unchanged even when the affected eye was tested monocularly.

Several researchers have investigated the effects of simulated visual degradation on auditory-visual speech perception. Tye-Murray et al. (2008) evaluated discourse comprehension by young and older adults under favorable and unfavorable visual conditions. Unfavorable visual conditions were simulated by reducing the contrast of the original video files by 98%. The comprehension levels of the older adults were reduced disproportionally by the contrast reduction. Gordon and Allen (2009), likewise, reported that visual enhancement was abolished for older adults, but not for a group of younger adults under conditions of simulated blur that was estimated, but not demonstrated, to be comparable to 20/50 acuity. Their finding that the simulated blur had a pronounced effect on speech intelligibility for the older adults suggests that the level of blur may have been more severe than was estimated by the authors. Interpretation of these results is complicated because the commercial software applications (i.e., Adobe Premiere Pro 1.5, Adobe Premiere Elements) used to simulate visual degradation do not reproduce the optical effects of refractive blur including spurious resolution (Akutsu, Bedell, & Patel, 2000), or scattering of light caused by lens opacities. Recently, Dickinson and Taylor (2011) reported impaired speechreading ability with filters (Bangerter occlusion foils) that produced only small changes in visual acuity

(6/4.8→6/6, logMAR -0.1→0.0) and contrast sensitivity (24 dB→20.2 dB), assessed using the Melbourne Edge Test (version 2.4, chart 1). The interpretation of their findings, however, also poses problems because custom generated speech and noise stimuli were used rather than widely available, standardized stimuli. In addition, participants' hearing was not assessed to ensure that they had normal auditory sensitivity. Thus, it is unclear whether previous findings can be generalized to cataracts and other forms of commonly occurring visual impairments; or whether they are due to effects of visual impairment alone, or an interaction between hearing and visual impairment; this is an important issue because these conditions tend to co-exist in older adults (Chia et al., 2006). Finally, Thorn and Thorn (1989) investigated the effects of refractive blur on speechreading (i.e., understanding a spoken message by watching a speaker's mouth movements without hearing the speaker's voice) in one patient with cataracts and reported no effect. However, the absence of any added detrimental effect of blur is perhaps not all that surprising given the presence of the cataract. Speechreading may have been significantly compromised by the cataract (the cataracts already reduced visual acuity to 20/80) so any additional degradation of the visual image may have had little measureable impact on performance. Other studies of effects of refractive blur on speechreading indicate that performance is robust and that significant declines in speechreading are only observed when visual acuity is 20/60 (logMAR 0.48) or worse (Erber, 1979; Johnson & Snell, 1986).

Although cataracts have been cited anecdotally as a visual condition that may interfere with speechreading (Erber, 2002; Erber & Scherer, 1999; Karp, 1988; Tye-Murray, 2009), we are unaware of any systematic investigations of the effects of real or simulated cataracts on adult speech perception or auditory-visual integration. Studies of patients with bilateral congenital cataracts suggest that the presence of cataracts can interfere with the normal development of visual speech perception. Adults who had had bilateral congenital cataracts show a reduced McGurk effect (Putzar, Hötting, & Röder, 2010), and are significantly poorer at speechreading than age-matched controls who had normal vision during infancy (Putzar et al., 2010). Thus cataracts which affect contrast sensitivity may interfere with speech perception; though limitations in the experimental approaches adopted in these studies precludes clear conclusions being drawn.

The purpose of the current study was to investigate effects of simulated cataracts on auditory-visual speech perception in young adults. Young participants were selected because the visual effects of simulated cataracts on speech perception could be investigated independently of co-existing cognitive and sensory changes that are more common among older adults.

2. METHODS

2.1 Participants

Participants were 21 college students (7 males and 14 females) with a mean age of 23 yrs. ± 3.1 yrs. (age range 18 – 40 yrs.), who spoke American-English as their first language. They self-reported good general health, no neurological illness or cognitive impairment, and no ocular disease. All participants had distance visual acuity equal to or better than 20/20; normal color vision as assessed with the Ishihara color vision test; and normal pure-tone hearing sensitivity in both ears (i.e., equal to or better than 20 dB HL at octave frequencies from 250 Hz to 8000 Hz).

Vision Assessment

Distance visual acuity and letter contrast sensitivity were measured binocularly for each participant for each of the two visual conditions (no filter, cataract filter) presented in a random order. Visual acuity was tested using a high contrast (90%) EDTRS chart at a working distance of

4m under the recommended illumination conditions. Participants were instructed to read the letters from left to right on the chart and were encouraged to guess letters even when unsure. Visual acuity was scored letter by letter, with each letter correctly identified representing a score of 0.02 log units.

Letter contrast sensitivity was measured using the Pelli-Robson chart at 1m under the recommended viewing conditions (Pelli, Robson, & Wilkins, 1988). Participants were asked to read as far down the chart as they could; and were encouraged to look at a line of letters and guess the letter when they were unsure. Each letter reported correctly was scored as 0.05 log units.

2.2 Procedure

Testing was performed in a sound-treated booth used for hearing screening. The examiner's booth was a single-wall Industrial Acoustics Company (IAC) booth, and the participant's booth was a double-wall IAC booth that met ambient noise standards (ANSI S3.1-1991) for pure-tone threshold testing. Speech intelligibility was assessed using Central Institute for the Deaf (CID) *Everyday Speech Sentences* (Davis & Silverman, 1970). The *Everyday Speech Sentences* have been used in auditory and auditory-visual research because they consist of words that adults commonly use during daily conversations, while varying in length and grammatical structure (i.e., they offer 2 to 13 words per sentence with a distribution of declarative, imperative, exclamatory, and interrogative sentences).

Before initiating the experiment, we devoted extensive consideration and pilot testing regarding whether *Everyday Speech Sentences* should be presented from a televised, audio-video recording of a talker or through live, face-to-face presentation of a talker. Live presentations offer more realistic, three-dimensional viewing of a talker's face and more natural fidelity of a talker's voice. Live presentations can be problematic, however, due to potential variability in a talker's speech within and across presentations of speechreading stimuli. Even when talkers monitor their vocal intensity with a sound level meter during live presentations, they may consciously or subconsciously introduce bias by altering their speaking rate, articulation, and prosody.

Accordingly, to enhance consistency across presentations we developed a *Self-Monitored Live Voice (S-MLV)* technique, described shortly. This technique tended to preserve the external validity advantages of live speechreading presentations while maintaining internal validity advantages in the consistency of recorded speechreading presentations. Pilot testing, moreover, suggested *S-MLV* presentations were preferable to audio-video recordings televised on a high-resolution, digital, flat-screen television. Specifically, the three-dimensional face of a real talker was blurred when pilot participants viewed it live, face-to-face when wearing the simulated cataract glasses. Conversely, the televised talker's face looked unaltered when viewing through the same cataract glasses – even with standard screen adjustments in brightness and contrast

Based on our pilot studies, we thus employed the *S-MLV* technique during the experiment in an Industrial Acoustics of American, two-booth, sound suite. The audio portion of a DVD recording of *Everyday Speech Sentences* – originally produced at the National Technical Institute for the Deaf – was routed from an LG Super-Multi disk, DVD player to a Grason-Stadler 13, two-channel audiometer located in a single-wall (tester) booth. The sentences were then routed to EAR 5A, binaural, insert earphones located in a double-wall (participant) booth. The earphones were worn by a female talker (i.e., first author NLM) who was trained in the S-MLV technique during pilot testing to mimic the vocal characteristics of the female talker on the audio-video recording. Specifically, the recorded sentences were presented to each earphone at slightly different intensities that allowed her to perceive sentences at a similar loudness in each ear, resulting in a single, fused percept when presented binaurally. She then mimicked the loudness, rate, articulation, and prosody of each recorded sentence using a normal, conversational, vocal effort that consistently availed an average peak intensity of 62 dB SPL ± 2 dB (i.e. a normal, conversational, speech level), as measured one meter from her lips using the slow speed of a Quest 1700 sound level meter.

A compact disc recording of four-speaker babble (i.e. four adult's simultaneously reading different stories) was routed from a Maico 42, two-channel audiometer to a Samson two-channel amplifier in the single-wall booth. The babble was rerouted to two loudspeakers in the double-wall booth. The diaphragms of the loudspeakers were positioned at +125˚ and -125˚ azimuth and at the average height of participants' ears. The babble was calibrated to be presented binaurally to participants at 75 dB SPL. In other words, participants heard the sentences in a background of babble at -13 dB SNR. This SNR was determined in a pilot study to yield, on average, 50% accuracy in participants hearing key words in *Everyday Speech Sentences* under an auditory-only condition (see Figure 1). This SNR, moreover, avoided a ceiling effect in speech intelligibility for sentences played in an easier auditory-visual condition.

Insert Figure 1 here

A participant and talker sat facing one another in the double-wall sound booth approximately one meter apart; this resulted in a visual angle of approximately 4˚ measured from pupil to pupil of the talker's eyes. A small desk was positioned between the talker and participants. During the experiment, participants wrote the sentences that they heard on a pack of response sheets placed on the desk. The response sheets also indicated to participants which randomized experimental condition they were completing. Participants wore one of three sets of glasses with their optimal correction (if they had one) during each of three conditions: glasses with opaque lenses to mask the talker's face during an auditory-only (A) condition; glasses without lenses to view the talker's face during a "normal" auditory-visual (AV) condition; and glasses with cataract simulation filters to view the talker's face during a "cataract" AV condition. Cataracts were simulated using the Vistech™ cataract simulation filters (Vistech Consultants Inc., Dayton, OH). Elliot, Bullimore, Patla and Whitaker (1996) reported that the Vistech™ simulation glasses produce wide-angle, light scatter with an angular distribution similar to normal and cataractous eyes. They also have been shown to reduce contrast sensitivity more than visual acuity. Finally, the talker also wore identical glasses with opaque lenses throughout the experiment to ensure that she was masked as to which condition the participant was completing.

During the experiment, participants listened to three lists of 10 sentences randomized among the three conditions, yielding a total of 30 sentences for each condition. Participants were instructed to listen to each sentence, then remove their glasses and write on a response sheet each sentence exactly as they heard it. Participants were instructed to guess those words they were unsure of, and to leave blanks for words they could not understand. Finally, participants were instructed to put on the experimental glasses immediately after writing down each sentence. Meanwhile, an assistant in the single-wall booth controlled the pace of presentations. He viewed participants via an audio-video camera in the double-wall booth that fed a live signal to a television monitor in his booth. The assistant presented a new sentence to the talker once the participant finished writing each sentence and cued him by putting on the glasses.

Speech intelligibility was scored by another experimenter who was masked to which experimental condition was being tested (normal vision, cataracts, auditory-only). Each list of 10 sentences contained 50 key words, yielding 150 key words for the 30 sentences per condition.

Responses scored as correct included: a key word written with correct spelling; a key word written as a homophone of the actual key word; a key word written with a spelling error which was identifiable from the context of the sentence; and a key word written without pluralization which did not change the meaning of an actual pluralized key word. Any other key words written, or not written, by participants were scored as incorrect. The experimenters then calculated each participant's percentage of correct key words for each of the three experimental conditions. Finally, the visual-enhancement (VE) score was calculated for each participant using Equation 1 (Sumby & Pollack, 1954) in which A represents the percentage correct in the auditory-only condition, and AV represents the percentage correct in either the normal auditory-visual condition or under the cataract auditory-visual condition.

$$VE = (AV-A)/(1-A) \quad (1)$$

3. RESULTS

The mean scores for binocular visual function (visual acuity and contrast sensitivity) for normal vision and the cataract simulation are shown in Table 1. The cataract simulation filters reduced participant's visual acuity from 20/16 (logMAR -0.01, SD=.0.07) to a group mean of 20/32 (logMAR 0.20, SD= 0.07) which represents a loss of three lines of visual acuity on a standard logMAR chart. Mean contrast sensitivity was reduced to 1.15 (SD=0.08) Log units from a baseline level of 1.82 (SD=.05) on the Pelli-Robson Contrast Sensitivity Chart.

Insert Table 1 here

Mean speech intelligibilities of the 21 participants for each visual condition were: auditory-only = 54.8%; normal viewing = 88.3%; and simulated cataract vision = 81.8%. The VE score of each participant was computed independently for normal and simulated cataract viewing conditions. Figure 2 demonstrates the mean VE for participants in the normal viewing condition was 73.6%, whereas, the mean VE for participants in the simulated cataract viewing condition was only 58.3%. A paired sample t-test between the VE of the normal viewing condition and simulated cataract viewing condition revealed that this 15 percentage point difference in VE which was statistically significant, $t(20) = 4.17$, $p < .01$, Cohen's d =1.0 (large effect size).

Insert Figure 2 here

4. DISCUSSION

The findings of this study demonstrate that simulated cataracts have a significant detrimental impact on participants' use of visual cues to improve speech intelligibility. Compared to normal viewing conditions, the simulated cataract filters had only a modest effect on participants' visual acuity, but a greater effect on contrast sensitivity, significantly reducing visual enhancement and reducing visual acuity and contrast sensitivity to levels similar to that of moderate bilateral cataracts (Wood & Carberry, 2006). These findings suggest that individuals with moderate levels of cataracts may have a diminished ability to use visual information to support speech intelligibility under noisy conditions. The results also support anecdotal clinical claims that cataracts might hinder speechreading.

Our results initially appear inconsistent with empirical findings suggesting speechreading is robust to the effects of optical blur. Gordon and Allen (2009), for example, reported that *simulated blur* estimated to reduce acuity to ~20/50 (logMAR 0.4) had no effect on visual enhancement in young participants. Our results, however, are not necessarily incongruous given that the visual effects of cataractous diffusive blur and that of refractive blur are quite different. Refractive blur primarily affects higher spatial frequencies, whereas the light scatter caused by cataracts reduces image contrast across a range of spatial frequencies including high-range and mid-range spatial frequencies (Hess & Woo, 1978). Mid-range spatial frequencies may be particularly important given evidence that they alone can support speechreading performance comparable to normal viewing conditions (Munhall, Kroos, et al., 2004). Cataracts may moderate speechreading by reducing the visibility of larger scale facial cues, including subtle differences in the shading of the cheekbones, chin, and mouth regions that vary as a speaker makes mouthing movements.

Our results are consistent, with studies of face perception that highlight the importance of contrast sensitivity. West et al. (2002) reported a large population based study showing contrast sensitivity was an independent predictor of face recognition performance. Similarly, a recent study of visually normal young and older adults and patients with age-related macular degeneration (Barnes, De l'Aune, & Schuchard, 2010) found that contrast sensitivity was correlated significantly with performance on tests of facial identification (but cf Bullimore, Bailey, & Wacker, 1991).

Dickinson and Taylor (2011) also reported impaired speechreading ability with occlusion foils that produce nominal changes in acuity and contrast sensitivity relative to normal viewing conditions. However, as stated in the introduction, mitigating factors relating to the procedures of the study make it difficult to specify the amount of visual enhancement (VE) from the foils using any type of VE metric (i.e., AV - A or AV-A/A) that is traditionally used in speechreading.

The results of our study highlight differences in the visual effects of reduced contrast sensitivity and acuity on performance. Visual acuity is known to be a poor predictor of performance for visual tasks like driving. Acuity may account for drivers' difficulty in reading street signs (Higgins, Wood, & Tait, 1998), but does not predict other aspects of driving performance or crash risk (Burg, 1971; Hills & Burg, 1977). Similarly, speechreading isn't dependent on the ability to resolve fine facial details. Auditory-visual speech perception is robust to various forms of visual degradation that principally affect high spatial frequencies including pixelating the image (e.g., image quantization) (MacDonald, Andersen, & Bachmann, 2000), size of the video image (Jordon & Sergeant, 2000), distance of the target (Johnson & Snell, 1986), and optical blur (Erber, 1979; Thorn & Thorn, 1989). These findings suggest that information available at fine scales may be redundant or might be inferred from other cues (i.e., contextual cues).

Our results contribute to the growing literature showing that the effects of cataracts are more pervasive than previously thought. Studies comparing effects of cataracts and blur on complex tasks like driving (Wood, Chaparro, Carberry, & Chu, 2010) and walking (Anand, Buckley, Scally, & Elliott, 2003) demonstrate that cataracts are often more deleterious to performance than refractive blur, even when visual acuity is matched across conditions. The effects of cataracts are observed at multiple stages of processing. It is known for example that reduced contrast sensitivity slows the speed of processing (Anstey et al., 2006) and affects pattern recognition (Harley, Dillon, & Loftus, 2004; Li, Sweet, & Stone, 2005; Pashler, 1984). Simulated cataracts have been shown to affect performance on standard pen and paper tests used to assess higher level cognitive abilities including working memory and executive function (Wood et al., 2009; Wood et al., 2011). In addition, the detection and interpretation of a degraded sensory signal (visual or acoustic) is cognitively demanding, drawing resources from upstream cognitive processes involved in the elaborative encoding and processing of visual and acoustic information. Similarly, listening to speech in noise diminishes the recall and understanding of linguistic information (Schneider, Daneman, Murphy, & Kwong See, 2000). While our results demonstrate a deficit in speechreading that can result from cataracts they do not allow us to conclude whether the change in speech intelligibility that we report is due to reduced visual cues, less effective integration or a combination of the two effects.

One advantage of the experimental approach taken in this study is that by using younger adults we minimized the potential confounding effects of other age-related changes affecting speech perception. This allows stronger conclusions to be drawn regarding the contrast sensitivity requirements for aging adults to engage in speechreading (Norton, McBain, & Chen, 2009) and recognition of faces (Lott, Haegerstrom-Portnoy, Schneck, & Brabyn, 2005; Owsley, Sekular, & Boldt, 1981). In addition, older adults are also more likely to experience changes in higher cognitive processing including auditory selective attention (Barr & Giambra, 1990), inhibitory processes (Eckert et al., 2008), working memory (Dalton, Santangelo, & Spence, 2009) and exhibit an increased susceptibility to distraction (Tun, O'Kane, & Wingfield, 2002) that can further compromise speech intelligibility.

In summary, the novel results of this study show that simulated cataracts—that reduce contrast sensitivity but have only a relatively small effect on visual acuity—can significantly affect speechreading performance. These results provide the basis for further studies to determine the critical level of contrast sensitivity below which there is a decrease in the accuracy of speech intelligibility during speechreading. Further speechreading research is needed to understand the impact of true cataracts on speech intelligibility and how these effects may be ameliorated. Accordingly, our laboratories are continuing to study the impact of cataracts on speech intelligibility through: (1) basic research measuring the effect of a range of different levels of simulated cataracts and their associated spatial frequency reductions, and (2) clinical research exploring whether speechreading improves in older adults following cataract surgery.

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Figure 1. Effect of different Signal-to-Noise Ratios (SNR) on the percentage of key-words (± SE) correctly reported by three participants. The line indicates the SNR level supporting 50% correct performance.

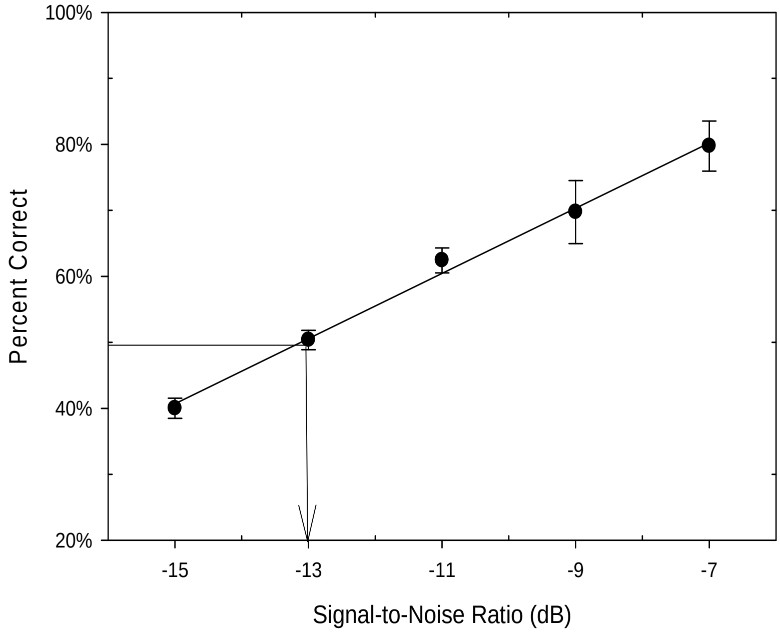

Figure 2. Visual enhancement (±SE) obtained under normal and cataract viewing conditions.

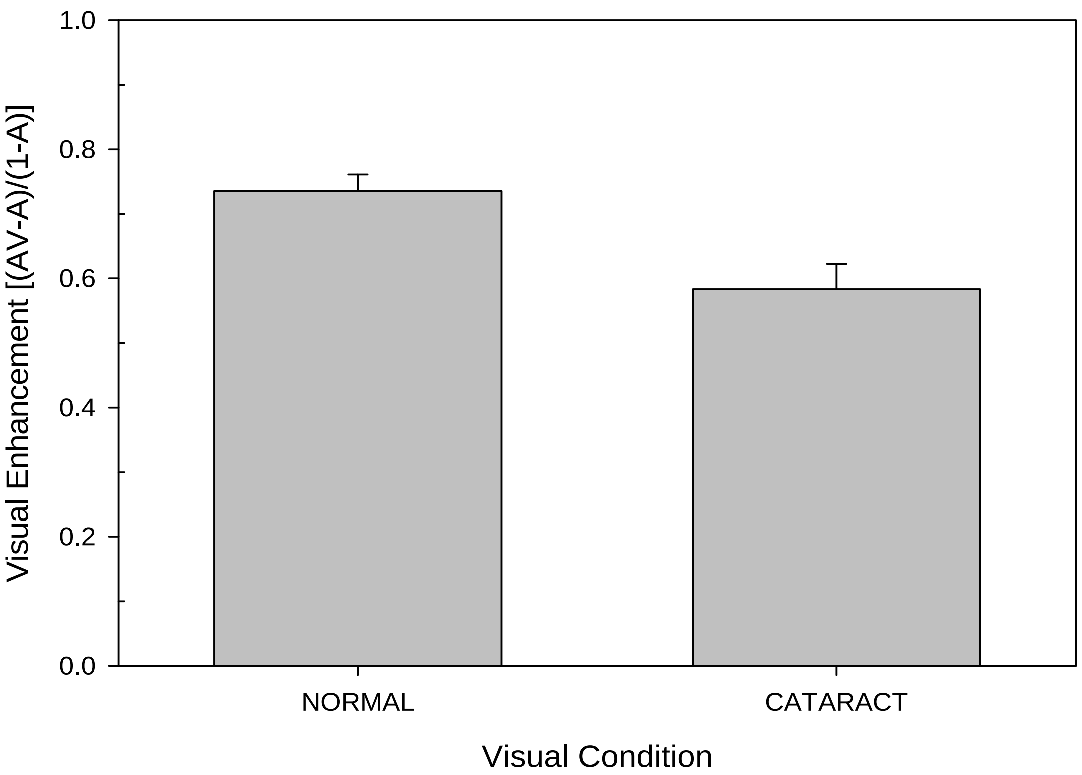

Table 1

Mean (SD) scores for the tests of visual acuity and contrast sensitivity under normal and simulated cataract conditions.

Measure	Normal	Cataract
Visual Acuity	-0.1 (0.07)	0.20 (0.07)
Contrast sensitivity (Pelli-Robson)	1.82 (0.05)	1.15 (0.08)