532

The Quarterly Journal of Experimental Psychology (1986), **38A**, 193–212

Access to Spoken Language and the Acquisition of Orthographic Structure: Evidence from Deaf Readers

Vicki L. Hanson

Haskins Laboratories, New Haven, Connecticut, U.S.A.

Sensitivity to two types of orthographic structure was investigated: linguistically based orthographic regularity and summed single letter positional frequency. Deaf college students were found to make use of positional frequency information no less than hearing college students; however, the extent to which they made use of orthographic regularities in word recognition was related to their speech production skills. In one task, subjects were presented nonword letter strings for short durations, each followed by a masking stimulus and a target letter. They were asked to indicate whether or not the target had been present in the letter string. It was found that the accuracy of deaf subjects with good speech, like that of hearing subjects, was considerably greater for orthographically regular than irregular strings. In contrast, the accuracy of deaf subjects with poor speech was much less related to orthographic regularity. In a second task, in which subjects made judgements about how word-like various letter strings appeared, the judgements of the hearing subjects were more influenced by regularity than those of deaf subjects with poor speech. These results are discussed in terms of how expertise in speech relates to appreciation of orthographic regularity.

Requests for reprints should be sent to Vicki L. Hanson, Haskins Laboratories, 270 Crown Street, New Haven, CT 06511 U.S.A.

This research was supported by National Institutes of Health Grants NS-18010 and HD-01994. I am grateful to Rena Krakow and Nancy Fishbein for their help in stimulus preparation and subject testing, and to Tom Carr, Laurie Feldman, Carol Fowler, Alvin Liberman, John Richards and the journal reviewers for very helpful comments on earlier versions of this manuscript. The cooperation of Gallaudet College, particularly Horace Reynolds and William McFarland, in this research project is gratefully acknowledged.

Introduction

It has been known for some time that hearing readers identify letters more accurately in orthographically legal nonwords (pseudowords) than in orthographically illegal nonwords (Adams, 1979; Aderman and Smith, 1971; Baron and Thurston, 1973; Gibson, Pick, Osser and Hammond, 1962). This finding has suggested that readers of English are influenced by orthographic structure in word recognition. Orthographic structure could facilitate perception by producing constraints on letter sequences that facilitate visual processing of letter strings (e.g. Carr, Posner, Pollatsek and Snyder, 1979; Massaro, Taylor, Venezky, Jastrzembski and Lucas, 1980; Singer, 1980) or facilitate perception by allowing well-structured strings to be more readily translated into a speech representation (e.g. Spoehr and Smith, 1975).

Differences have arisen as to how to describe the nature of this structure. Descriptions have generally been divided into those based on linguistic regularity and those based on statistical redundancy (for a review, see Massaro et al., 1980). Descriptions of orthographic structure based on linguistic regularity take into account phonological and scribal constraints of English. Orthographically regular words must therefore be pronounceable and contain only legal consonant and vowel combinations: the letter string REMOND, for example, would be considered as orthographically regular and the string RMNOED would be irregular. Descriptions of orthographic structure based on statistical redundancy take into account frequency of letters or letter combinations occurring in natural text. These redundancy descriptions have taken two forms: spatial (or positional) redundancy based on counts of single letters and their positions of occurrence, and sequential redundancy based on bigram or trigram frequency counts. According to a spatial redundancy description, for example, strings high on such a measure contain letters occurring in common positions, while strings low in such a measure contain letters occurring in low-frequency positions.

The evidence indicates that both orthographic regularity and statistical redundancy measures describe sources of perceptual facilitation (Henderson, 1982). That is, strings that are orthographically regular are recognized more accurately than strings that are irregular (Massaro, Venezky and Taylor, 1979; Massaro et al., 1980), and strings high in spatial redundancy are recognized more accurately than strings low in such redundancy (Mason, 1975, 1978; McClelland, 1976; McClelland and Johnston, 1977; Massaro et al., 1979, 1980). Although there has been some support in the literature for the notion that bigram and trigram frequency influence perceptual processing independent of regularity and spatial redundancy (Massaro, Jastrzembski and Lucas, 1981; Massaro et al., 1980), such evidence has not been consistently obtained under differing procedures (Gernsbacher, 1984; Gibson, Shurcliff and Yonas, 1970; Johnston, 1978; Manelis, 1974; McClelland and Johnston, 1977).

The question of central interest to the present paper is whether sensitivity to structural constraints of the orthography is related to speech production. One suggestion is that this sensitivity is acquired through experience with how the orthography maps the spoken language. For example, Gibson et al. (1962) suggested that experience with a consistent mapping of letter clusters to pronunciation may aid the reader in acquiring an appreciation of orthographic structure. Related to this notion, Venezky and Massaro (1979) suggested that phonics instruction, with its emphasis on analytic reading through attention to regular spelling–pronunciation correspondences, may help the beginning reader to acquire information about allowable letter sequences. In contrast to the importance that such suggestions place on a mapping between print and the spoken language, there is the suggestion that a sensitivity to orthographic structure might be acquired through strictly visual means, without reference to the spoken language (e.g. Baron and Thurston, 1973; Gibson et al., 1970; Mason, 1978). Since structural constraints on the orthography—both linguistic regularities and statistical redundancies—impose recurrent visual patterns, such a suggestion is quite feasible.

One argument that has often been used to support the notion of acquisition via visual means is the finding by several researchers that deaf subjects are sensitive to orthographic structure in word recognition and spelling (Dodd, 1980; Doehring and Rosenstein, 1960; Gibson et al., 1970; Hanson, 1982b; Hanson, Shankweiler and Fischer, 1983; Stone, 1980). It is often assumed that deaf subjects could not employ mapping between written and spoken language, and that the orthographic structure effect must therefore be purely visual (see, for example, Baron and Thurston, 1973; Gibson et al., 1970). As some have noted earlier, however, such a conclusion need not necessarily follow (see, for example, Coltheart, 1977; Crowder, 1982). As a rule, deaf children in English-speaking countries receive intensive instruction in speaking and lipreading; this is true both in schools that use an oral educational approach (speech being the means of communication in the classroom) and in schools that use a simultaneous or total communication approach (with speech being accompanied by manual communication in the classroom). Through this speech training, some prelingually, profoundly deaf persons develop quite good speech skills, while others develop very little, and between these two extremes there exists a continuum. Thus, the finding that deaf subjects display a sensitivity to orthographic structure does not necessarily imply a purely visual basis.

The studies examining deaf subjects' sensitivity to orthographic structure have not discriminated between whether the benefit obtained for orthographic structure was due to structure based on orthographic regularity or statistical redundancy. The only attempt to do so was by Gibson et al. (1970). Using multiple regression analyses, they found that sequential redundancies contributed only minimally to performance in a tachistoscopic full report task and were no greater a predictor of performance for deaf subjects than for hearing subjects. However, since Gibson et al. (1970) did not control for word length, it has been suggested that their study may not be an adequate test of the statistical redundancy descriptions of orthographic structure (Massaro et al., 1980, 1981).

Nor have any of the studies examining deaf subjects' sensitivity to orthographic structure examined how such sensitivity might vary in relation to subjects' speech skills. Although Gibson et al. (1970) found that the number of errors in their letter recall task was not related to speech intelligibility, these investigators did not examine whether the magnitude of any orthographic structure effects varied as a function of speech skills.

The present study examines sensitivity to orthographic structure among two groups of deaf subjects: those with relatively good speech productions, and those with poor speech productions. Their performance will be compared with that of a control group of hearing subjects on two tasks: (1) a perceptual task and (2) a judgement task that examines the extent to which subjects in the three groups are influenced by orthographic structure in rating how word-like certain letter strings appear. To determine the degree to which subjects are sensitive to orthographic regularity and to positional redundancy, these two types of structure are independently varied in the stimuli of the two tasks. If sensitivity to linguistically based orthographic regularities is related to expertise in speech, then deaf readers with poor speech skills may have difficulty in using orthographic structure, while deaf readers with fairly good speech skills would be expected to exhibit little or no difficulty in using this type of structure. However, the fact that orthographic regularity, by definition, is based on phonological constraints does not necessarily mean that the reader need be aware of these constraints in order to appreciate such regularity. If the principles of regularity can be acquired from visual patterns, then deaf readers, regardless of their speech skills, would be expected to be as sensitive as hearing readers to these regularities. Since statistical redundancy measures are based on visual properties inherent in the written representation of words, such structure is a feature of the orthography that might be expected to be as readily accessible by deaf readers, regardless of their speech skills, as by hearing readers. Spatial (positional) redundancy is the measure of statistical redundancy tested here. By this measure, the frequency of a letter string is based on the sum of the frequency for each letter in the string at its position of occurrence (Mason, 1975). The frequency of each letter in this summed single letter positional frequency measure is taken from the Mayzner and Tresselt (1965) letter frequency counts.

Method

Subjects

Subjects for the study were two groups of deaf subjects and a control group of hearing subjects. The two groups of deaf subjects differed in the intelligibility of their speech productions: one group had relatively good speech, the other had relatively poor speech. All were paid volunteers.

Deaf Subjects. The deaf subjects were prelingually, profoundly deaf. They were undergraduates or recent graduates of Gallaudet College, a liberal arts college for deaf students. All were experienced signers. Background information on hearing loss and speech intelligibility ratings for each of the subjects was obtained from school records.

The two deaf subject groups were determined on the basis of the speech intelligibility ratings of the subjects. These ratings were judgements made by experienced listeners on the staff of the college. In making these judgements, the listeners heard a taperecording of each student's reading of a passage, and rated, on a scale of 1–5, the intelligibility of the student's speech, with "1" on the scale representing speech that is readily understood by the general public, a "5" representing speech that cannot be understood by listening to the tape.

For the purposes of this experiment, the good-speech group was defined as subjects with a speech intelligibility rating of 1, 2, or 3, and the poor-speech group was defined as subjects with a rating of 4 or 5. There were 11 subjects in the good-speech group, and 12 in the poor. The data of three of these subjects were eliminated from analysis: one subject in the good-speech group failed to meet the accuracy criterion for inclusion in the experiment, and the data of two subjects in the poor-speech group were lost owing to equipment problems. As a result, 10 subjects remained in each of the two deaf groups.

There were no audiological conditions that readily distinguished between deaf subjects in the two groups. The subjects in the good-speech group had a median hearing loss of 100.5 dB (range = 83–113), better-ear average. The subjects in the poor-speech group had a median hearing loss of 103 dB (range = 90–113), better-ear average. Measures of residual hearing and vowel discrimination were available for six of the subjects in the good-speech group and for eight in the poor-speech group. Since response/no response in the frequency of 2,000 Hz. and above has been found to be related to speech intelligibility,[1] the measure of residual hearing used here was whether or not there was a response at 2,000 Hz or above in the better ear. Three of the subjects in the good-speech group and six in the poor-speech group did have responses in this range. In terms of vowel discrimination (better ear), the median discrimination of the subjects in the good-speech group was 40.0% (range = 24–76%),

---

[1] C. R. Smith. "Residual hearing and speech production in deaf children". Doctoral dissertation, The City University of New York, 1972.

and in the poor speech group it was 32.5% (range = 0–52%). For five of the ten subjects in each group, the presence of deafness in immediate family members (parents and/or siblings) suggested that the etiology of deafness was hereditary.

Hearing Subjects. The hearing subjects were 17 college undergraduates or recent graduates from the New Haven, Connecticut, area (primarily from Yale University). All had normal hearing and were native speakers of English. The data of five of these subjects were eliminated from analysis, one owing to equipment failure and four owing to accuracy outside the acceptable range. This resulted in 12 subjects in the hearing group.

Stimuli

The experimental stimuli were the six-letter nonsense words from List 1 of Massaro et al. (1979). These stimuli were constructed to vary orthographic regularity and letter positional frequency independently. This resulted in four types of stimuli: strings high in summed single letter positional frequency that were orthographically regular (e.g., REMOND, SIFLET) or irregular (e.g., RMNOED, TLFIES) as well as strings low in summed positional frequency that were regular (e.g., ENDROM, ESTFIL) or irregular (e.g., RDENMO, EFLSTI). Forty words of each type were included in the experimental list. The same stimuli were used in both the perceptual task and the judgement task.

Procedure

A perceptual task and judgement task, similar to those in earlier studies testing hearing subjects (e.g. Massaro et al., 1979, 1980), were administered to each of the subjects. The inclusion of the hearing subjects in the present study allowed for a replication of the earlier studies under the present test conditions. In addition to these tasks, a Reading Test was given to obtain a measure of each subject's reading achievement level.

Perceptual Task. Subjects were told that they would be seeing letter strings that were word-like but were not actual words. After each string, a probe letter would appear. If that probe letter was present in the string they had just seen, they were to press a right-hand button to indicate the response YES. If the probe letter was not present, they were to press a left-hand button to indicate the response NO. There were no time constraints on responding. They were informed that each letter string would be shown for just a brief time and that the length of presentation would be adjusted throughout the task to maintain the accuracy rate at about 75%. In addition, they were informed that half the trials would have the probe letter present, while the other half would not, and that they should therefore have about half YES responses and half NO responses. For the deaf subjects, instructions were signed in American Sign Language (ASL) by a deaf experimenter, a native signer of the language. For the hearing subjects, instructions were spoken by a hearing experimenter.

Stimuli were displayed for a controlled duration in the centre of a CRT display driven by an Atari microcomputer. Following stimulus presentation, a non-character dot mask was presented for 250 msec. Following offset of the mask, a probe letter was presented 3 spaces to the left of the stimulus item, on the same line. This probe remained on until a subject responded. There was an intertrial interval of 250 msec. Since the upper-case character set of the Atari was clearer than the lower-case character set, the stimuli were presented in all upper-case letters. The four stimulus types were mixed throughout each block.

As practice, subjects were presented with 20 blocks of 8 trials each. Following each practice block, the percentage accuracy on the block was displayed. The initial exposure duration was set at 325 msec. Based on the accuracy at the end of each block, the exposure duration was adjusted in steps of 10–25 msec to be longer or shorter to attain 75% accuracy. Practice trials were taken from Massaro et al. (1979), List 2.

Each letter string was used once as a target trial (i.e, the probe letter was present in the strings) and once as a catch trial (i.e. the probe letter was not present in the string). These experimental stimuli were presented in 4 blocks of 80 trials each. Each of the subjects was tested with a randomly chosen ordering of these four test blocks. Following each block, exposure duration was adjusted, if necessary, to maintain approximately 75% accuracy. The criterion for inclusion of subjects in the study was accuracy within the range of 60–90%. The mean exposure durations were 164.7 msec ($SD = 44.1$) for the 10 deaf subjects in the good-speech group, 155.7 msec ($SD = 35.9$) for the 10 deaf subjects in the poor-speech group, and 125.0 msec ($SD = 42.1$) for the 12 hearing subjects. This difference in exposure durations for the three subject groups was not statistically significant [$F(2, 29) = 2.89$, $p > 0.05$.]

Judgement Task. Following the perceptual task, the judgement task was administered. The stimuli were typed, in a random order, in upper-case letters on pages of 40 stimuli each. Following each string was a line on which subjects were to indicate their rating. The four test pages were presented in a randomly chosen order for each of the subjects.

The written instructions for the task informed subjects that their task was to rate several letter strings in terms of how "word-like" the strings were. The instructions indicated that none of the strings were real English words, but that some of the letter strings might seem more "word-like" than others. Subjects were shown a drawing of a scale from 1–10 with the numbers equally spaced and were told to use this scale for their ratings, with the number 1 marked as the "worst," being not much like an English word, and the number 10 marked as the "best," being very much like an English word. They were instructed to use all the numbers between 1 and 10 and to look quickly through the whole set of stimuli before starting to write down their ratings.

One deaf subject in the good-speech group, owing to time considerations, was not given the judgement task. The data of one hearing subject were excluded from this analysis as the person failed to use the rating scale correctly. (This hearing subject used the numbers 0 through 10 rather than the numbers 1 through 10, as instructed.)

Reading Test. The comprehension subtest of the *Gates-MacGinitie Reading Tests* (1969, Survey F, Form 2) was administered to all subjects. Form F is designed to be appropriate to hearing students in grades 10 through 12 (approximately the reading level of an average hearing child of 15 to 18 years of age),[2] a level which, based on the author's past research, was deemed appropriate for the

---

[2] These chronological ages are only approximate and are based on the average ages of hearing children in these grades. The *Gates-MacGinitie Reading Tests* (1969) do not provide norms for making direct translations from grade level equivalents to ages.

deaf subjects. A score for reading achievement of each subject was a standard score based on the grade equivalent of 10.1. By this standard score, a score of 50 represents reading achievement of grade 10.1 and each ten points represents performance that is one standard deviation better or worse than grade 10.1.

Results

Perceptual Task

The results of the perceptual task will be considered first. A 3 × 2 × 2 × 2 analysis of variance was performed on the percentage of correct responses in this task for the three groups of subjects with Regularity (regular, irregular), Summed Positional Frequency (high, low), and Trial Type (target, catch) varied within subjects. The same effects were significant, whether the data were subjected to an arcsine transformation or were untransformed. The results reported here are for the untransformed data. The analysis revealed a significant main effect of orthographic regularity [$F(1, 29) = 54.41$, $p < 0.001$], that was qualified by an interaction with group [$F(2, 29) = 3.93$, $p < 0.05$]. As shown in Figure 1, this interaction resulted from the deaf subjects in the poor-speech group demonstrating less of an advantage due to orthographic regularity than the subjects in the other two groups. Hearing subjects were 7.4% more accurate for regular than irregular letter strings, and deaf subjects in the good-speech group were 7.0% more accurate for regular than irregular strings. In contrast, deaf subjects in the poor-speech group were only 2.6% more accurate for regular strings. (Although this regularity advantage for the deaf subjects in the poor-speech group was small, it was still significant, $F(1, 9) = 5.52$, $p < 0.05$, as determined in a post hoc analysis.) There was also a significant main effect of frequency [$F(1, 29) = 19.60$, $p < 0.001$] that did not interact with subject group ($F < 1$). Overall, subjects in the three groups were 4.0% more accurate for high than low frequency strings. There were two significant three-way interactions involving Regularity × Trial Type. The first was the interaction of these two factors with Frequency [$F(1, 29) = 5.18$, $p < 0.05$], reflecting greater facilitation due to regularity for high than low frequency strings in the target trials, but a greater effect of regularity for low frequency strings in the catch trials. The second was the interaction of these two factors with subject group [$F(2, 29) = 3.87$, $p < 0.05$], reflecting greater facilitation due to regularity on target than catch trials for the hearing subjects, but a greater effect of regularity on catch trials than target trials for deaf subjects in the good-speech group. The facilitation due to regularity for deaf subjects in the poor-speech group was quite small in both cases. The mean percentages correct for each subject group as a function of regularity, frequency and trial type are given in Table I.

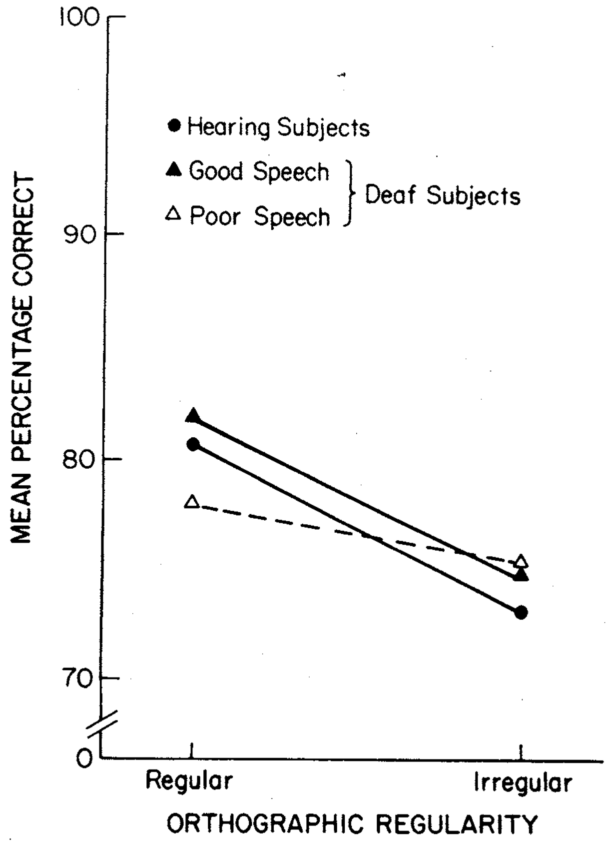

Figure 1. Mean percentage correct responses as a function of orthographic regularity for hearing subjects, deaf subjects with good speech, and deaf subjects with poor speech.

Judgement Task

The judgement task was used to determine the extent to which subjects were influenced by orthographic regularity and spatial redundancy in decisions about how word-like letter strings appeared. As shown in Table II, subjects in all three groups rated orthographically regular strings as more word-like than irregular strings, and rated strings high in single letter positional frequency as more word-like than strings low in such frequency.

An analysis of variance of the ratings data for the factors of Subject Group × Regularity × Frequency obtained a main effect of subject

Table I

Mean Percentage Correct in the Perceptual Task for Each Subject Group as a Function of Orthographic Regularity, Summed Single Letter Positional Frequency and Trial Type

	Summed single letter positional frequency	Trial type			
		Target		Catch	
		Regular	Irregular	Regular	Irregular
Hearing	High	83.1	70.8	81.0	80.2
	Low	75.6	66.3	83.1	75.8
Deaf —Good speech	High	84.0	78.9	84.9	75.7
	Low	78.9	74.9	80.9	71.1
Deaf —Poor speech	High	80.3	76.9	78.6	79.9
	Low	77.5	74.0	76.5	71.5

Table II

Mean Ratings in the Judgement Task for Each Subject Group as a Function of Orthographic Regularity and Summed Single Letter Positional Frequency

	Frequency	Regularity		
		Regular	Irregular	Mean
Hearing	High	7.7	3.2	5.4
	Low	5.9	2.4	4.1
	Mean	6.8	2.8	
Deaf—Good speech	High	5.5	2.6	4.1
	Low	3.9	2.1	3.0
	Mean	4.7	2.4	
Deaf—Poor speech	High	6.9	4.7	5.8
	Low	5.4	3.0	4.2
	Mean	6.1	3.8	

group [$F(2, 27) = 5.67$, $p < 0.01$], indicating that there was a difference in absolute ratings between the subject groups. A post hoc analysis indicated that this difference was due to the deaf subjects with good speech generally rating the letters strings as less word-like than subjects in the other two groups (Newman-Keuls, $p < 0.05$). The mean absolute ratings for subjects in the three groups were 4.79 for the hearing subjects, 4.97 for the deaf subjects with poor speech, and 3.54 for the deaf subjects with good speech. Since the conservative use of the rating scale by the deaf subjects with good speech would have reduced indications of orthographic sensitivity, the ratings of these subjects cannot be fairly compared with those of the subjects in the other two groups. Therefore, two different analyses were performed on the ratings data: one on the ratings of the hearing subjects and the deaf subjects in the poor-speech group, the second on the ratings of the deaf subjects in the good-speech group.

In the first analysis with the two subject groups, there were large main effects of both regularity [$F(1, 19) = 257.37$, $p < 0.001$] and frequency [$F(1, 19) = 158.39$, $p < 0.001$]. There was also an interaction of Regularity × Subject Group [$F(1, 19) = 18.58$, $p < 0.001$], reflecting greater effects of regularity for the hearing subjects than the deaf subjects. (A post hoc analysis, however, indicated that the effect of regularity was still significant when only the deaf subjects with poor speech were considered, $F(1, 9) = 43.01$, $p < 0.001$.) The only other effect to approach significance was an interaction of Regularity × Frequency × Group [$F(1, 19) = 3.95$, $p < 0.07$]. Post hoc analyses determined that this interaction was due to the fact that for the hearing subjects, but not for the deaf subjects with poor speech, regularity was a much greater determiner of wordness than was frequency (there was a significant interaction of Regularity × Frequency for the hearing subjects [$F(1, 10) = 23.15$, $p < 0.001$] that was not obtained for the deaf subjects with poor speech, $F < 1$).

In the second analysis, of only the deaf subjects with good speech, there were significant main effects of both regularity [$F(1, 8) = 89.03$, $p < 0.001$] and frequency [$F(1, 8) = 93.38$, $p < 0.001$], as well as an interaction between these variables [$F(1, 8) = 44.15$, $p < 0.001$]. This interaction reflected the fact that regularity was a greater determiner of ratings than was frequency.

Correlation of Perceptual and Judgement Data

To examine whether the same factors that influenced perceptual processing also influenced subjects' decisions about how word-like the letter strings were, subjects' ratings in the judgement task were correlated subjects in each of the three groups in the two tasks, as shown in Table IV. In all cases, strings high in frequency were responded to more accurately and rated as more word-like than strings low in frequency. As can be seen, the correlations between performance and frequency in the judgement task were not as high, however, as the correlations between performance and regularity.

As can also be seen in Table IV, the correlations with regularity and frequency were comparable for the deaf and hearing subjects in the perceptual task, with the exception, of course, of the deaf subjects in the poor-speech group. However, when the deaf and hearing subjects were compared on the judgement task, a difference between the groups emerged: the correlations with regularity for the deaf subjects with poor speech were significantly less than for the hearing subjects [$t(157) = 7.19$, $p < 0.001$, two-tailed], whereas the correlations with frequency were significantly *greater* for the deaf subjects with poor speech than for the hearing subjects [$t(157) = -3.94$, $p < 0.001$, two-tailed]. (Since the deaf subjects in the good-speech group demonstrated a conservative use of the rating scale, a restricted range problem was indicated for these subjects. This problem would have tended to reduce the magnitude of the correlations of their ratings data with both regularity and frequency, making comparisons of their correlations with those of subjects in the other two groups difficult to interpret.)

Correlations with Reading Proficiency

Finally, analyses were performed to determine whether sensitivity to structural constraints of the orthography varied as a function of reading proficiency in either task for the deaf subjects. There was nothing in the data to suggest any such relationship. The mean reading score of the deaf subjects in the good-speech group was 49.0, and of those in the poor-speech group it was 46.2. Thus, on the average, subjects were reading at very nearly 10th-grade level (approximately the reading level of an average hearing child 14 to 15 years old), a level indicating that they were quite successful readers by comparison with most prelingually, profoundly deaf individuals (for discussion of reading ability of deaf individuals see, for example, Conrad, 1979, and Karchmer, Milone, and Wolk, 1979). The reading scores of the two groups did not differ significantly ($t < 1$). There were no significant correlations between reading comprehension and the regularity advantage or the frequency advantage on either task (all ps > 0.05, two-tailed).

The hearing subjects were also given the reading test, but their performance could not accurately be ascertained on the scale. The accuracy of many of these subjects was so great that it fell outside the range for which the test had reliable norms. All that can reasonably be reported about the hearing subjects' data is that all of them obtained scores of 70 or greater.

Discussion

Consistent with earlier studies, deaf subjects in the present study were found to be sensitive to orthographic structure (Doehring and Rosenstein, 1960; Gibson et al., 1970; Hanson, 1982b; Stone, 1980). Such findings have often been taken as evidence that orthographic sensitivity need not be related to an appreciation of the phonological constraints that govern word formation. That is, since deaf individuals are presumed not to use speech, it follows that if they have acquired a sensitivity to orthographic structure principles then they must have acquired it through strictly visual means, quite independently of experience with how the written language maps the spoken. As mentioned earlier, however, such an interpretation of the findings with deaf subjects is problematic. Deaf individuals generally do have some experience with speech, although they differ in their expertise in this area: some are quite proficient with speech, others are considerably less so. The present study investigated whether sensitivity to two aspects of orthographic structure (namely, orthographic regularity and statistical redundancies) relates to speech intelligibility by comparing the orthographic sensitivity of hearing subjects with that of two groups of deaf subjects who varied in one aspect of speech proficiency—speech intelligibility—but did not differ in their reading proficiency or, in any discernible respect, audiometrically.

The outcome of the perceptual and judgement tasks indicated that sensitivity to orthographic regularity (defined in terms of phonological and scribal constraints) differed as a function of expertise in speech. In the perceptual task, it was found that deaf subjects with good speech exhibited perceptual facilitation due to regularity that was comparable to that of the hearing subjects, while deaf subjects in the poor-speech group exhibited much less facilitation than those in the other two groups. Post hoc correlations provided additional evidence for this relationship; the accuracy of the deaf subjects in the good-speech group, like that of the hearing subjects, was significantly correlated with orthographic regularity, but the accuracy of the deaf subjects in the poor-speech group was not. The results of the judgement task were consistent with the perceptual task in indicating a relationship between speech intelligibility and sensitivity to orthographic regularity. In that task, the correlation with regularity was not as great for the subjects with poor speech as for the hearing subjects, nor, apparently, for the deaf subjects with good speech.

It is worth noting that the deaf subjects in the poor-speech group did not appear to be completely insensitive to orthographic regularity. In the perceptual task, these subjects exhibited a small facilitation due to regularity that was significant in the orthogonal contrast, although it failed to reach significance in the post hoc correlation. Given the significance in the orthogonal contrast, though, it might be posited that this type of structure does influence their perceptual processing to some limited extent. Moreover, in the judgement task their ratings were significantly higher for regular than irregular strings, and there was a significant correlation between their ratings and the post hoc measure of regularity. This sensitivity to regularity on the part of the deaf subjects with poor speech is not inconsistent with the notion that such sensitivity is related to speech intelligibility. It must be borne in mind that even these readers are not completely without speech ability—their proficiency with speech is just less than that of the hearing subjects and the deaf subjects in the good speech group. Correspondingly, their sensitivity to orthographic regularity was found to be less.

It is of interest that the present study found that the perceptual facilitation of the deaf subjects in the good-speech group was comparable to that of the hearing subjects. Although subjects in this group had good speech in relation to other deaf speakers, the speech of most of these subjects was only moderately intelligible. Only three of the subjects in this group had speech that was rated as better than a "3" on the speech intelligibility rating scale (a "3" represents speech that the general public has some difficulty in understanding, at least initially). Thus, sensitivity to orthographic regularity can apparently be acquired without perfect production of speech. What is crucial is not that speech is perfectly intelligible as perceived by listeners, but that the deaf individual is able to appreciate the phonological distinctions of the language. Although some correlation undoubtedly exists between perceived intelligibility and phonological appreciation, the two are not one and the same. The deaf subjects in this study whose speech was only moderately intelligible to listeners were, apparently, quite phonologically competent.

In contrast to the indications for regularity, the deaf subjects in both the good- and poor-speech groups exhibited a sensitivity to spatial (positional) redundancy that was no less than that of the hearing subjects. This finding suggests that these statistical redundancies, which are based on properties of the visual signal itself, can be learned through strictly visual means. The subjects in all three groups were influenced by spatial redundancy information in their ratings, but the deaf subjects with poor speech showed *higher* correlations with frequency than the hearing subjects. This is suggestive that deaf readers with poor speech may compensate for their lesser proficiency with regularity by relying more heavily on statistical redundancies of the orthography.

The difference in sensitivity to orthographic regularity as a function of speech intelligibility stands as the major finding of the present study, suggesting an important relationship between expertise in speech and acquisition of orthographic regularity (e.g., Gibson et al., 1962; Venezky and Massaro, 1979). Given the correlational nature of this finding, however, it cannot be determined from this study how regularity and speech intelligibility are causally linked. One possibility is that direct relationships between sensitivity to orthographic regularity and speech do exist. For example, it could be that speech ability improves an individual's ability to perform a linguistic analysis of words, an analysis that would provide the information needed to acquire an appreciation of the phonological structure of words underlying orthographic regularity.

Alternatively, it is possible that the tasks of the present study tapped the use of an internal speech code, and that the obtained relationship between orthographic regularity and speech intelligibility reflects the fact that both are related to this internal code. In this regard, the present findings are compatible with results from short-term memory studies. In those studies, hearing readers have been more effectively able than deaf readers to use a speech code, and deaf readers with good speech intelligibility have been more effectively able than deaf readers with poor speech intelligibility to use a speech code (Conrad, 1979; Hanson, 1982a; Lichtenstein, in press). The obtained relationship is generally assumed to be causative, such that the better speech skills promote ability to use an internal speech code (see Conrad, 1979).

In actuality, other factors (e.g., lipreading and reading achievement) also have been found to be associated with the ability to use an internal speech code by deaf readers (Conrad, 1979; Lichtenstein, in press). It is likely that there is no simple relationship among these factors; probably there are multiple directions of causation. For example, good speech production could promote acquisition of an internal speech code, which, in turn, could promote lipreading skill. This lipreading skill could then serve to sharpen the speech code, which could then further enhance speech production. Similarly with reading, an effective speech code could promote reading success, and experience with reading could provide information that would serve to enhance the internal code, lipreading and speech production. Such interactions between language forms need not be limited to deaf readers. These same factors could also interact for hearing individuals in the acquisition of linguistic sensitivity, although hearing readers would have the advantage of an additional reliable auditory input.

In addition to the factors named above, another source of linguistic input might influence acquisition of linguistic sensitivity for deaf readers: for deaf readers skilled in manual communication, fingerspelling could prove useful. Fingerspelling is a manual communication system in which words are spelled out by the sequential production of the handshapes of a manual alphabet. (The American manual alphabet uses a one-handed configuration for each letter; the British system uses a two-handed configuration for each letter.) For deaf persons skilled in fingerspelling, orthographically permissible letter strings conform to the structure inherent in the manual production. As a result, production of illegal letter strings would feel "difficult" or "awkward" to produce on the hand. Thus, it is reasonable to hypothesize that fingerspelling could be useful in the acquisition of orthographic structure. While fingerspelling may contribute, in part, to sensitivity to orthographic structure for deaf readers, since the deaf subjects in both groups were skilled signers, the observed differences in sensitivity between the two groups cannot be accounted for on the basis of fingerspelling.

Although it has been suggested in the literature that hearing children (sixth-graders, ages 11–13 years) who are good readers may be more sensitive both to orthographic regularity and to spatial redundancy information than are children who are poor readers (Mason and Katz, 1976; Massaro and Taylor, 1980), the same characterization does not appear to distinguish between good and poor hearing readers at the college level (Massaro and Taylor, 1980). In the present study, the deaf readers were less proficient readers than the hearing subjects. Yet, consistent with the earlier findings with hearing college students, no difference in perceptual facilitation due to orthographic structure resulted from this discrepant reading proficiency. In their perceptual facilitation due to orthographic regularities, the deaf subjects with good speech were comparable to the hearing subjects, and in their perceptual facilitation due to spatial redundancy, the deaf subjects, regardless of their speech production ability, were no less sensitive than the hearing subjects. Moreover, considering only the deaf subjects, advantages due to regularity and spatial redundancy did not correlate significantly with reading comprehension in the perceptual or judgement tasks.

In summary, the present results suggest a relationship between a sensitivity to at least one aspect of orthographic structure—namely, linguistically-based regularity—and expertise in speech. However, sensitivity to spatial redundancy does not appear to be related to such expertise. Further, the present results indicate that despite the fact that regularity and spatial frequency are normally confounded in written English (e.g., Massaro et al., 1980), acquisition of sensitivity to the two can occur independently: although the deaf subjects with poor speech were less sensitive to regularity than hearing subjects, they were no less sensitive to spatial frequency.

REFERENCES

Adams, M. J. (1979). Models of word recognition. *Cognitive Psychology*, **11**, 133–176.

Aderman, D. and Smith, E. E. (1971). Expectancy as a determinant of functional units in perceptual recognition. *Cognitive Psychology*, **2**, 117–129.

Baron, J. and Thurston, I. (1973). An analysis of the word-superiority effect. *Cognitive Psychology*, **4**, 207–228.

Carr, T. H., Posner, M. I., Pollatsek, A. and Snyder, C. R. R. (1979). Orthography and familiarity effects in word processing. *Journal of Experimental Psychology: General*, **108**, 389–414.

Coltheart, M. (1977). Critical notice. *Quarterly Journal of Experimental Psychology*, **29**, 157–167.

Conrad, R. (1979). *The deaf school child*. London: Harper & Row.

Crowder, R. G. (1982). *The psychology of reading: An introduction*. New York: Oxford University Press.

Dodd, B. (1980). The spelling abilities of profoundly pre-lingually deaf children. In U. Frith (Ed.), *Cognitive processes in spelling*. London: Academic Press. Pp. 423–440.

Doehring, D. G. and Rosenstein, J. (1960). Visual word recognition by deaf and hearing children. *Journal of Speech and Hearing Research*, **3**, 320–326.

Gates-MacGinitie reading tests. (1969). New York: Columbia Teachers' College Press.

Gernsbacher, M. A. (1984). Resolving 20 years of inconsistent interactions between lexical familiarity and orthography, concreteness, and polysemy. *Journal of Experimental Psychology: General*, **113**, 256–281.

Gibson, E. J., Pick, A., Osser, H. and Hammond, M. (1962). The role of grapheme–phoneme correspondence in the perception of words. *American Journal of Psychology*, **75**, 554–570.

Gibson, E. J., Shurcliff, A. and Yonas, A. (1970). Utilization of spelling patterns by deaf and hearing subjects. In H. Levin and J. P. Williams (Eds.), *Basic studies in reading*. New York: Basic Books, Inc. Pp. 51–73.

Hanson, V. L. (1982a). Short-term recall by deaf signers of American Sign Language: Implications of encoding strategy for order recall. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **8**, 572–583.

Hanson, V. L. (1982b). Use of orthographic structure by deaf adults: Recognition of fingerspelled words. *Applied Psycholinguistics*, **3**, 343–356.

Hanson, V. L., Shankweiler, D. and Fischer, F. W. (1983). Determinants of spelling ability in deaf and hearing adults: Access to linguistic structure. *Cognition*, **14**, 323–344.

Henderson, L. (1982). *Orthography and word recognition in reading*. London: Academic Press.

Johnston, J. C. (1978). A test of the sophisticated guessing theory of word perception. *Cognitive Psychology*, **10**, 123–153.

Karchmer, M. A., Milone, M. N., Jr. and Wolk, S. (1979). Educational significance of hearing loss at three levels of severity. *American Annals of the Deaf*, **124**, 97–109.

Lichtenstein, E. (in press). The relationships between reading processes and English skills of deaf college students: Parts I and II. *Applied Psycholinguistics*.

Manelis, L. (1974). The effect of meaningfulness on tachistoscopic word perception. *Perception & Psychophysics*, **16**, 182–192.

Mason, M. (1975). Reading ability and letter search time: Effects of orthographic structure defined by single-letter positional frequency. *Journal of Experimental Psychology: General*, **104**, 146–166.

Mason, M. (1978). The role of spatial redundancy in grapheme recognition: Perception or inference? *Journal of Experimental Psychology: Human Perception and Performance*, **4**, 662–673.

Mason, M. and Katz, L. (1976). Visual processing of nonlinguistic strings: Redundancy effects and reading ability. *Journal of Experimental Psychology: General*, **105**, 338–348.

Massaro, D. W., Jastrzembski, J. E. and Lucas, P. A. (1981). Frequency, orthographic regularity, and lexical status in letter and word perception. In G. Bower & A. R. Lang (Eds.), *The psychology of learning and motivation: Vol. 15*. New York, Academic Press. Pp. 163–200.

Massaro, D. W. and Taylor, G. A. (1980). Reading ability and utilization of orthographic structure in reading. *Journal of Educational Psychology*, **72**, 730–742.

Massaro, D. W., Taylor, G. A., Venezky, R. L., Jastrzembski, J. E. and Lucas, P. A. (1980). *Letter and word perception: Orthographic structure and visual processing in reading*. Amsterdam: North-Holland.

Massaro, D. W., Venezky, R. L. and Taylor, G. A. (1979). Orthographic regularity, positional frequency, and visual processing of letter strings. *Journal of Experimental Psychology: General*, **108**, 107–124.

Mayzner, M. S. and Tresselt, M. E. (1965). Tables of single-letter and digram frequency counts for various word-length and letter position combinations. *Psychonomic Monograph Supplements*, **1**(2), 13–32.

McClelland, J. L. (1976). Preliminary letter identification in the perception of words and nonwords. *Journal of Experimental Psychology: Human Perception and Performance*, **2**, 80–91.

McClelland, J. L. and Johnston, J. C. (1977). The role of familiar units in perception of words and nonwords. *Perception & Psychophysics*, **22**, 249–261.

Singer, M. H. (1980). The primacy of visual information in the analysis of letter strings. *Perception & Psychophysics*, **27**, 153–162.

Spoehr, K. T. and Smith, E. E. (1975). The role of orthographic and phonotactic rules in perceiving letter patterns. *Journal of Experimental Psychology: Human Perception and Performance*, **1**, 21–34.

Stone, R. E. (1980). Factors affecting the tachistoscopic recognition of trigrams for both deaf and hearing college students. *Proceedings of the Gallaudet Conference on Reading in Relation to Deafness*. Washington, D.C.: Division of Research, Gallaudet College. Pp. 171–192.

Venezky, R. L. and Massaro, D. W. (1979). The role of orthographic regularity in word recognition. In L. B. Resnick and P. A. Weaver (Eds.), *Theory and practice of early reading* (Vol. 1). Hillsdale, N.J.: Lawrence Erlbaum Associates. Pp. 85–107.

Revised manuscript received 9 August 1985