The Effect of Age on Visual Enhancement in Adults with Hearing Loss

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It is possible to study auditory-visual speech perception to understand the peripheral and central aspects of speech recognition. This investigation determined whether visual enhancement under adverse listening conditions was correlated with age, gender, hearing loss, auditory processing, and speech understanding in noise. Adults with hearing loss between 55 and 75 ($n = 97$) completed auditory-alone and auditory-visual speech perception tests. Visual enhancement for words in isolation decreased as age increased. Visual enhancement decreased as auditory-alone performance in noise decreased. Females had superior visual enhancement abilities. Findings suggest that central abilities are paramount to peripheral auditory abilities in integration of the auditory and visual speech signals.

As peripheral hearing loss increases, adult hearing aid users typically begin to rely more on their visual speech perception abilities. In fact, individuals with early onset profound hearing loss have been shown to be better lipreaders (visual-only speech perception) than individuals with normal hearing (Bernstein, Demorest, & Tucker, 2000) and individuals with progressive hearing loss have been shown to be better lipreaders than individuals with sudden hearing loss (Bergeson & Pisoni, 2004). It is not clear, however, whether elderly individuals with

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hearing loss receive as much benefit from visual speech perception as do younger individuals with hearing loss. It is well established that auditory speech perception declines with age (Kricos, 2006; Pichora-Fuller & Singh, 2006; Weinstein, 2000). This decline in auditory speech perception with age has been shown to be associated with peripheral hearing loss, central auditory factors, and overall cognitive abilities. Age-related declines in central auditory processing have been demonstrated in areas such as temporal processing and listening to speech in the presence of a distractor (Fitzgibbons & Gordon-Salant, 1996; Tun, O'Kane, & Wingfield, 2002). Age-related declines in cognitive processing have been demonstrated in the areas of speed of processing, working memory capacity, and divided attention (Salthouse & Davis, 2006; Wingfield & Tun, 2001). While there is a substantial amount of research in the area of auditory speech processing with age, there is only limited research in the area of auditory-visual speech processing with age.

It is well established that the visual speech signal complements the auditory speech signal and that the visual contribution to speech understanding becomes more important as the auditory signal becomes degraded (Sumby & Pollack, 1954). Auditory-visual speech perception can be quantified in a number of ways. Absolute auditory-visual performance can be measured for a fixed listening condition. Auditory-visual benefit can be calculated in terms of decibels (dB) by comparing the Speech Reception Threshold (SRT) measured in an auditory-alone condition to the SRT measured in an auditory-visual condition. Auditory-visual benefit can be calculated in terms of percentage correct by measuring the difference between auditory-visual and auditory-alone performance at a fixed signal-to-noise ratio (SNR). Finally, visual enhancement is the term used to describe the improvement in auditory-visual speech perception as compared with auditory-alone performance taking into account the total possible improvement: Visual Enhancement = (AV - A)/(1 - A) where AV refers to absolute auditory-visual performance and A refers to auditory-alone performance.

It is possible to study auditory-visual speech perception in order to better understand the peripheral, central, and cognitive aspects of speech recognition. In listeners with normal hearing, MacLeod and Summerfield (1987) found that participants received the greatest visual enhancement benefit for sentences that were easier to lipread. They also found that visual-alone performance was correlated with auditory-visual performance in individual participants. These results suggest that visual-alone speech perception is an important factor in predicting visual benefit. Others have not found that visual enhancement was related to visual-alone performance (Grant, Walden, & Seitz, 1998). Grant et al. found that auditory-visual speech recognition was correlated with individual abilities to integrate the auditory and visual speech information, presumably at a central level. Taken together, these results suggest that auditory-visual speech perception is dependent upon both adequate peripheral processing of the speech signal and integration of the auditory and the visual signal at a central level.

There is substantial evidence that auditory-only speech perception declines with age as a result of peripheral hearing loss (Pichora-Fuller & Souza, 2003). There is also substantial evidence that visual-only speech recognition ability for both word and sentence materials decreases with age in individuals with age-appropriate hearing (Cienkowski & Carney, 2002; Dancer, Krain, Thompson, & Davis, 1994; Middelweerd & Plomp, 1987; Shoop & Binnie, 1979; Sommers, Tye-Murray, & Spehar, 2005) and in individuals with hearing loss (Walden, Busacco, & Montgomery, 1993). As discussed previously, these declines in auditory-alone and visual-alone speech understanding may be due to peripheral and/or central declines. A recent study by Spehar, Tye-Murray, and Sommers (2004) investigated visual-only speech perception performance for sentence materials presented at an average rate and at a speeded rate in a group of older adults (older than 64 years) and a group of younger adults (18-26 years). While the older group had significantly poorer visual-only performance as compared to the younger group for both the average and the speeded speech rates, both groups showed a similar change in performance between the average and the fast speech. In other words, there were no age-related declines in processing increased speech rates. These findings do not support a central component, of a temporal nature, in explaining the reduced lipreading abilities seen with increasing age. In a recent investigation, Tye-Murray, Sommers, and Spehar (2007) measured superior lipreading abilities in older adults with hearing loss compared with older adults with typical hearing levels. It is possible then, that lipreading performance may be preserved with age in individuals who rely on this ability for communication.

While most studies have demonstrated declining lipreading abilities with age, several studies have reported stable auditory-visual benefit with increasing age. Walden et al. (1993) measured auditory-visual benefit in percentage correct in middle aged (35 to 50 years) and older adults (65-80 years) who all had hearing loss. They held auditory-alone performance constant at 50% correct and then measured percentage correct when the visual signal was added. Both groups demonstrated similar auditory-visual benefit for syllable and sentence materials. A similar finding was also reported by Helfer (1998) in a group of older adults between 61 and 88 years of age with no more than a mild hearing loss. Nonsense sentences were presented in noise so that average auditory-alone performance was greater than 50% correct. When the visual signal was added, age was not correlated with auditory-visual benefit. More recently, Hickson, Hollins, Lind, Worrall, and Lovie-Kitchin (2004) did not find a relationship between age and auditory-visual benefit in a group of adults between 60 and 97 years who had a range of hearing abilities.

Cienkowski and Carney (2002) used a different approach to measure auditory-visual speech integration in younger versus older listeners. They used the McGurk effect in order to determine whether older adults were as successful as younger adults at integrating auditory and visual information for CV syllables. They measured the ability of younger adults with normal hearing (ages 18 to 35 years), younger adults with simulated hearing loss, and older adults with typical hearing (ages 65 to 74 years) to integrate auditory and visual information. They did not find a difference in the number of fused responses between the younger and older participants. This suggests that there were no age-related declines in auditory-visual integration for syllables. In a follow up study, Ballingham and Cienkowski (2004) measured visual enhancement in 12 young adults (19 to 30 years), and 11 older adults (65 to 85 years) with normal or near normal hearing. They did not measure any age effect for auditory-alone, visual-alone, or auditory-visual performance for the small set of CVs that were used in the original 2002 study. They also measured visual enhancement (auditory-visual performance relative to auditory-alone performance) and found no significant difference across the two age groups.

Sommers et al. (2005) measured the effects of age on visual enhancement abilities for a variety of speech materials. They measured visual-alone and auditory-visual performance for consonants, words, and sentences in a group of younger (mean age 20 years) and older (mean age 70) adults with typical hearing. The SNR was set individually so that each participant received a score of about 50% correct in the auditory-alone condition. They measured significantly poorer performance in the older adults as compared with the younger adults in the auditory-visual condition and in the visual-only condition. There were no significant differences, however, in the visual enhancement abilities between the older and the younger adults. Sommers et al. did not find age differences in central integration abilities (the ability to integrate auditory and visual speech information). In a more recent study by the same investigators, Tye-Murray et al. (2007) did not find any difference in visual enhancement abilities between older adults with hearing loss in comparison with older adults with typical hearing levels. It is important to note that in the Sommers et al. study, and in the other studies which measured visual enhancement as a function of age which are reported here, auditory-alone performance was fixed at an SNR of 50% correct or higher. Sommers et al. did point out that:

> An important direction for future research will be to examine whether the age equivalence in enhancement observed in the present study maintains for more adverse listening conditions where A (auditory-alone) scores are reduced and the need for integrating auditory and visual speech signals is even greater. (p. 274)

Individuals with hearing loss rely on the visual signal in order to improve their ability to understand speech, especially in the most difficult listening situations. It has not been shown, however, whether the ability to improve auditory-alone speech recognition with the addition of the visual signal declines with age for difficult listening conditions. The purpose of the present investigation was to determine whether visual enhancement in adults with peripheral hearing loss was correlated with age under adverse listening conditions. An additional purpose was to determine whether visual enhancement was correlated with additional factors, including gender, degree of hearing loss, auditory processing ability, and performance on an auditory-alone speech-processing task.

METHODS

Subjects

Participants were recruited in conjunction with a concurrent study assessing the efficacy of group audiologic rehabilitation. All data reported here were collected prior to participation in a rehabilitation program. All participants had corrected binocular visual acuity of at least 20/40. This level of acuity is considered the minimum necessary for lipreading training (Hardick, Oyer, & Irion, 1970). All participants were between 55 and 75 years of age. Participants had at least a mild hearing loss bilaterally (three-frequency pure tone average [PTA] of at least 25 dB HL), and had no more than a severe hearing loss (PTA no greater than 80 dB HL). All participants were experienced hearing aid users with at least 6 months of hearing aid experience. All participants passed a cognitive screen; they had performance within the normal range for age and educational level on the Mini-Mental State (Folstein, Folstein, & McHugh, 1975).

Evaluation Measures

Auditory Processing Disorder (APD) screening. All participants underwent an APD screen using the Synthetic Sentence Index (SSI) and the NU-6 word list. This screen consisted of the Synthetic Sentence Identification – Ipsilateral Competing Message (SSI-ICM) test and the Phonetically Balanced (PB) word test comparison as described by Cooper and Gates (1991) and Stach, Spretnjak, and Jerger (1990).

Speech perception: words. Auditory-alone and auditory-visual speech perception abilities were measured with the City University of New York (CUNY), AB Isophonemic Word Lists (Boothroyd, 1984; Boothroyd, Hnath-Chisolm, Hanin, & Kishon-Rabin, 1988). The original video recordings had been stored on laserdisc and then were converted to .avi files with sampling rates of 44,100 Hz for audio and a video resolution of 304 × 228 pixels. Twelve 10-word lists (120 words total) were stored on a computer. Percentage-correct scores were based on performance for 50 words (5 word lists, 150 phonemes), presented in the auditory-alone condition and for 50 new words in the auditory-visual condition. The 5 word lists presented auditory-alone and the 5 word lists presented auditory-visual were randomly selected for each participant.

Speech perception: sentences. Auditory-alone and auditory-visual speech perception abilities were measured with the CUNY, Topic Related Sentences (Boothroyd et al., 1988). The original video recordings had been stored on laserdisc and then were converted to .avi files with sampling rates of 44,100 Hz for audio and a video resolution of 304 × 228 pixels. Eighteen 12-sentence lists were stored on a computer. Performance in percentage correct was measured for 48 sentences (4 sentence lists, 408 words) presented in the auditory-alone condition and for 48 new sentences in the auditory-visual condition. The 4 sentence lists presented auditory-alone and the 4 sentence lists presented auditory-visual were randomly selected for each participant.

Procedures

The APD screening consisted of the SSI test and NU-6 word lists presented through insert earphones. Two practice lists preceded the SSI test in order to increase test reliability (Feeney & Hallowell, 2000). Fifty NU-6 words per ear were presented individually. APD was considered to be present if the PB-SSI difference was greater than 20 percentage points in either ear. Participants were classified as APD negative if they passed the screening in both ears and as APD positive if they failed the screening in either ear or in both ears.

Speech perception testing was conducted in an audiometric test booth while each individual wore his/her hearing aid(s) at use gain. All testing was conducted in the presence of speech-shaped noise generated by an audiometer (GSI 61) presented at 180° azimuth 1 m from the listener's head. The word and sentence files were stored in a digital format, routed through a programmable attenuator (TDT PA5) to the audiometer and then presented through a loudspeaker located 1 m from the listener's head at 0° and a 10 × 13 in. monitor located 0.5 m from the listener's head at 15° azimuth. When the .avi files were presented in the auditory-visual format the talker's face was contained in a 4 × 5 in. rectangle.

All testing began using two lists of the AB words in order to set the SNR for auditory-visual speech perception. The speech shaped noise was fixed at 50 dBA located at the position of the subject's head. With both the auditory and the visual signal available, the level of the speech signal was varied using a simple up-down technique (Levitt, 1971). After the initial 4 reversals the step size was reduced to 2 dB and the 50% point was estimated based on the average of the final 16 reversals; this SNR was maintained for the next step. The visual signal was eliminated and the participant completed five practice words in an auditory-alone format. If necessary, the signal was raised using a 2 dB step size until performance exceeded 30% correct for all phonemes in the auditory-alone format. This SNR was used for all subsequent AB word testing (both auditory-alone and auditory-visual). In this manner, auditory-visual performance approximated 50% for all participants.

The SNR had to be adjusted for the synthetic testing (CUNY sentences) in order to avoid ceiling effects. Using 5 or 10 practice sentences, the SNR that had been used for the AB words was adjusted until the participants could repeat approximately 50% of the words in the auditory-alone condition. This SNR was used for both auditory-alone and auditory-visual testing. (It is important to note that the auditory-alone condition for sentences was adjusted to 50% while the auditory-visual condition for words was adjusted to 50%. This was due to the large variability of performance for the sentence materials in the auditory-visual condition.)

RESULTS

Demographic Characteristics of Participants

Ninety-seven experienced hearing aid users were evaluated. Their mean demographic characteristics are shown in Table 1. Their mean age was 67 years and the mean three-frequency PTA was 42.85 dB HL. The majority of participants were male and a minority of participants failed the auditory processing screen in either one or both ears. Table 1 also displays the mean auditory-alone and auditory-visual performance for phonemes in words, words in isolation, and words in sentences. These values were used to calculate visual enhancement. As discussed in the methods, the SNR was adjusted so that auditory-visual performance for words in isolation and the auditory-alone performance for words in sentences was approximately 50%. Table 1 shows a mean value of 51% for the auditory-

Table 1

Characteristics of the Participants

	PTA dB HL[a]	**Age years**	**Adjusted SNR words**[b]
Means	42.85	67.06	7.03
Standard deviation	15.32	5.86	8.45
	APD[c]	**Gender (male)**[d]	
Percents	30%	69%	
	Auditory-alone phonemes	**Auditory-alone words isolation**	**Auditory-alone words sentences**
Means	41.41%	17.95%	54.08%
Standard deviation	12.58%	10.86%	15.91%
	Auditory-visual phonemes	**Auditory-visual words isolation**	**Auditory-visual words sentences**
Means	72.95%	51.11%	73.07%
Standard deviation	8.84%	12.23%	13.25%

[a]PTA is the three-frequency pure tone average (500, 1000, 2000 Hz) of the better ear. [b]Adjusted SNR Words is the predicted signal-to-noise ratio (in dB) necessary for 40% correct for the words in isolation. [c]APD displays the percentage classified as positive for the auditory processing screen. [d]Gender displays the percentage of subjects who were male.

visual presentation of words in isolation and a mean value of 54% for the auditory-alone presentation of words in sentences.

Auditory-alone performance for speech perception was used as a predictor variable in the current analyses. As described in the Methods section, the SNR was adjusted so that performance in the auditory-visual condition was approximately 50% correct for understanding words in isolation. As a result, it is not possible to compare the auditory-alone percentage correct scores, because these were measured at different SNRs. Nor was it possible to compare SNRs, because individuals did not achieve the exact same percentage correct performance in the auditory-alone conditions (performance was equalized for the auditory-visual condition not for the auditory-alone condition). The expected SNR for words in isolation was calculated using 40% correct as the target performance level (as this was near the upper end of the auditory-alone performance). The SNR ratio required for each subject to obtain 40% correct for word recognition in the auditory-alone condition was estimated using a correction factor of 8% per dB (Studebaker & Sherbecoe, 1991). As shown in Table 1, the mean predicted SNR to achieve 40% correct was 7 dB across all participants. For the words in sentences a 12% per dB correction factor was used (Sherbecoe & Studebaker, 2003) in order to estimate auditory-alone performance of 50% correct. These resultant SNR values were independent of the visual enhancement calculation, thus they could be used as predictors of visual enhancement.

Visual Enhancement and Age

The first purpose of this study was to determine whether visual enhancement was associated with age in a group of adults who wore hearing aids between the ages of 55 and 75 years. A correlation analysis of visual enhancement and age was conducted for phonemes in words, words in isolation, and words in sentences; these results are demonstrated in Figure 1. It is important to note that the word stimuli were the same for the top two graphs; that is why performance is very similar. In all cases there was a significant correlation between visual enhancement and age. For phonemes in words there was a significant negative correlation ($r = -0.372$, $p < .001$) and a similar relation was measured for words in isolation ($r = -0.374$, $p < .001$). The equation for the trend line in the middle graph (performance for words in isolation) has a slope of .901 indicating a decline in visual enhancement of 0.9% per year for individuals with hearing loss between the ages of 55 and 75 years. The results for words in sentences are represented in the bottom graph of Figure 1. The results shown here are not as tightly packed around the least squares regression slope as is demonstrated in the top two graphs, however, the correlation is still significant ($r = -0.22$, $p = .036$). In summary, under difficult listening conditions, significant correlations were measured between visual enhancement and age. These findings were more consistent for words in isolation as compared to performance for words in sentences, suggest-

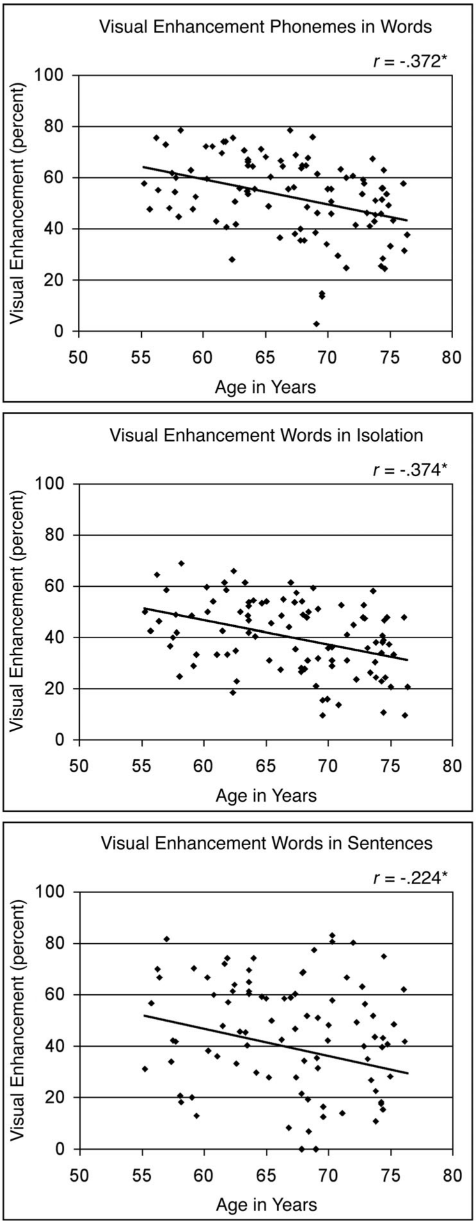

Figure 1. Visual Enhancement as a function of age. The top graph shows the results for phonemes in words in isolation, the middle graph shows the results for words in isolation, and the bottom figure shows the results for words in sentences.

ing that factors other than age become increasingly important when predicting performance in higher context listening situations.

Visual Enhancement and Additional Demographic Factors

PTA in the better ear. The second purpose of this study was to determine whether visual enhancement was correlated with the factors: degree of hearing loss, performance on an auditory-alone speech-processing task, auditory processing ability, and gender. The results for degree of hearing loss are represented in Figure 2. The correlation between visual enhancement and the three-frequency PTA of the better ear is significant, for phonemes in words (r = -0.176, p = .043) and for words in isolation (r = -0.176, p = .042). The slopes of the lines in the top two graphs are quite shallow (-0.168 for words in isolation), demonstrating only a 0.17% drop in visual enhancement performance for every additional 1 dB of hearing loss. The results for words in sentences are represented in the bottom graph of Figure 2; this correlation is not significant.

Auditory-alone speech perception. The relationship between auditory-alone speech perception and visual enhancement is shown in Figure 3. The top two graphs display the predicted SNR for 40% correct on the x-axis. Both of these graphs demonstrate a significant negative correlation for phonemes in words (r = -0.397, p < .001) and for words in isolation (r = -0.332, p < .001). These results demonstrate that as auditory-alone performance decreases, visual enhancement also decreases. In other words, the individuals who could benefit the most from the visual signal (those with the poorest auditory-alone performance in noise) actually benefit the least. This relationship was not shown for visual enhancement and the predicted SNR for words in sentences as shown in the bottom graph of Figure 3. Here the correlation is non-significant (r = 0.050, p = .396).

APD. The relationship between visual enhancement and the presence or absence of APD is shown in Figure 4. Those classified as APD negative passed the APD screen in both ears, while those classified as APD positive (30% of the subjects) failed the APD screen in one or in both ears. A two-factor repeated measures analysis of variance (ANOVA) was performed for the within subject factor stimulus type and the between subject factor APD status. Examination of Figure 4 suggests an effect of stimulus type; performance appears best for phonemes in words and poorest for words in isolation and words in sentences. This was confirmed by the results of the ANOVA. Results for the within-subject effect (stimulus type) indicated that there are significant differences across these three groups, $F(1, 95) = 25.176$, $p < .001$. There was also a significant effect for the between-subject effect APD status, $F(1, 95) = 4.160$, $p = .044$, but there was no interaction between stimulus type and APD status, $F(1, 95) = 0.072$, $p = .788$. These results demonstrate that individuals classified as APD negative received more visual enhancement than those classified as APD positive across all speech materials.

Gender. The relationship between visual enhancement and gender is shown in

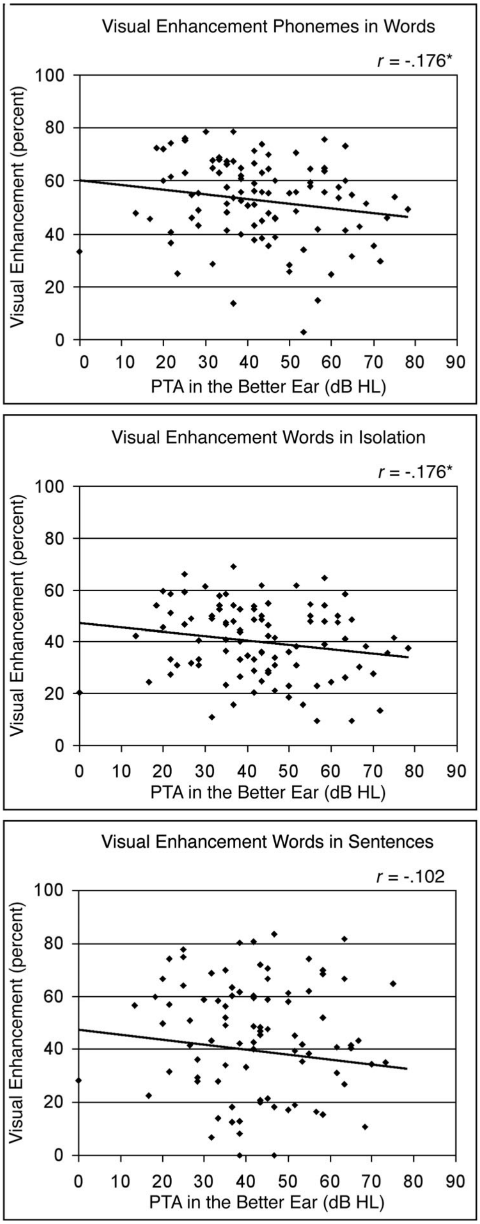

Figure 2. Visual Enhancement as a function of pure tone average (PTA) in the better ear. The top graph shows the results for phonemes in words in isolation, the middle graph shows the results for words in isolation, and the bottom figure shows the results for words in sentences.

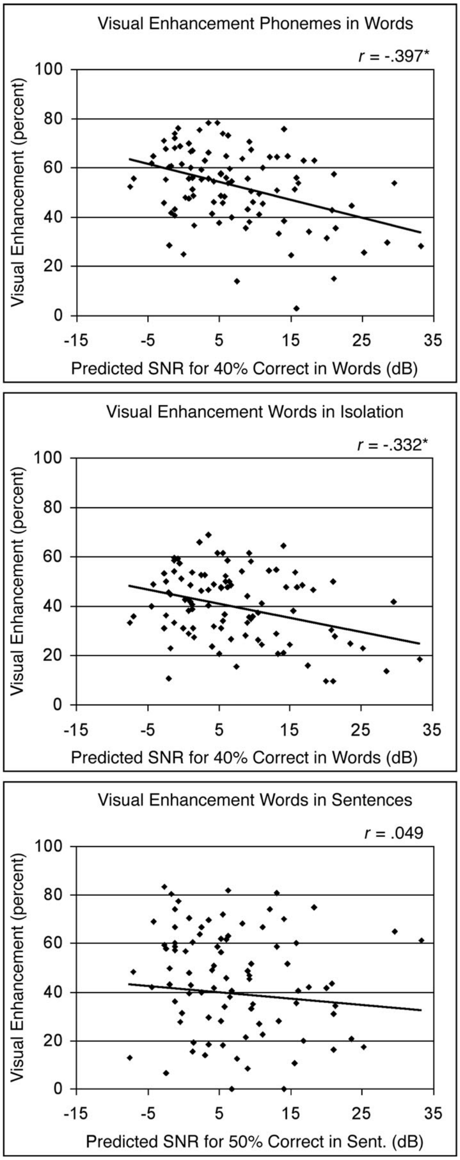

Figure 3. Visual Enhancement as a function of signal-to-noise ratio (SNR) required for a predetermined performance level in the auditory-alone condition. The top graph shows the results for phonemes in words in isolation and the middle graph shows the results for words in isolation. In both of these cases the predetermined performance level was 40% correct for words in isolation. The bottom figure shows the results for words in sentences and in this case the predetermined performance level was 50% correct for words in sentences.

Figure 5. A two-factor repeated measures ANOVA was performed for the within subject factor stimulus type and the between subject factor gender. Results for the within-subject effect (stimulus type) indicated that there are significant differences across these three groups, $F(1, 95) = 26.548$, $p < .001$. There was also a significant effect for the between-subject effect gender status, $F(1, 95) = 727.081$, $p < .001$, but there was no interaction between stimulus type and gender, $F(1, 95) = 0.252$, $p = .617$. These results demonstrate that females received greater visual enhancement than males across all speech materials.

Multiple Linear Regression Analyses

The data in Figures 1 through 5 demonstrate that visual enhancement is significantly correlated with age, degree of hearing loss, auditory-alone performance in noise, APD status, and gender. In some cases however, a significant relationship may be confounded by a third uncontrolled variable. For example, it is possible that individuals who were classified as APD positive were older than individuals who were classified as APD negative. In that case it is not clear whether visual enhancement is truly correlated with APD or if it just appears that way because individuals classified as APD tend to be older. Table 2 shows the bivariate

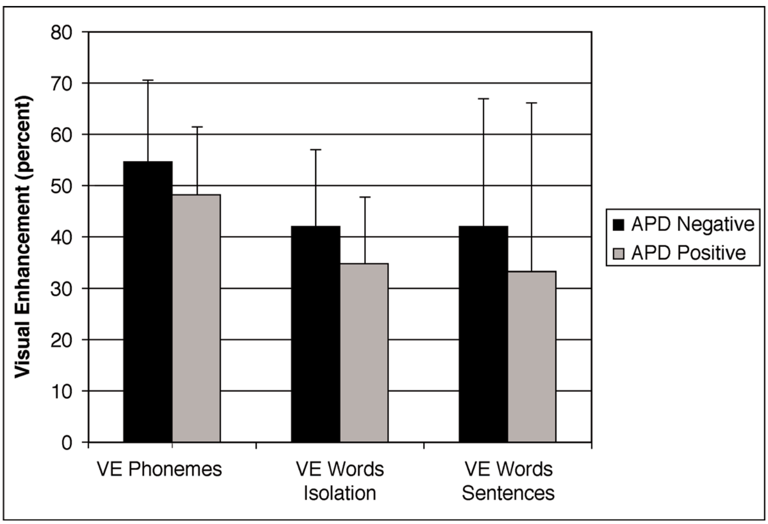

Figure 4. Visual Enhancement (VE) as a function of auditory processing status (APD). Black bars represent average performance for individuals classified as APD negative in each ear and gray bars represent average performance for individuals who failed the APD screen in one or both ears. Error bars represent one standard deviation. The pair of bars on the left represent the results for phonemes in words in isolation, the pair of bars in the middle represent the results for words in isolation, and the pair of bars on the right represent the results for words in sentences.

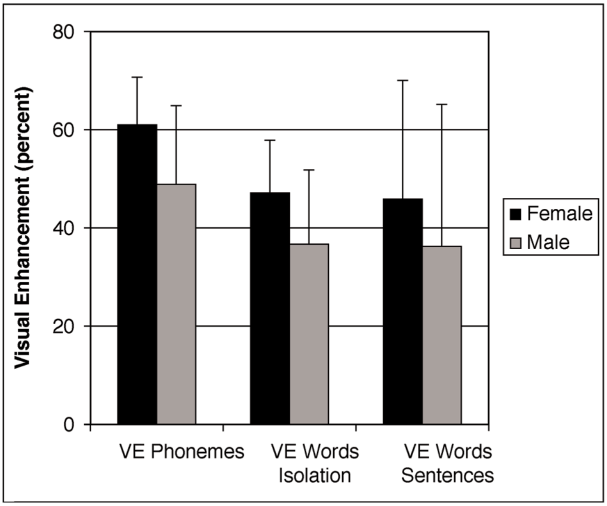

Figure 5. Visual Enhancement (VE) as a function of gender. Black bars represent average performance for females and gray bars represent average performance for males. Error bars represent one standard deviation. The pair of bars on the left represent the results for phonemes in words in isolation, the pair of bars in the middle represent the results for words in isolation, and the pair of bars on the right represent the results for words in sentences.

Table 2

The Bivariate Correlations Between the Independent Variables

	APD[a]	PTA[b]	Age	Gender[c]
PTA	0.34***			
Age (years)	0.25*	0.16		
Gender[c]	-0.15	-0.02	0.12	
Adjusted SNR words[d] (dB HL)	0.24*	0.52***	0.16	0.20*
Adjusted SNR sentences[e] (dB HL)	0.26**	0.55***	0.20*	0.15

[a]APD displays the percentage classified as positive for the auditory processing screen. [b]PTA is the three-frequency pure tone average (500, 1000, 2000 Hz) of the better ear. [c]Gender displays the percentage of subjects who were male. [d]Adjusted SNR Words is the predicted signal-to-noise ratio necessary for 40% correct for the words in isolation. [e]Adjusted SNR Sentences is the predicted signal-to-noise ratio necessary for 50% correct for the words in sentences.
*$p < .05$. **$p < .01$. ***$p < .001$.

correlations between all of the predictor variables. Many of these variables were highly correlated. For example, degree of hearing loss (PTA) was significantly correlated with APD status and with auditory-alone performance in noise. In order to determine which predictor variables had the strongest association with visual enhancement after controlling for the impact of possible confounding effects multiple regression analyses were performed. A standard multiple regression was performed for the three outcome variables: (a) visual enhancement for phonemes, (b) visual enhancement for words in isolation, and (c) visual enhancement for words in sentences. APD status (dummy coded as 0 [negative] or 1 [positive]), PTA, age, SNR loss, and gender (dummy coded as 0 [females] and 1 [males]) were the predictor variables.

Phonemes in Words

Table 3 depicts the analysis for phonemes in words. The table displays the amount of variance explained by the predictor variables in visual enhancement for phonemes in words (r^2), the unstandardized regression coefficients (B), the standardized regression coefficient (β), and the semipartial correlations (sr^2) which indicate the amount by which r^2 would be reduced if the predictor variables were omitted from the model (Tabachnick & Fidell, 1989). The multiple R for the predictive model of phonemes was statistically significant, $F(5, 91) = 9.48$, $p < .001$, with the amount of variance explained being 34%. Age, gender, and adjusted SNR were statistically significant in the regression model. The

Table 3

The Results of the Standard Multiple Regression Analysis for the Dependent Variable: Visual Enhancement for Phonemes in Words

Independent variables	Dependent variable VE phonemes[a]	B[b]	β[c]	sr^{2}[d]
APD	-0.20*	-4.26	-0.13	0.010
PTA	-0.18	0.06	0.06	0.002
Age	-0.37***	-0.70**	-0.27	0.070
Gender`	-0.37***	-9.89***	-0.30	0.080
Adjusted SNR words	-0.40***	-0.54**	-0.30	0.060
				$r^2 = 0.340$
				Adjusted $r^2 = 0.310$
				$r = 0.590$***

Note. The bottom three rows display the r, r^2, and adjusted r^2.VE = Visual Enhancement. APD = Auditory processing disorder. PTA = Pure tone average. SNR = Signal-to-noise ratio.
[a]Column lists the bivariate correlations between the independent variables and the dependent variable. [b]Column lists the unstandardized regression coefficients (B). [c]Column lists the standardized regression coefficients (β). [d]Column lists the semipartial squared correlations (sr^2).
*$p < .05$. **$p < .01$. ***$p < .001$.

semipartial squared correlation shows that age explained 7% of the variance above and beyond what the other three variables in the model explained; likewise gender explained 8%, and adjusted SNR words 6%. While APD had a significant bivariate correlation with the independent variable, it was not significant in the regression equation.

Words in isolation. The multiple R for the predictive model of visual enhancement for words in isolation (see Table 4) was statistically significant, $F(5, 91) = 7.60$, $p < .001$, with the model explaining a total of 29% of the variance in words in isolation. These results are expected to be similar to the results found in Table 2 since these are the same words that were used in the phonemes in words analysis. While four of the predictor variables had significant bivariate correlations with visual enhancement for words in isolation, only age and gender were significant in the regression equation.

Words in sentences. The multiple R for the predictive model of words in sentences was statistically significant, $F(5, 91) = 2.48$, $p < .037$, with the model explaining only 12% of the variance in words in sentences; the results are shown in Table 5. Age was statistically significant in the bivariate correlation and approached statistical significance in the multiple regression model ($p = .067$). Gender was not statistically significant in the bivariate correlations ($p = .116$), but approached significance in the multiple regression model ($p = .061$). Adjusted SNR sentences was not statistically significant in the bivariate correlation, but

Table 4

The Results of the Standard Multiple Regression Analysis for the Dependent Variable: Visual Enhancement for Words in Isolation

Independent variables	Dependent variable: VE words isolation[a]	B[b]	β[c]	sr^{2}[d]
APD	-0.22*	-4.74	-0.15	0.02
PTA	-0.18	0.02	0.02	0.00
Age	-0.37***	-0.68**	-0.27	0.07
Gender`	-0.33***	-8.88**	0.28	0.07
Adjusted SNR words	-0.33***	-0.36	-0.21	0.03
				$r^2 = 0.29$
				Adjusted $r^2 = 0.26$
				$r = 0.54$***

Note. The bottom three rows display the r, r^2, and adjusted r^2. VE = Visual Enhancement. APD = Auditory processing disorder. PTA = Pure tone average. SNR = Signal-to-noise ratio.
[a]Column lists the bivariate correlations between the independent variables and the dependent variable. [b]Column lists the unstandardized regression coefficients (B). [c]Column lists the standardized regression coefficients (β). [d]Column lists the semipartial squared correlations (sr^2).
*$p < .05$. **$p < .01$. ***$p < .001$.

was significant in the multiple regression model. It explained roughly 4% of the variance in words in sentences beyond that of what the other variables explained. None of the independent variables were as effective in predicting visual enhancement for words in sentences as they were for predicting visual enhancement for words in isolation.

DISCUSSION

Visual Enhancement and Age

One purpose of the present investigation was to determine whether visual enhancement in adults with peripheral hearing loss under adverse listening conditions was correlated with age. The results indicate that age and visual enhancement performance are significantly correlated for phonemes, words in isolation, and words in sentences. The analyses show that visual enhancement for both phonemes and words in isolation decrease by about 1% for each 1-year increase in age between the ages of 55 and 75 years.

Previous research has shown a decline of lipreading abilities with increasing age, but has not shown a decline in visual enhancement as a function of age. Yet, in the present study, age was highly correlated with visual enhancement. The discrepancy in results between the findings in the present study and those previously reported in the literature are likely due to the difficulty levels of the auditory-

Table 5

The Results of the Standard Multiple Regression Analysis for the Dependent Variable: Visual Enhancement for Words in Sentences

Independent variables	Dependent variable: VE words in sentences[a]	B[b]	β[c]	sr^{2}[d]
APD	-0.14	-7.42	-0.12	0.010
PTA	-0.10	-0.30	-0.17	0.020
Age	-0.22*	-0.91	-0.19	0.030
Gender`	-0.16	-11.61	-0.20	0.040
Adjusted SNR words	-0.05	0.88*	0.24	0.040
				$r^2 = 0.120$
				Adjusted $r^2 = 0.070$
				$r = 0.346$*

Note. The bottom three rows display the r, r^2, and adjusted r^2. VE = Visual Enhancement. APD = Auditory processing disorder. PTA = Pure tone average. SNR = Signal-to-noise ratio.
[a]Column lists the bivariate correlations between the independent variables and the dependent variable. [b]Column lists the unstandardized regression coefficients (B). [c]Column lists the standardized regression coefficients (β). [d]Column lists the semipartial squared correlations (sr^2).
*$p < .05$.

alone and auditory-visual testing procedures. Most of the research reported in the literature measured auditory-alone abilities for moderately difficult listening conditions and auditory-visual abilities for fairly easy listening conditions. Walden et al. (1993), Helfer (1998), and Sommers et al. (2005) all fixed auditory-alone performance at approximately 50% or higher, as a result, auditory-visual performance was near 80% or higher. These three studies did not demonstrate a significant relationship between visual enhancement and age. In the present study auditory-visual performance for words was fixed near 50% correct, and as a result auditory-alone performance ranged primarily between 15 to 40% correct. It appears then, that age influences visual enhancement for more difficult listening conditions, but not for easier listening conditions. Similar findings have been reported for auditory-alone speech perception. For example, Pichora-Fuller and Souza (2003) stated the following in a discussion about auditory-alone speech perception:

> Generally, those studies which found no effect of age per se used relatively simple stimuli: words or sentences presented in quiet or background noise with little temporal complexity (i.e. steady-state noise). In contrast, age-related deficits seem to be most apparent in difficult or complex auditory perception tasks. (p. S212)

In the present study age was not a significant predictor variable in the regression equation for visual enhancement for words in sentences. It is important to remember, however, that the sentence materials were presented at less difficult SNRs than the word materials. This was due to the large variability in performance within participants for the sentence materials; as a result it was difficult to equalize performance across participants for the sentence materials in the auditory-visual condition. Therefore, performance was equalized in the auditory-alone condition. It is possible then, that age would have been an important predictor of visual enhancement for words in sentences if the sentences had been presented at more difficult SNRs. On the other hand, it is possible that when presented with sentence materials older adults were able to take advantage of context and this might offset any declines in visual enhancement. The psychological literature has demonstrated that while many cognitive abilities decline with age, crystallized abilities which include the use of context, remain relatively stable with age (Salthouse & Davis, 2006). It would be informative to study visual enhancement for highly contextual materials under more difficult listening conditions, as a function of age, in future research.

It is also important to consider the effect of vision on visual enhancement with age. In the present study we did measure visual acuity, but we did not measure other aspects of vision such as visual contrast. Research has demonstrated no significant relationship between visual benefit in speech perception and visual acuity in participants over the age of 60 (Hickson et al., 2004). In the present study, the visual image was presented in a 4 × 5 in. rectangle located approximately 20 in. from the participant. Due to the small size of the face on the computer monitor, it is possible that visual acuity may have influenced visual enhancement abilities. These authors were unable to find any research relating visual contrast sensitive and lipreading ability, however, there is research available which demonstrates that contrast sensitivity is correlated with high-cognitive demand visuospatial tasks (e.g., working memory tasks that involve rotated letters on a screen; Glass, 2007). This is an interesting finding which suggests that visual function may contribute to cognitive aging. Future research on the affects of visual acuity, visual contrast sensitivity, and age, on visual enhancement would be useful.

Visual Enhancement and Factors in Addition to Age

The three most important predictors of visual enhancement ability were age, gender, and auditory-alone performance in noise. In general, visual enhancement decreased with increasing age and with poorer auditory-alone performance in noise. Females had superior visual enhancement in comparison with males, regardless of the speech stimuli. Previous research has also demonstrated gender effects for specific speech perception abilities. For example, previous research has shown that older women are better speechreaders than older men (Dancer et al., 1994). In addition, older women have been shown to outperform older men in auditory-alone tasks involving dichotic listening (Bellis & Wilber, 2001). These findings suggest that central abilities may be an important factor in determining visual enhancement.

Factors that have been shown to be important predictors of auditory-alone or visual-alone speech processing were not found to be important predictors of visual enhancement. This includes degree of hearing loss and APD status. It was discussed in the introduction that individuals with early onset profound hearing loss have been shown to be better speechreaders than individuals with normal hearing (Bernstein et al., 2000), yet individuals with hearing loss have not been shown to receive more benefit from visual enhancement than individuals with normal hearing (Tye-Murray et al., 2007). Our findings are in agreement with the later study; the current results suggest that the ability to integrate the auditory and visual signal does not necessarily improve with increased hearing levels. On the other hand, the current results did demonstrate that visual enhancement was highly correlated with auditory-alone speech recognition abilities. Individuals, who required greater SNRs to maintain equivalent auditory-alone performance, experienced less visual enhancement than those individuals who could tolerate more difficult SNRs. The fact that visual enhancement was influenced by auditory-alone speech in noise abilities but not by degree of hearing loss, suggests that visual enhancement is mediated more by central processing rather than peripheral factors.

Age-related declines in central auditory processing have been demonstrated in areas such as temporal processing and listening to speech in the presence of a distractor (Fitzgibbons & Gordon-Salant, 1996; Tun et al., 2002). In the present study APD was not an important predictor of visual enhancement. APD is thought to affect only the auditory pathway (McFarland & Cacace, 1995). Our results suggest then that the central area responsible for the combination of auditory and visual remains unaffected by suspected APD. However, the role of APD in visual enhancement needs to be explored further in future studies. In the present study APD was defined based on SSI performance. It may be possible that other evaluation measures are better used in the classification of APD in older adults. In addition, many of the participants in the present study had moderately-severe or severe hearing losses. In these individuals it is difficult to separate out APD from peripheral hearing loss (Yellin, Jerger, & Fifer, 1989). It may be inappropriate to even consider APD as a factor in individuals with greater than a moderate hearing loss.

CONCLUSIONS

The results of this study indicate that the three most important predictors of visual enhancement ability were age, gender, and auditory-alone performance in noise. Visual enhancement decreased with increasing age, visual enhancement decreased as auditory-alone performance in noise decreased, and females had superior visual enhancement in comparison with males. Taken together these findings suggest that central abilities are more important than peripheral auditory abilities in determining the ability to integrate auditory and visual speech signals.

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