Visual Intelligibility of Deaf and Hearing Talkers

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The purpose of this study was to test the visual intelligibility of deaf talkers under the supposition that learning language through lipreading results in implicit knowledge of how to produce lipreadable speech. Subjects were eight profoundly deaf adults and eight task-sophisticated normal-hearing professionals. Intelligibility of 15 vowels in a homophenous consonant environment was tested in a closed-set format. Consonant intelligibility was tested in a multiple choice task using 10 contrasting articulations (e.g., alveolar vs. velar as in "take" vs. "cake"). Silent videotapes were shown to 21 profoundly deaf lipreaders of college age. Identification responses indicated that, among talker groups, young deaf adults were significantly less intelligible than the other talkers; but, older deaf adults were as intelligible as normal-hearing professionals, though there were differences in error patterns. It is suggested that studying oral deaf adults as talkers may yield informative data in defining the critical stimulus for lipreading.

The sound of what is called "deaf speech" has been studied at great length; characteristics of its visible component, however, have been largely ignored. (An exception is the use of lipreading to aid a listener's understanding of the deaf voice as in Monsen, 1983, for example.) Visible aspects of "normal-hearing speech" that have been studied include extent of facial exposure (Berger, Garner, & Sudman, 1971), expression (Stone, 1957), depth cues (Sudman & Berger, 1971), lip thickness (Berger, Perry, Hofmann, & Smith, 1977), exaggerated articulation (Franks, 1979), and rate (Byers & Lieberman, 1959). Oral measurements have also been made to explain visual speech perception, especially for vowels produced by normal-hearing talkers (Erber, Sachs, & De

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Filippo, 1979; Jackson, Montgomery, & Binnie, 1976; Montgomery & Jackson, 1983).

Research has suggested why talker performance is one determinant of lipreader performance. Lesner and Kricos (1981) and Kricos and Lesner (1982) found that talkers who were difficult to lipread produced fewer visemes than talkers with higher intelligibility scores. Identification of the critical aspects of visually intelligible speech may also come from efforts to simulate lipreadable mouth images via computer generation and manipulation (Erber, Sachs, & De Filippo, 1978).

Talkers — as well as lipreaders — for lipreading studies are usually drawn from the normal-hearing population. This practice may influence the kind of information gained in studies of the visible speech stimulus. Owens and Blazek (1985) recently compared normal-hearing and adventitiously hearing-impaired lipreaders' viseme groupings (those discerned by the lipreaders; not those generated by the talkers) and concluded that "persons who have learned a common auditory language share the same ability in identifying the articulatory movements associated with the consonants" (p. 392). Persons who do not share a common auditory language may reveal a different pattern of results. For example, those with profound hearing loss, whose dominant modality for speech reception throughout life has been vision, may look for and/or perceive different cues produced by talkers. Relevant subject characteristics for both talkers and lipreaders may be (a) experience in learning language through lipreading and (b) experience in producing messages to be lipread. As a result of such experience, talkers who have been profoundly hearing-impaired from an early age may have special skills to make themselves understood through lipreading. That is, they may develop implicit knowledge of how best to position and move the visible articulators for a lipreader.

The purpose of the present study was to evaluate the effectiveness of talker experience in producing lipreadable speech. Specifically, it was hypothesized that selected deaf[1] talkers are at least as visually intelligible to deaf lipreaders as are task-sophisticated normal-hearing talkers.

METHOD

Talkers

The subjects of this experiment were eight normal-hearing and eight deaf persons who participated as talkers. As a strict test of the hypothesis, normal-hearing talkers were selected for their knowledge and experience in communicating with hearing-impaired persons. One group of four (two men and two women) were rehabilitation audiologists who worked exclusively with severely and profoundly hearing-impaired young adults. A second group of

[1]The term "profoundly hearing-impaired" will be abbreviated to "deaf" throughout the remainder of the text.

four (two men and two women) were certified by the Registry of Interpreters for the Deaf in oral interpreting and were employed as interpreters.

The deaf talkers represented two levels of maturity. Four of them (two men and two women) were college students, aged 20 to 28 years. They were paid volunteers who met three criteria: (a) profound bilateral hearing loss (90 dB HL or greater); (b) moderate or better auditory speech intelligibility (3.5 or higher on a 5-point rating scale; Subtelny, Orlando, & Whitehead, 1981), and (c) moderate or better speechreading ability (at least 50% on a silent videotaped test of CID Everyday Sentences with key-word scoring; Johnson, 1975). Onset of deafness was at birth in three cases and at 8 years of age in the fourth student. Two students had better-ear pure tone averages for 500, 1000, and 2000 Hz of 90 and 98 dB HL (ANSI, 1969). The remaining two had no responses above 1000 Hz; their better-ear pure tone averages for 500 and 1000 Hz were 95 and 108 dB HL.

The second group of deaf talkers were two men and two women, from the faculty of a college for the deaf, who consistently used spoken communication with normal-hearing persons both receptively and expressively. Each had sustained his or her hearing loss before the age of speech and language acquisition in normal-hearing children.

Lipreaders

Evaluation of the four talker groups — audiologists, interpreters, deaf students, and deaf faculty — was based on the performance of a panel of deaf college students. They met the same three criteria as the student talkers: profound bilateral hearing loss, moderate (or better) auditory speech intelligibility, and moderate (or better) speechreading scores without sound cues.

Twenty-one students with these characteristics (11 male and 10 female) volunteered to participate for pay. Their ages ranged from 19 to 24 years. Their two- or three-frequency pure tone averages were 90-105 dB HL (M = 97.7 dB; ANSI, 1969) in the better ear. Hearing loss was congenital for two-thirds of the group. The others acquired their losses at 1½ to 8 years of age. They represented a range of lipreading ability, scoring 56-98% (M = 71.3%) on a silent videotape of CID Everyday Sentences spoken by a talker who was not a subject in this study. Their grade equivalent levels on the California Test of Reading Ability were 8.9-12.0 prior to college entrance. In addition, these students had passed a battery of screening tests for vision.

Materials

The lipreaders' task was to observe each of the talkers speaking 100 monosyllabic words. The word level was selected for ease of description, control, and scoring; and to isolate perceptual from linguistic task requirements. Also, it was reasoned that, if talkers were successful at the syllable level, they could ultimately disambiguate any stimulus. Two tests were constructed, one to focus on the vowel element of syllables, the other to test consonant intel-

ligibility.

Vowels. The vowel test was multiple choice, with the same 15 alternatives on each trial (see Table 1). All items began with a bilabial and ended with an alveolar articulation, forming words in English that were visually distinguishable on the basis of a medial vowel or diphthong. The 15 words were presented four times each in a different quasi-random sequence by each talker for a total of 60 test items per talker.

Table 1
Word Choices in a Vowel Test of Talker Intelligibility

BEAT	BERT	BAIT
BIT	BOOT	BITE
BET	PUT	BOAT
BAT	BOUGHT	BOUT
POT	BUT	BOYD

Consonants. The consonant set sampled articulatory positions that were expected to maximize differences among talkers. Table 2 represents the 10 consonant contrasts used. For want of an accepted viseme terminology, each contrast is represented by the phonetic symbols for sounds that use those articulations. The first contrast in Table 2, between alveolar articulation (as in [t]) and velar articulation (as in [k]), illustrates one test item. There were four similar items to test each contrast, for a total of 40 trials. Details of test construction are explained in the Appendix.

Procedure

The 60 vowel and 40 consonant items were videotaped with a 6-s interval between words. Talkers were instructed as follows:

> Visualize a specific deaf friend who relies primarily on lipreading for spoken communication. On each trial, speak to that friend as if she or he were standing here trying to lipread you. Do whatever you normally do to make your speech clear without using signs or gestures. Appear friendly and relaxed, but minimize extraneous movements.

Talkers' knowledge of the test vocabulary was checked. Manner of production was not constrained beyond the scope of the instructions. An audio track was recorded for monitoring, but talkers were told that no sound cues would be given to the lipreaders.

The video image was a front view, head only, color picture. The chin just touched the bottom of the screen when the talker spoke an exaggerated [a], and the top of the head just touched the top edge of the screen. Mouth-level lighting illuminated the front third of the tongue during a typical [a]. Trial number appeared in a corner of the screen and advanced 1 s before the next

Table 2
Contrasts and Sample Test Items in a Consonant Test of Talker Intelligibility

Contrast	Test Word	Distractors
[t]-[k] Initial	take	cake, rake, make
[t]-[k] Final	bake	bat, bear, bath
[k]-[Ø][a] Final	wake	way, wave, wear
[s]-[t] Initial	see	tea, me, fee
[s]-[t] Final	mass	mat, map, math
[s]-[st] Initial	say	stay, they, may
[p]-[w] Initial	bay	way, hay, day
[p]-[pl] Initial	pay	play, lay, say
[p]-[sp] Initial	mile	smile, style, file
[f]-[fl] Initial	fire	flier, tire, wire

Note. Each visible contrast is represented by phonetic symbols for sounds that use those articulations. The contrast element in test words could be any phoneme that shared the visible aspects of those articulations.

[a]The null symbol represents an open syllable.

item was spoken. A 1-s control signal was recorded as the trial number changed. This silently activated a vibrator attached to the lipreaders' table, providing a ready cue before every trial.

Prior to the test, lipreaders read the 15 vowel choices aloud for familiarization and to confirm knowledge of the words and their pronunciation. This was followed by a practice list of 10 vowel trials and 10 consonant trials spoken by a talker who was not one of the subjects in this study. Instructions were to circle the correct word on each trial.

Lipreaders were tested in groups of three or four. Each group viewed the 16 talkers in a different sequence, eight talkers on one day and eight on a second day. A talker's vowel test was immediately followed by that same talker's consonant test. Silent playback was on two 12-inch monitors that reproduced the head approximately life sized. Distance from screen to lipreader was 1 m.

RESULTS

Vowels

On each vowel test, the first 15 items were regarded as an opportunity for familiarization with a given talker and were not scored. This was necessary because the response sheets indicated that some lipreaders made adjustments in their perceptual set as each item was presented for the first time.

Mean scores for the talkers were 68.7% correct for deaf students (range = 40-93%), 72.9% for deaf faculty (38-96%), 78.0% for interpreters (47-98%), and 83.4% for audiologists (47-96%). Confusion matrices were similar in pattern across talker groups, but intelligibility was not uniform across vowels. Figure 1 is a plot of intelligibility scores for vowels articulated with lips spread. In most instances, productions of the deaf talkers (students and faculty) scored nominally lower than those of the normal-hearing talkers (interpreters and audiologists); [i] was one prominent exception. The vowels [ɑ] and [ɛ] scored low for all groups. The difficulty of transmitting [ɛ] is a general finding in most vowel lipreading studies (Lesner & Kricos, 1981; Wozniak & Jackson,

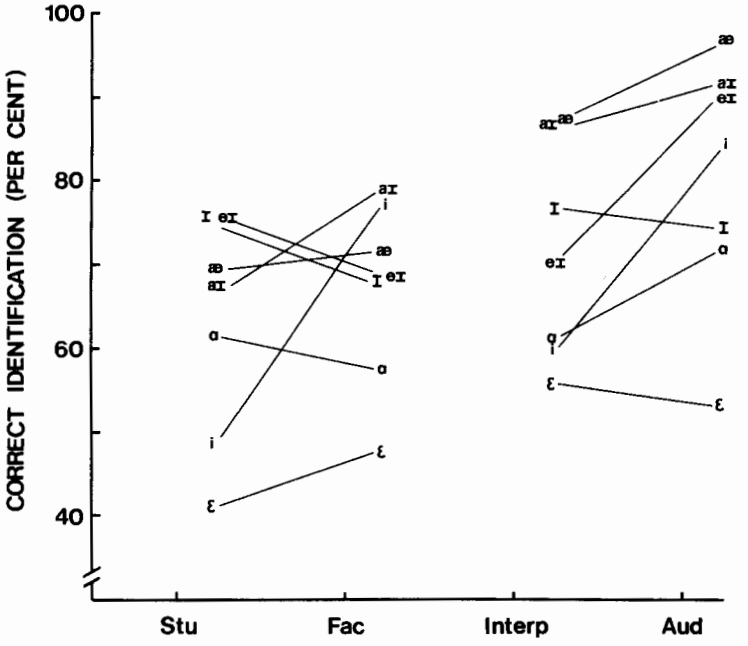

Figure 1. Mean visual intelligibility scores as a function of talker group — deaf students (Stu), deaf faculty (Fac), oral interpreters (Interp), and audiologists (Aud) — and vowel stimulus. Vowels appeared in medial word position and were articulated with lips spread. Scores are percent correct identification by 21 profoundly hearing-impaired lipreaders.

1979). One might have expected [ɪ] to score lower than [i] because it is not an end-point in the front vowel series, but even the students were successful in communicating this vowel.

On average, vowels with lip rounding were more intelligible than spread vowels, as shown in Figure 2. Three of the rounded vowels were diphthongs in which movement usually increases intelligibility (Jackson et al., 1976). Lip rounding cues in general may be easy to produce and discern reliably, whereas graded horizontal and vertical spread of the lips may be more subtle to control and perceive. An exception was [ʊ], a relatively lax vowel, which scored low for the two deaf groups. This vowel typically had lower intelligibility than the other vowels (Lesner & Kricos, 1981; Wozniak & Jackson, 1979).

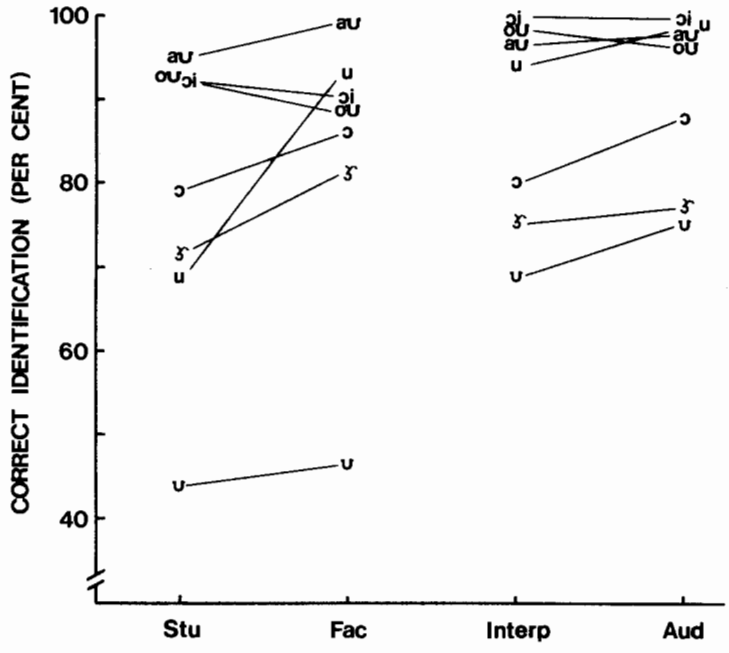

Figure 2. Mean visual intelligibility scores as a function of talker group and vowel stimulus. Vowels appeared in medial word position and were articulated with rounded lips. See Figure 1 for a description of talkers and lipreaders.

Consonants

In contrast to the vowels, consonants yielded a narrower range of mean intelligibility scores: deaf students, 79.3% (range = 72-87%); deaf faculty, 84.8% (80-89%); interpreters, 82.2% (75-85%); and audiologists, 81.8% (79-85%). These high scores on isolated words indicates that the word context may have facilitated control of consonant production. Secondly, lipreaders

may have prepared to look for the presence or absence of a specific differentiating cue by reading the response alternatives before each trial began.

All talker groups achieved greater than 90% for the three contrasts [p]-[w], [p]-[sp], and [f]-[fl]. The [p]-[pl] contrast yielded equally high scores for all but the deaf students who achieved 81% on this contrast. Figure 3 shows the relationships among the six less intelligible contrasts that do not depend on lip articulation. Among the normal-hearing talkers, there was clearly greater success transmitting contrasts with velar articulation than those requiring tongue tip and teeth articulation. The deaf talkers outperformed the normal-hearing talkers in differentiating [s]-[t] (the squares in Figure 3) and [s]-[st] (diamonds). Students had particular difficulty making the contrast between a velar articulation such as [k] and an open syllable (e.g., "wake" vs. "way").

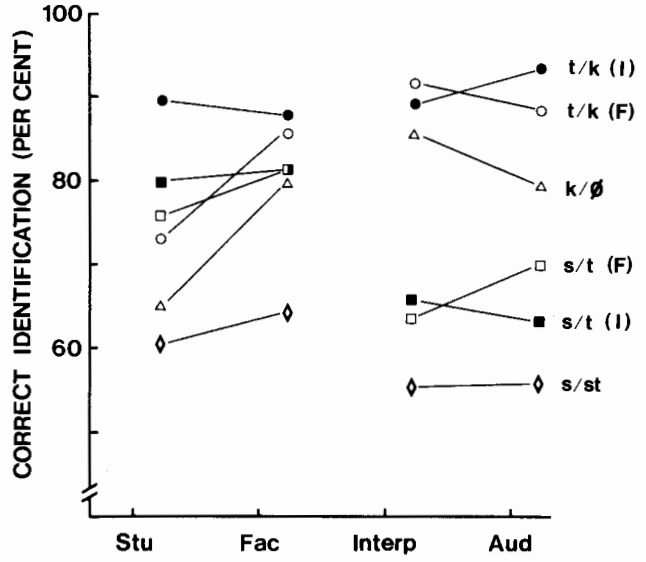

Figure 3. Mean visual intelligibility scores as a function of talker group and consonant contrast. Contrasts appeared in initial (I) or final (F) word position. Speech sound symbols indicate the nature of the articulatory contrasts. The null symbol (Ø) represents an open syllable (e.g., "way"). See Figure 1 for a description of talkers and lipreaders.

For comparisons between vowels and consonants, scores were corrected for guessing:

$$\text{corrected score} = \frac{\text{number of items correct} - \frac{\text{number of items wrong}}{\text{number of choices} - 1}}{\text{total number of items}}$$

and expressed in percent. A chance score on the consonant test was con-

servatively considered to be 50%, ignoring the two less confusable distractors for each item. Figure 4 shows the corrected scores across talker groups. When corrected for guessing, scores indicate that consonant distinctions were nominally harder for all groups to transmit than vowel distinctions.

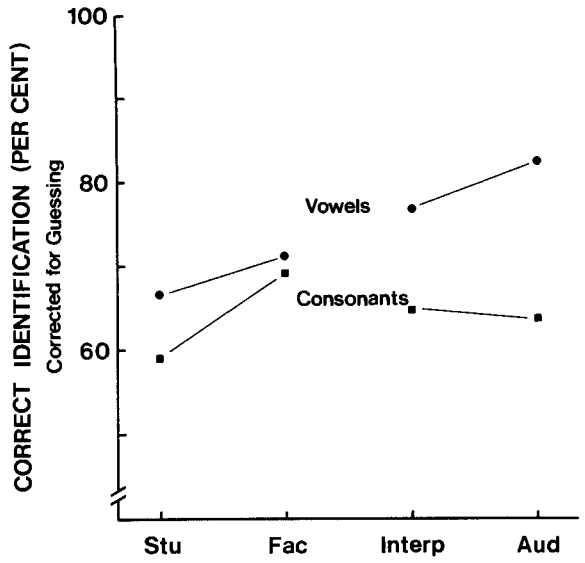

Figure 4. Mean visual intelligibility scores, corrected for guessing, as a function of talker group and type of stimulus. See Figure 1 for a description of talkers and lipreaders.

Talker Effects

Significance of the differences among groups was tested in an analysis of variance for repeated measures with a 3 × 4 × 2 (Lipreader Ability × Talker Group × Stimulus) design (Dixon, 1981). It was expected that talker differences would be more apparent in the scores of poorer lipreaders than in the scores of more skilled lipreaders; that is, that good lipreaders would not be as affected by talker ability. The ANOVA included a grouping variable, lipreader ability. The basis for grouping was the lipreaders' scores on CID Everyday Sentences without sound. Lipreaders were rank-ordered and divided into three groups of seven: lower range (M = 60.4% on CID Everyday Sentences; range = 56-65%), middle range (M = 69.9%; range = 66-72%), and upper range (M = 83.7%; range = 74-98%). The data for the ANOVA were vowel and consonant scores from the present study, corrected for guessing, expressed in percent, and averaged across the four members in each talker group. In summary, the ANOVA included two within variables, stimulus (vowels and con-

sonants) and talker (students, faculty, interpreters, and audiologists); and one between variable, lipreader ability (low, mid, and high).

As is evident in Figure 4, there was a significant main effect for stimulus ($F(1, 18) = 46.93$, $p < .01$) and a significant interaction between stimulus and talker ($F(3, 54) = 12.92$, $p < .01$). The analysis also yielded a significant main effect for talker ($F(3, 54) = 28.47$, $p < .01$). Applying Tukey's multiple comparison procedure (Glass & Stanley, 1970) to the six pair-wise comparisons among talker groups showed that only those comparisons involving student talkers were significant ($p < .01$). The deaf students were significantly different from the deaf faculty, the interpreters, and the audiologists, but there were no significant differences among deaf faculty, interpreters, and audiologists.

The main effect for lipreader ability was also significant as shown in Figure 5, top panel ($F(2, 18) = 6.02$, $p < .01$). Tukey's test indicated that the significant difference was between lower-scoring lipreaders and the other two groups, but that the lipreaders in the mid and high ranges did not differ significantly from each other.

Despite the distinctiveness of the lower-scoring lipreaders and the deaf student talkers, the interaction between talker and lipreader ability was not significant ($F(6, 54) = 1.03$, $p > .10$), nor was the interaction significant between lipreader ability and stimulus ($F(2, 18) = 0.98$, $p > .10$), or among lipreader ability, talker, and stimulus ($F(6, 54) = 0.18$, $p > .10$). The effect is similar across lipreaders and talker groups for vowels (Figure 5, middle panel) and for consonants (Figure 5, bottom panel).

DISCUSSION

On a test of visual intelligibility, selected deaf talkers (hearing-impaired faculty in this study) were not significantly different from normal-hearing talkers even in a stringent comparison with task-sophisticated subjects (interpreters and audiologists). Between the two deaf groups, one can wonder what the critical difference is. Will the deaf students turn into more intelligible adults after 15 or 20 years of additional experience? Variables that may prove interesting to test are consistency of articulation and degree of confidence that the talker generates in the lipreader. With maturity may come greater accommodation to lipreaders.

For additional work in this area, it is recommended that aspects of a realistic communication situation be simulated for talkers during videotaping so that the vividness of their imaginations need not be relied upon. In one stage of modification, experimenters could provide a live receiver, a familiar oral deaf observer, whose presence may motivate talkers to produce their best visible speech. In a second stage, talkers' adaptive abilities might be tested by supplying feedback from the lipreader and an opportunity for talkers to modify their visual cues in repeated utterances.

Concerning the present study, it must be noted that subject selection factors

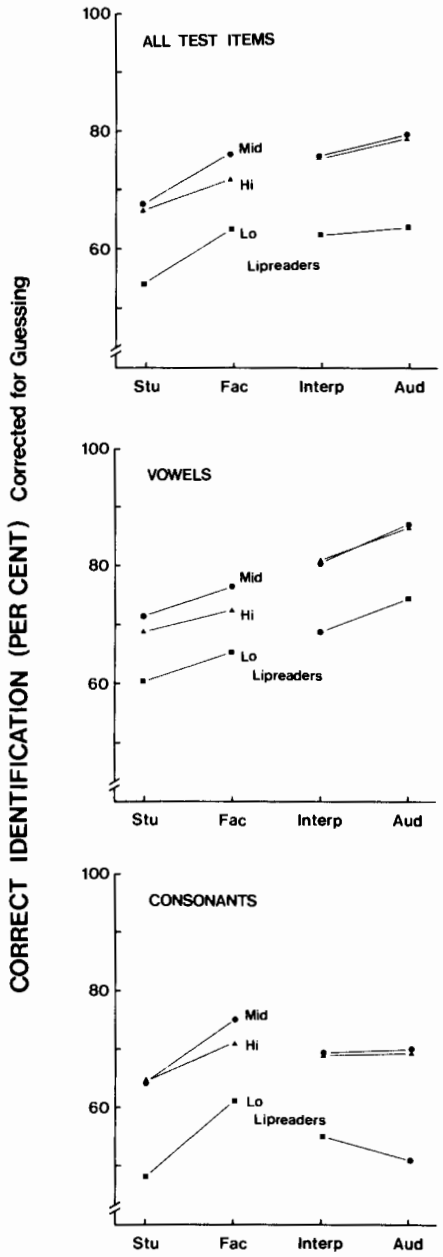

Figure 5. Mean visual intelligibility scores, corrected for guessing, as a function of talker group and ability of lipreader. Top panel: scores averaged over all stimuli. Middle panel: vowel stimuli. Bottom panel: consonant stimuli. See Figure 1 for a description of talkers and lipreaders.

limit the generalizability of results. Talkers in this study were selected for their ability to be understood through listening, as well as for their receptive (lipreading) skills. On the basis of the present data, it cannot be determined to what extent auditorally intelligible speech is associated with visually intelligible speech. One may only conclude that auditory intelligibility is probably not sufficient for visual intelligibility because of the poorer lipreadability of the deaf student talkers. This would be counter to the findings of O'Neill (1951) whose best of three talkers for listening was also the best for lipreading. The question of differential effect due to lipreader ability also needs further study with a group of subjects who represent a wide range of lipreading performance. Finally, how these results relate to transmission of connected speech is beyond speculation at this time.

Application of these data may be appropriate in defense of subject-selection criteria for future lipreading studies. It is suggested that there is much to be learned about the critical stimulus for lipreading by continued visual study of the deaf talker.

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APPENDIX

CONSTRUCTION OF CONSONANT TEST

Table A-1 illustrates the construction of the test of consonant intelligibility. Eight word pairs (16 words) with the appropriate consonant contrast in initial or final position were compiled. Four of these words were assigned to each of the four talkers in a group. Two of the words were examples of one of the articulations in the contrast and the other two were examples of the other articulation. Thus, there were four trials per talker testing a given contrast.

For each trial, the lipreaders' response sheets listed the word spoken by the talker as well as three distractors. One of the distractors was the other member of the word pair (not spoken by this talker). The other distractors were two less confusable rhyming words. Because the test words were identical across talker groups, there was a different randomization for each talker and a unique ordering of response choices on the answer sheets.

Table A-1

Contrasts in Initial (I) and Final (F) Word Position in Test Items in a Consonant Test of Talker Intelligibility

Talker 1 Test Word/Distractors		Talker 2 Test Word/Distractors		Talker 3 Test Word/Distractors		Talker 4 Test Word/Distractors	
s/t (I):							
see	/tea, me, fee	tea	/see, me, fee	seam	/team, beam, cream	team	/seam, beam, cream
sail	/tail, jail, fail	tail	/sail, jail, fail	sank	/tank, rank, thank	tank	/sank, rank, thank
tight	/sight, might, fight	sight	/tight, might, fight	tie	/sigh, buy, rye	sigh	/tie, buy, rye
tell	/sell, well, fell	sell	/tell, well, fell	tent	/sent, rent, went	sent	/tent, rent, went
s/t (F):							
mass	/mat, map, math	mat	/mass, map, math	bus	/but, bum, bunch	but	/bus, bum, bunch
pat	/pass, patch, Pam	pass	/pat, patch, Pam	race	/rate, ray, rage	rate	/race, ray, rage
nice	/night, knife, ninth	night	/nice, knife, ninth	wide	/wise, wife, wipe	wise	/wide, wife, wipe
fate	/face, fame, faith	face	/fate, fame, faith	ate	/ace, ape, age	ace	/ate, ape, age
s/st (I):							
say	/stay, they, may	stay	/say, they, may	sale	/stale, fail, mail	stale	/sale, fail, mail
sir	/stir, her, fir	stir	/sir, her, fir	sore	/store, for, more	store	/sore, for, more
snow	/so, row, show	so	/snow, row, show	stole	/soul, pole, hole	soul	/stole, pole, hole
snip	/sip, ship, rip	sip	/snip, ship, rip	stick	/sick, Rick, pick	sick	/stick, Rick, pick
t/k (I):							
take	/cake, rake, make	cake	/take, rake, make	tape	/cape, drape, shape	cape	/tape, drape, shape
top	/cop, shop, pop	cop	/top, shop, pop	tap	/cap, wrap, map	cap	/tap, wrap, map
guy	/die, my, why	die	/guy, my, why	kite	/tight, bite, right	tight	/kite, bite, right
gay	/day, way, they	day	/gay, way, they	cab	/Tab, grab, Fab	Tab	/cab, grab, Fab
t/k (F):							
back	/bat, bear, bath	bat	/back, bear, bath	sack	/sat, Sam, sash	sat	/sack, Sam, sash
lake	/late, laugh, lap	late	/lake, laugh, lap	fake	/fate, fame, faith	fate	/fake, fame, faith
mate	/make, match, math	make	/mate, match, math	Kate	/cake, cage, came	cake	/Kate, cage, came
wait	/wake, wave, wear	wake	/wait, wave, wear	rate	/rake, range, rave	rake	/rate, range, rave

Continued on next page

Table A-1 *Continued*

Talker 1 Test Word/Distractors		Talker 2 Test Word/Distractors		Talker 3 Test Word/Distractors		Talker 4 Test Word/Distractors	
k/Ø (F):							
wake	/way, wave, wear	way	/wake, wave, wear	lay	/lake, lame, layer	lake	/lay, lame, layer
be	/beak, beef, beam	beak	/be, beef, beam	pea	/peek, peach, peep	peek	/pea, peach, peep
bake	/bay, bathe, pave	bay	/bake, bathe, pave	stake	/stay, stage, stare	stay	/stake, stage, stare
we	/week, weave, weep	week	/we, weave, weep	seek	/see, seem, Sears	see	/seek, seem, Sears
p/w (I):							
bay	/way, hay, day	way	/bay, hay, day	pave	/wave, Dave, gave	wave	/pave, Dave, gave
buy	/why, lie, tie	why	/buy, lie, tie	mine	/wine, line, fine	wine	/mine, line, fine
wig	/big, king, fig	big	/wig, king, fig	will	/bill, fill, hill	bill	/will, fill, hill
wall	/ball, fall, tall	ball	/wall, fall, tall	wear	/bear, fair, hair	bear	/wear, fair, hair
p/pl (I):							
pay	/play, lay, say	play	/pay, lay, say	pace	/place, lace, face	place	/pace, lace, face
bead	/bleed, lead, feed	bleed	/bead, lead, feed	beach	/bleach, teach, reach	bleach	/beach, teach, reach
plan	/pan, can, than	pan	/plan, can, than	plants	/pants, aunts, grants	pants	/plants, aunts, grants
black	/back, lack, sack	back	/black, lack, sack	blank	/bank, Frank, sank	bank	/blank, Frank, sank
p/sp (I):							
mile	/smile, style, file	smile	/mile, style, file	pie	/spy, tie, guy	spy	/pie, tie, guy
peak	/speak, seek, cheek	speak	/peak, seek, cheek	peach	/speech, reach, each	speech	/peach, reach, each
spin	/pin, sin, thin	pin	/spin, sin, thin	spark	/park, shark, dark	park	/spark, shark, dark
spot	/pot, dot, shot	pot	/spot, dot, shot	spill	/pill, chill, kill	pill	/spill, chill, kill
f/fl (I):							
fire	/flier, tire, wire	flier	/fire, tire, wire	four	/floor, more, door	floor	/four, more, door
fat	/flat, that, cat	flat	/fat, that, cat	fed	/fled, led, bed	fled	/fed, led, bed
flake	/fake, lake, bake	fake	/flake, lake, bake	flame	/fame, name, came	fame	/flame, name, came
flight	/fight, light, white	fight	/flight, light, white	flown	/phone, loan, cone	phone	/flown, loan, cone