THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 1989, *41A* (2) 273–292

Modality Effects: Do They Fall on Deaf Ears?

Randall W. Engle and Judy Cantor
University of South Carolina, Columbia, South Carolina, U.S.A.

and

Marilyn Turner
Wichita State University, Wichita, Kansas, U.S.A.

The present study tests the assumption of the PAS theory of echoic memory (Greene & Crowder, 1984) that the representation of acoustic features is necessary in producing modality effects. Performance by deaf subjects was compared to hearing subjects on serial and free-recall tasks with vocalizing and non-vocalizing conditions. For the serial tasks, typical modality and acoustic similarity effects were observed with hearing subjects, and no such effects were found with deaf subjects. However, for the free-recall task, modality effects were found for both deaf and hearing subjects. It is unlikely that phonological coding resulting from gestural cues mediates the modality effect, as phonological confusion errors for deaf and hearing subjects did not correlate with the size of this effect.

One commonly used index of auditory or echoic memory is the modality effect. When subjects are presented with a list of items to be immediately recalled, performance on the last one or two items is better following auditory presentation than following visual presentation (Crowder & Morton, 1969). The recency advantage found with audition was originally attributed to a Precategorical Acoustic Store (PAS) consisting of sensory representations of at least the terminal item of stimulus lists for upwards of three seconds (Crowder & Morton, 1969). Accordingly, subjects can use the relatively long-lasting traces of items in PAS to supplement information held in short-term memory (STM). The result is two sources of information available to the subject about recency items in auditory lists. Because the duration of the visual store is much shorter, the subject receiving visual

Requests for reprints should be sent to Randall W. Engle, Psychology Department, University of South Carolina, Columbia, SC 29208, U.S.A.

presentation cannot supplement the STM in recall. Thus, the modality effect was thought to reflect the advantage of an additional source of information for recall with auditory presentation.

Also supporting the original PAS model is the suffix effect (Crowder & Morton, 1969), in which the auditory advantage is eliminated if a redundant, non-recalled verbal item is appended to the list. There is no decrement in recall, however, when a suffix is appended to a visually presented list. Subsequent items (e.g. the suffix) mask or supplant the trace of the previous item in PAS and the magnitude of modality effect is reduced or eliminated.

Recently however, the PAS theory of echoic memory has been revised (Crowder, 1983; Crowder, 1986; Greene & Crowder, 1984) as a result of several findings inconsistent with the original model. Several studies (cf. Nairne, 1988) have shown modality and suffix effects in the absence of sound. Campbell and Dodd (1980) found a significant recency advantage of lipread lists over visually presented lists, and a suffix effect when an auditory suffix was appended to lipread lists. Spoehr and Corin (1978) demonstrated that a lipread suffix appended to auditory lists produced a suffix effect, and similar findings were reported when visually presented lists were silently articulated (mouthed), and when there was either a mouthed or auditory suffix (Greene & Crowder, 1984; Nairne & Walters, 1983). Clearly the original PAS model cannot account for the numerous demonstrations of suffix and modality effects in the absence of sound.

The original PAS theory assumed that activation of auditory features occurs directly as a result of auditory input. The newer theory (Crowder, 1983; Greene & Crowder, 1984) is based on the assumption that gestural cues can cause the auditory features associated with these cues to be activated. Crowder (1983) suggests that when gestural information is presented, we first calculate the sounds that these gestures would have produced, and then activate the corresponding auditory features. The ability to utilize these gesture-to-sound rules presumably relies on the associations between auditory and non-auditory stimulation formed during infancy. It is this initial experience of simultaneously hearing sounds and associating these sounds with gestures that provides subsequent non-auditory stimulation access to PAS. The result is gestural stimulation that leads to "functional sound" (Crowder, 1983, p. 261).

The revised PAS model still requires auditory feature synthesis, even when gestural information is the catalyst. Modality effects found with mouthed and lipread stimuli can be accounted for, and the integrity of the modality effect procedure as an index of echoic memory is upheld. There is, however, an alternative possibility.

An underlying assumption of both the original and revised PAS models is that the primitive acoustic features are temporarily preserved, allowing time for integration of PAS traces with information in STM. The result is enhanced recency for auditory lists. However, the necessity of this synthesis in producing the modality effect has not been directly tested. The effects of gestural information such as mouthing and lipreading suggest that auditory presentation may be one of several ways to produce enhanced recency; it does not necessarily reflect echoic memory processes. If it can be demonstrated that gestural information alone, independent of acoustic feature activation, is sufficient to produce modality effects, then this effect does not simply reflect an acoustic memory.

The present study was designed to test whether articulation by deaf subjects is sufficient to produce the modality effect. Although not directly addressed by Crowder (1983), the PAS model seems to predict that as the feature selection mediated by gestures reflects infantile associations of gestures and sounds, congenitally deaf individuals should not have access to such a system. However, predictions about adventitiously deaf subjects are less clear. While these individuals should have formed the initial gesture-to-sound associations that Crowder (1983) describes, we do not know how subsequent physical damage to the auditory system would affect the processes of PAS. This issue will be further explored in the analyses of our data.

A recent study by Hanson and Fowler (1987) demonstrated that deaf individuals can utilize phonological (articulatory) information. In a series of lexical decision tasks, they presented pairs of words and pseudowords that varied along several dimensions, including phonological similarity. They found facilitation in reaction times for rhyming, phonologically similar words, and suggested that "given the impoverished auditory experience of deaf individuals, phonological information need not be tied to the auditory modality" (Hanson & Fowler, 1987, p. 207). They further assert that this phonological information may closely resemble articulatory coding. In addition, Conrad (1979) demonstrated that deaf children can use speech-based codes when performing in a visual memory span task. Thus, it appears that the deaf can demonstrate a sensitivity to phonology and may utilize articulatory coding. For the purposes of this article, the terms phonological and articulatory will be used interchangeably. Whereas deaf subjects may use articulatory coding, the new PAS model predicts that congenitally deaf subjects could not have formed the gesture-to-sound associations necessary to utilize auditory feature selection.

Although auditory stimuli cannot be presented to deaf subjects, modality effects have been consistently demonstrated when hearing subjects vocalize visual stimuli (e.g. Crowder, 1986; Watkins, Watkins, & Crowder, 1974). In the present study, performance by deaf subjects in immediate serial and free-recall tasks was compared to hearing subjects when stimuli were vocalized or silently read. If, as suggested by Crowder (1983) and Greene and Crowder (1984), the modality effect reflects the acoustic feature synthesis of echoic memory, then because the deaf cannot take advantage of this process, there should be enhanced recency in the vocalizing condition for hearing subjects only. If, on the other hand, gestural information alone is sufficient to produce modality effects, then both groups of subjects should show enhanced recency in vocalizing conditions.

Should the data indicate modality effects for both deaf and hearing subjects, one possible explanation is that the modality effect occurs as a result of the articulatory coding generated from gestural stimulation, rather than acoustic feature synthesis. This possibility was tested by manipulating the phonological confusability of stimulus lists. Conrad (1964, 1970) used this type of procedure to demonstrate articulatory coding in both deaf and hearing subjects with visual stimuli.

The revised model incorporates gestural movements, but modality effects are still contingent on the activation of acoustic features rather than motoric or phonological coding. Although deaf subjects can produce the motor movements necessary for speech, they presumably cannot represent the acoustic nature of the spoken stimuli. Thus, the present study tests the assumption underlying both the original and revised PAS models: that acoustic feature representation is necessary for producing modality effects.

In the first and second tasks serial recall was required, and the effects of phonological similarity and modality for deaf as compared to hearing subjects was examined. Watkins et al. (1974), and Crowder (1971) have demonstrated that phonologically confusable stimuli will reduce or eliminate the modality effect, suggesting that PAS represents acoustic information. Conrad (1970) demonstrated that deaf subjects who are good articulators will make phonological confusion errors. Greene and Crowder (1984) suggested that because auditory and mouthed modality effects are both influenced by acoustic similarity, they must share a common source. Thus, Conrad's (1970) task was replicated with the addition of a vocalizing condition. Conrad's procedure and stimuli were chosen because he was able to demonstrate that this may be an appropriate technique for distinguishing between articulators and non-articulators in a deaf population. In this procedure, phonological similarity is manipulated within lists, so that each stimulus list contains both phonologically similar and non-similar items. However, Watkins et al. (1974) assert that presenting mixed-letter lists reduces the effect of acoustic similarity and may prompt other inter-list memory strategies that do not rely on phonology. They posit that a more sensitive measure of phonological coding can be obtained by blocking lists that are either all similar or all non-similar. Thus, in the second task, blocked lists in the manner suggested by Watkins et al. (1974) were presented. In the third task, free-recall performance of deaf and hearing subjects was compared in lists of items to be vocalized and silently read. If the modality effect reflects echoic memory processes, then in both serial and free-recall tasks this effect should be demonstrated with hearing subjects only. If, on the other hand, the modality effect simply reflects the processing of gestural information and is independent of echoic memory, then both deaf and hearing subjects should exhibit enhanced recency for vocalized lists over silently read lists.

Method

Subjects

Hearing. The hearing subjects were 40 college students from the University of South Carolina who volunteered for this study and received credit towards their introductory psychology course.

Deaf. There were 40 deaf volunteers from Gallaudet College whose hearing loss was at least 80 dB in the better ear. Three subjects had a hearing loss of 80–90 dB, in which even shouted conversation cannot be heard. The remaining subjects had a hearing loss of greater than 90 dB, a profound loss in which only vibrations rather than complete sound patterns can be perceived.

Hearing loss was congenital for 31 subjects. One subject's onset age could not be identified, and the remaining 8 subjects had become deaf between the ages of 3 and 15.

Although this study was not designed to examine the verbal learning characteristics of deaf individuals, Gallaudet did provide a pool of test scores that they had retained about their students, and we examined these measures in relation to performance on our tasks. It is important to note, however, that the Gallaudet measures are viewed as supplemental information secondary to the experiment that we conducted. Thus, there are no predictions advanced about the relationship between performance on our experimental tasks and subjects' scores on the following measures provided by Gallaudet:

1. Cattell I.Q.;
2. lipreading scores with visual presentation;
3. lipreading scores with visual and auditory presentation;
4. etiology and magnitude (in dB) of hearing loss;
5. speech discrimination score.

Two additional measures, a speech score, and whether the student was or was not an articulator, were assigned by a hearing experimenter who was proficient in sign language and familiar with deaf speech.

The experimenter assigned a speech score to each subject quite subjectively but based on the following five-point rating scale:

1. The student is easily understood by the general public and has no obvious voice and/or articulation errors.
2. The student is easily understood by the general public, but has obvious voice and/or articulation errors.
3. The general public has some difficulty understanding the student initially, but the student can be understood once the listener adjusts to "deaf speech".
4. The student's speech is very difficult for the general public to understand. Probably understood only by family and teachers.
5. The student's speech cannot be understood.

The experimenter then labelled each subject as either an articulator or a non-articulator, based on their speech score, tape conversations, and questions such as "When you read, do you ever talk to yourself?" and "When you think, do you think in words?" Of the 40 subjects, 23 were labelled as articulators.

Materials and Apparatus

TASK 1: Mixed-Letter Lists (Serial Recall). There were 50 lists of seven letters each, chosen from the same pool (B C T Z X H L Y) and with the same restrictions as Conrad (1970). B C T Z were regarded as phonologically similar, and X H K L Y were considered to be non-similar. Both sets of letters were represented in each list.

TASK 2: Blocked-Letter Lists (Serial Recall). The second set of serial recall lists was chosen from a pool of stimulus letters that were either phonologically similar (B C D E G T V Z) or non-similar (F H I J N O Q R). There were 24 lists of seven letters each. Each list contained only similar or non-similar letters, and lists were blocked by similarity.

TASK 3: Free Recall. There were 24 lists of 12 high-frequency words (nouns) that were presented at a rate of 1.5 per sec, with a 60-sec delay between lists for immediate written free recall.

The letters and words were presented via a Kodak slide projector. Serial lists were presented at a rate of 1.1 per sec with a 15-sec delay between lists that was used for immediate, written recall.

Procedure

All subjects participated in all conditions over a two-day period. Half of all lists were to be vocalized, the other half read silently. For half of the subjects, lists presented on Day 1 were vocalized, and lists presented on Day

2 were read silently. For the remaining subjects this order was reversed. Each task was represented on both days.

For all subjects, the mixed-letter task was presented first, followed by the blocked-letter task. The presentation order of blocked lists (acoustically similar or dissimilar) was counterbalanced across subjects. The free-recall task was the last task presented on each day.

Subjects were presented with typical serial-recall instructions for letter lists. Response booklets were provided in which subjects were to write their recall. As our deaf subjects were chosen from a highly regarded university, we did not feel written responses would in any way impair their performance.

Results

The raw data and a normalized version were analysed. To transform the data, the total number of correct responses collapsing across all lists of a given condition and all serial positions was calculated for each subject. The number correct at each serial position was then divided by this total, resulting in the percentage of the total correct accounted for at each serial position. Although analyses were performed on both the raw and transformed data, the results of the transformation are presented only when they differ from the non-transformed results. A difference of this type was found only once, for hearing subjects in the blocked-letter task.

Analyses of Variance (ANOVA) on the raw data were performed on the mean number of items recalled in the correct serial position. For the free-recall word task, analyses were based on the mean number of correctly recalled items regardless of the order in which they were recalled. All post hoc analyses were computed with the Tukey HSD comparison, and any differences reported were at the 0.05 level of significance or better. Separate analyses were computed for deaf and hearing subjects.

TASK 1: Mixed-Letter Lists (Serial Recall)

Hearing Subjects. A 2×7 ANOVA was computed as a function of whether lists were vocalized or read silently (vocalizing condition) and serial position. As can be seen in Figure 1, a modality effect was found for hearing subjects, with recall being better for vocalized than silently read lists, but this superiority was confined to the end of the list.

This was confirmed by the significant Vocalization × Serial position interaction, $F(6, 234) = 6.51$, $p < 0.05$, $MSe = 23.08$, and post hoc analyses indicating a significant advantage of vocalized lists over non-vocalized lists at serial position seven. There was a significant serial position effect, $F(6, 234) = 17.59$, $p < 0.01$, $MSe = 31.63$, and the main effect for vocalization was

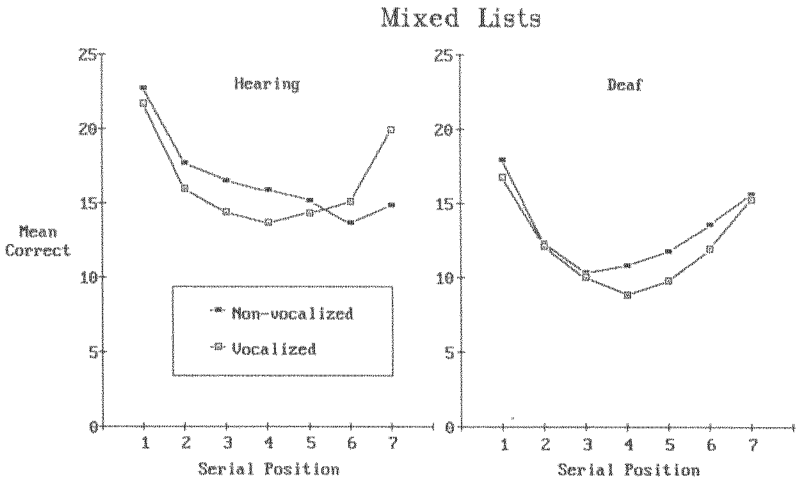

FIG. 1. The mean number of correctly recalled items for hearing and deaf subjects as a function of serial position, and whether subjects vocalized or silently read stimuli.

not significant, $F(1, 39)=0.04$, $p>0.05$, $MSe=59.79$. The same pattern of analysis was found for the transformed data.

To assess the influence of phonological coding in producing the modality effect, χ^2 analyses that compared the number of phonologically similar confusion errors made when phonologically similar letters were presented, to the number of errors when non-similar letters were presented, were performed on the recall scores for each subject. Two χ^2 scores were obtained for each subject, one for vocalized lists, and one for silently read lists. Twenty of the 40 hearing subjects showed significantly more phonologically similar confusion errors than non-similar errors with vocalized lists. These subjects are considered to have been engaging in phonological coding. Fifteen of the 40 hearing subjects exhibited phonological coding with silently read lists, nine of which had also shown this coding with vocalized lists.

The magnitude of the modality effect was then computed for each subject by subtracting the mean number of items recalled in serial position seven for silently read lists, from the same measure in vocalized lists. There was no significant correlation between the magnitude of the modality effect and the χ^2 score for vocalized lists ($r=0.2714$, $p=0.115$) or silently read lists ($r=0.2929$, $p=0.088$). Thus, the modality effect does not appear to be related to phonological coding for hearing subjects in this task.

Deaf Subjects. A $2\times2\times7$ ANOVA was computed with the variables being (a) whether the student was labelled as an articulator or non-articulator, (b) the vocalizing condition, and (c) serial position. As can be seen in Figure 1, the typical modality effect was not found for deaf subjects. This was confirmed by the lack of an interaction between vocalization and serial position $F(6, 228) = 1.05$, $p > 0.05$, $MSe = 12.22$. Although there was an effect of vocalization, $F(1, 38) = 6.52$, $p < 0.05$, $MSe = 27.0$, unlike hearing subjects, post hoc analyses on the Vocalization × Serial position interaction indicated that it was not a function of the final list position. Furthermore, recall performance does not appear to be influenced by whether subjects were labelled as articulators or non-articulators, reflected by the lack of an overall effect of this manipulation, $F(1, 38) = 0.44$, $p > 0.05$, $MSe = 133.9$, and the lack of an interaction with the other manipulations. No significant effects were demonstrated for Articulator × Vocalization, $F(1, 38) = 0.02$, $p > 0.05$, $MSe = 27.0$; Articulator × Serial position, $F(6, 228) = 1.56$, $p > 0.05$, $MSe = 20.82$; or Articulator × Vocalization × Serial position, $F(6, 228) = 0.20$, $p > 0.05$, $MSe = 12.23$. There was a main effect demonstrated for serial position, $F(6, 228) = 30.65$, $p > 0.01$, $MSe = 20.82$. Analysis of the normalized data produced the same conclusion.

As with hearing subjects, χ^2 analyses were computed for each subject comparing the type of errors made when phonologically similar vs. non-similar letters were presented. Only four of 40 deaf subjects showed significant articulatory coding in vocalized lists, and only one subject showed articulatory coding in silently read lists. This measure, indicating that only a few deaf subjects used articulatory coding, is obviously inconsistent with our labelling of the subjects as articulator or non-articulator. However, as previously mentioned, caution is necessary in interpreting phonological confusions in mixed lists, and it may be that our χ^2 measure is not a sensitive index of articulatory coding.

The results of the mixed-letter task analyses indicate that deaf subjects do not produce the modality-dependent performance characteristic of PAS. However, because 8 of the 40 deaf subjects who participated in this study became deaf after three years of age, it is possible that their data are not representative of those individuals who are congenitally deaf and have had no experience with acoustic information. Crowder (1983) postulated that the association between gestures and sounds is formed during infancy, and it is the formation of these associations that allows subsequent non-auditory stimuli to activate PAS. Our deaf sample provides an opportunity to test this otherwise unexplored premise. One possibility is that adventitiously deaf subjects can utilize PAS, as during infancy they would have formed the necessary gesture-to-sound associations required for subsequent auditory feature selection. Another possibility, however, is that physical damage to the auditory system that resulted in hearing loss may include those areas associated with PAS, thereby eliminating the ability to activate this system. To explore these possibilities, a point biserial correlation was computed between the onset age of hearing loss (greater or less than three years) and the magnitude of the modality effect at the terminal list position (vocalized minus silent). The results indicate no relationship between onset age and the modality effect, $r(37)=0.15$, $p>0.05$. Thus, regardless of when our subjects became deaf, they did not produce the vocalizing advantage at terminal list positions that is characteristic of PAS.

A final analysis on mixed-letter lists was performed in order to examine differences between deaf and hearing subjects. A mixed ANOVA on the raw data was computed with the factors of Hearing status (deaf/hearing), Vocalization, and Serial position. The results yield conclusions similar to the individual ANOVAs computed for each subject sample. Whereas hearing subjects recalled more items than did deaf subjects, the hearing advantage in the final serial position was evident only when subjects vocalized lists. Final position recall in silent lists did not differ between deaf and hearing subjects. As can be seen in Figure 1, the requirement of vocalizing improved hearing subjects' performance on the final list item relative to silent reading, whereas the corresponding performance by deaf subjects did not differ as a function of whether or not they engaged in vocalization. This conclusion was supported by the Hearing status × Vocalization × Serial position interaction, $F(6, 468)=3.95$, $p<0.001$, and the post hoc analysis on the final serial position indicating a superiority of vocalizing over silent reading for hearing subjects only.

The results from the mixed-letter lists are consistent with the PAS interpretation of modality effects. Hearing subjects, who according to the PAS model have the ability to utilize acoustic feature synthesis, produced an end-of-the-list advantage in vocalized lists that is characteristic of the modality effect. Deaf subjects, who do not have echoic memory traces, did not demonstrate this effect.

TASK 2: Blocked-Letter Lists

Hearing. A 2 × 2 × 7 ANOVA was performed on both the raw and transformed data as a function of acoustic similarity, vocalization, and serial position. The PAS theory predicts that the magnitude of the modality effect in non-similar lists will be greater than for similar lists. The analysis of the raw data confirms this prediction. As can be seen in Figure 2, a modality effect was found with hearing subjects when non-similar lists were presented and this effect was eliminated when list items were acoustically similar.

For the raw data, the interaction between vocalization, similarity, and serial position was not significant [$F<1$]. However, because the modality effect is expected in the final list position of non-similar lists only, post hoc analyses were performed on the recall from lists position. The analysis indicated an advantage of vocalization at serial position seven for non-

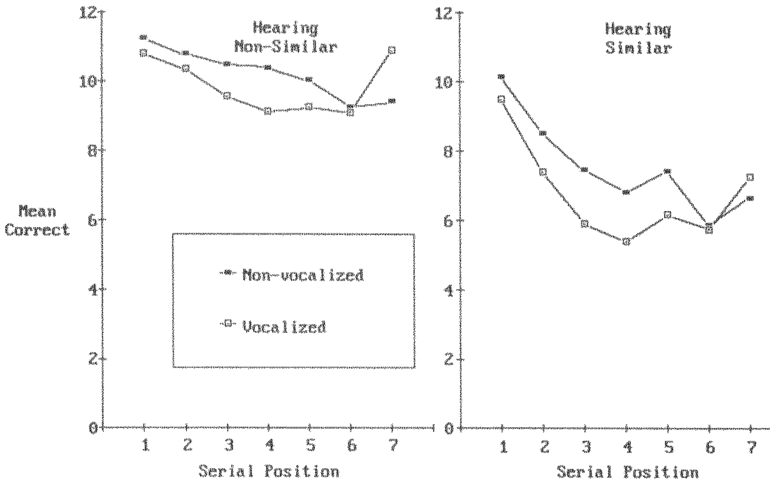

FIG. 2. The mean number of correctly recalled items in blocked-letter lists for hearing subjects only, as a function of similarity, serial position, and whether subjects vocalized or silently read stimuli.

similar lists only. Overall, non-similar lists were better recalled than similar lists [$F(1, 26) = 128.37$, $p < 0.001$], non-vocalized lists were better recalled than vocalized lists [$F(1, 36) = 7.93$, $p < 0.01$, $MSe = 11.97$], and the interaction between similarity and vocalization was not significant, $F(1, 36) = 1.63$, $p > 0.05$, $MSe = 7.88$. There was a main effect for serial position, $F(6, 216) = 32.34$, $p < 0.01$, $MSe = 4.67$, and a significant interaction of Similarity × Serial position, $F(6, 216) = 12.84$, $p < 0.01$, $MSe = 2.11$. Post hoc analyses indicated that overall, non-similar lists were better recalled than similar lists in all seven serial positions. The Vocalization × Serial position interaction was also significant, $F(6, 216) = 10.75$, $p < 0.01$, $MSe = 2.28$; however the post hoc analysis indicated that these differences were in primacy positions only (1–4), and favoured non-vocalization.

The analysis on the transformed data yield similar results, with one exception. Post hocs on the three-way interaction indicated a significant advantage of vocalizing in the terminal serial position of both similar and non-similar lists. The modality effect was equivalent for the acoustically similar and dissimilar lists (see Figure 3). It should be noted from the raw data in Figure 2, however, that performance by hearing subjects in the vocalized lists appears to be at ceiling for several serial positions, including the final item. This boundary condition reduces our ability to interpret the magnitude of the difference in modality effects in similar and non-similar lists. Given the prevailing literature in this area (Watkins et al., 1974; Crowder, 1971), it is likely that the modality effect in non-similar lists is still

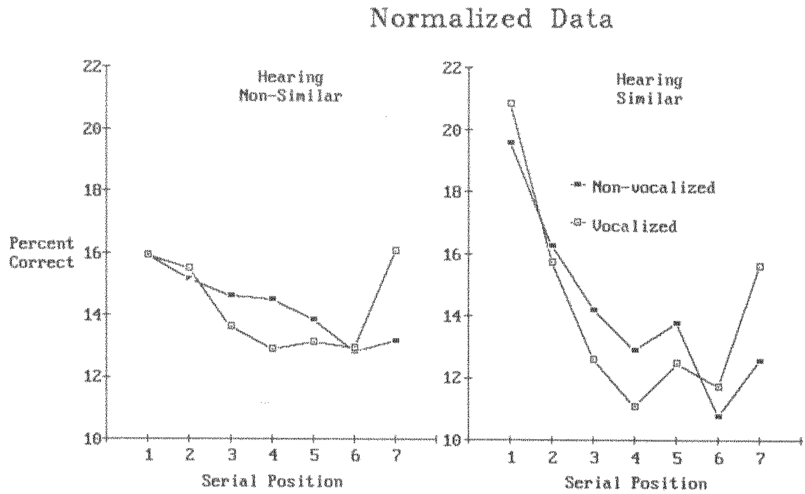

FIG. 3. The percentage of the total number of items recalled in blocked-letter lists for hearing subjects only as a function of similarity, serial position, and whether subjects vocalized or silently read stimuli.

greater than for similar lists. But, it is also clear that the modality effect is observed when similar items are presented, if the data are transformed.

In a further attempt to examine phonological coding, a confusability index was computed on the non-transformed data for each subject, based on the number of errors in similar lists, divided by the total number of errors (collapsing across similarity). A score of 0.50 indicated equal numbers of errors in similar and non-similar lists, thus representing chance. However, Conrad (1979) has argued that this technique yields unreliable results when the ratio falls within the range of 0.48–0.52. Thus, a t-test was performed on the difference between the mean confusability index for all subjects and 0.52. The results indicated that hearing subjects made significantly more phonologically based confusion errors than would be predicted by Conrad's criterion [$t(39) = 10.50$, $p < 0.001$]. Although this finding is inconsistent with our analysis of errors on the mixed-letter lists, it does correspond to the conclusions of Watkins et al. (1974) that blocked lists are a more sensitive measure of phonological coding than are mixed lists. To assess the influence of phonological coding on the modality effect, correlations were computed comparing the magnitude of the modality effect for serial position seven and the confusability index for each subject. As with the mixed-letter lists, no relationship was found [$r = 0.08$, $p = > 0.10$].

Deaf. A $2 \times 2 \times 7 \times 2$ ANOVA was computed with the variables of Similarity, Vocalization, Serial position, and whether or not a subject was classified as an articulator or non-articulator. As with mixed-letter lists, deaf subjects did not exhibit a modality effect (see Figure 4). There was no advantage of vocalization in recency positions for either similar or non-similar lists. This finding was the same for both the raw and transformed data. Thus, as predicted with both the original and revised PAS models, gestural information alone was not sufficient to produce the modality effect. This was confirmed by the lack of either a Similarity × Vocalization × Serial position interaction, $F(6, 228)=0.65$, $p>0.05$, $MSe=2.31$, or a Similarity × Vocalization × Serial position × Articulator–Non-articulator interaction $F(6, 228)=2.03$, $p>0.05$. There was no main effect for articulator, $F(1, 38)=0.56$, $p>0.05$, and overall, non-similar lists were better recalled than similar lists, $F(1, 38)=50.89$, $p<0.01$, $MSe=7.75$. There was a significant Articulatory × Similarity interaction, $F(1, 38)=7.55$, $p<0.01$, $MSe=7.75$, and post hoc analyses indicated that non-articulators performed better on similar lists than did articulators. There was a significant serial position effect, $F(6, 228)=15.95$, $p<0.01$, $MSe=9.11$, and a significant Vocalization × Serial position effect, $F(6, 228)=7.95$, $p<0.01$, $MSe=3.12$. Post hoc analyses on this interaction indicated significance at serial position three only, and favoured non-vocalization.

As with hearing subjects, a confusability index was obtained, the mean of which was compared to 0.52. To the extent that differential errors in similar and non-similar lists reflect coding, this analysis indicated that deaf subjects were engaging in significant articulatory coding, $t(39)=4.29$, $p<0.001$. We also examined the difference between the average confusability index for deaf versus hearing subjects and found that hearing subjects were significantly

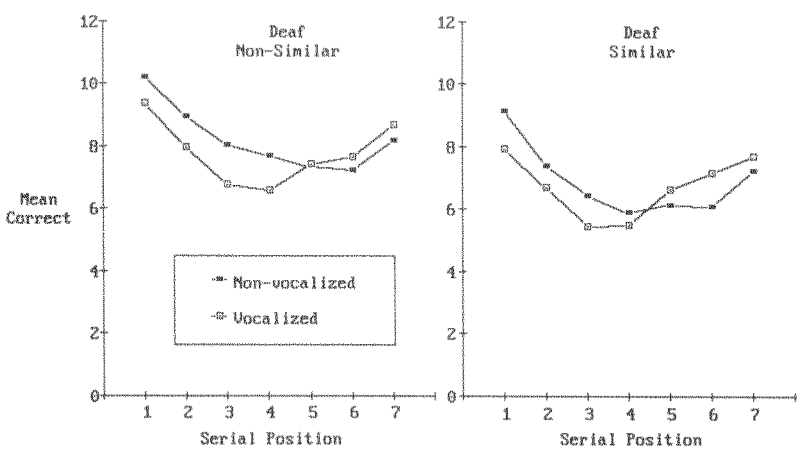

FIG. 4. The mean number of correctly recalled items in blocked-letter lists for deaf subjects only, as a function of similarity, serial position, and whether subjects vocalized or silently read stimuli.

more likely to produce articulatory confusions than were our deaf subjects $t(78) = 6.34$, $p < 0.001$.

Additionally, those subjects labelled as articulators by our experimenter exhibited significantly more articulatory coding than did non-articulators $t(38) = 4.00$, $p < 0.01$. It appears that our clinical labelling of articulator and our confusability index are reflecting similar processes. This finding again supports Watkins et al. (1974), who asserted that blocked lists are a more sensitive measure of phonological coding than are mixed lists. These data also confirm the findings by Hanson and Fowler (1987) that deaf subjects can utilize phonological information, and lends further support to the assumption that articulatory coding does not produce the modality effect.

As with the mixed-letter lists, an additional analysis was computed to examine performance differences between deaf and hearing subjects. A $2 \times 2 \times 2 \times 7$ mixed ANOVA was performed with the factors of Hearing status, Vocalization, Acoustic similarity, and Serial position. The results yielded several interesting findings.

For both deaf and hearing subjects, performance on non-similar lists was significantly better than on similar lists, but this improvement was much larger for hearing subjects across all but the first serial position. This finding complements the results of our confusability index, suggesting that although both groups of subjects used articulatory coding, hearing subjects relied on this form of coding to a greater extent than did the deaf. This was supported by the significant effect of Hearing status × Similarity × Serial position, $F(6, 468) = 6.31$, $p < 0.0001$, and the corresponding post hoc analysis. Moreover, whether subjects vocalized or silently read stimuli did not significantly change this relationship. Thus the Hearing status × Vocalization × Acoustic similarity × Serial position interaction was not statistically significant, $F(6, 468) < 1.0$.

Another interesting finding relates directly to the modality effect. When lists were read silently, there were no differences in performance on the final serial position between deaf and hearing subjects. In addition, when deaf subjects vocalized, their performance on the terminal item did not differ from when they silently read lists, or when hearing subjects read silently. By contrast, when hearing subjects vocalized, they produced significantly greater recall at the final list position than when they read silently, or when deaf subjects read silently or aloud. Thus, although both groups of subjects showed equivalent terminal list item performance with silent reading, only hearing subjects showed the end-of-the-list advantage with vocalizing that is typical of the modality effect. This was confirmed by the Hearing status × Vocalization × Serial position interaction, $F(6, 468) = 3.67$, $p < 0.01$, and corresponding post hoc analyses.

A point biserial correlation was computed to examine the relationship between the onset age of hearing loss (less than or greater than three years) and the magnitude of the modality effect (final position vocalized vs. silent) in similar and non-similar lists. The results indicated that onset age was not a good predictor of modality difference on the terminal list position for similar ($r = -0.092$, $p > 0.05$), or non-similar ($r = -0.215$, $p > 0.05$) lists.

Overall, the results of the serial tasks clearly support a PAS interpretation of modality effect. The ability to activate an acoustically based sensory trace may be necessary to produce these effects. Gestural information, as indexed by performance of deaf subjects on vocalized lists, is not sufficient to produce enhanced recency.

TASK 3: Free Recall

Hearing. A 2 × 12 ANOVA was computed with the variables of Vocalization and Serial position. As can be seen in Figure 5, the free-recall data for hearing subjects yielded results consistent with the serial tasks. A recency advantage was obtained for vocalized over silently read lists. This was confirmed by the significant interaction between serial position and vocalization, $F(11, 429) = 9.89$, $p < 0.01$, $MSe = 2.75$, and supported by post hoc analyses indicating an advantage of vocalizing over silent reading for serial positions 11 and 12. There was a significant main effect for serial position, $F(11, 429) = 106.44$, $p < 0.01$, $MSe = 4.07$, and no main effect for vocalization $F(1, 39) = 1.17$, $p > 0.05$. These results did not change as a function of transforming the data.

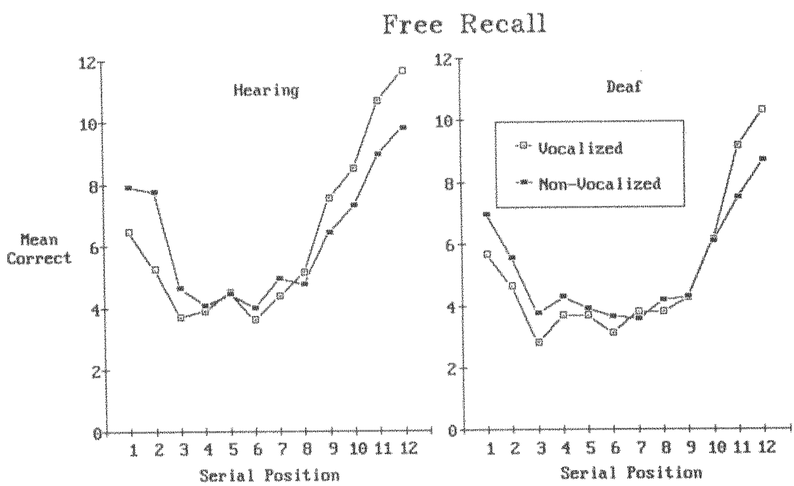

FIG. 5. The mean number of correctly recalled items in the free-recall task for hearing and deaf subjects as a function of serial position, and whether subjects vocalized or silently read stimuli.

Deaf. The results of 2 × 12 Vocalization × Serial position ANOVA for deaf subjects are inconsistent with the findings of the other tasks in this study. As can be seen in Figure 5, there was a vocalized superiority for deaf subjects over the final two positions and non-vocalized superiority over the primacy positions. These findings were confirmed by a significant Vocalization × Serial position interaction, $F(11, 429) = 6.9$, $p < 0.01$, $MSe = 2.61$, and post hoc analyses indicating an advantage of vocalizing over silent reading for serial positions 11 and 12. The analysis of the transformed data yielded similar conclusions.

As with the other tasks, an additional analysis was computed to examine performance differences between deaf and hearing subjects. A mixed ANOVA on the raw data was performed with the factors of Hearing status, Vocalization, and Serial position. Although there was a significant Vocalization × Serial position interaction, $F(11, 858) = 14.97$, $p < 0.001$, with an advantage of vocalizing over silent reading at serial positions 11 and 12, the Hearing status × Vocalization × Serial position interaction was not statistically significant, $F(11, 858) = 1.34$, $p > 0.05$. These results indicate that the relationship between modality of presentation and recall performance did not change as a function of hearing status.

Does this fit the definition of a "modality effect"? The similar pattern of non-vocalized superiority over primacy positions to that with hearing subjects suggests that the answer to this question may be yes. This finding complements findings of vocalized superiority on recency positions in most studies manipulating modality (either auditory or vocalized and silently read visual presentation).

Finally, correlations were calculated between the test scores obtained from Gallaudet records and the vocalized/non-vocalized difference for the last item in free recall for the deaf subjects. There were a few subjects for whom certain scores were not available from Gallaudet records; thus these subjects were omitted from this analysis. The results, presented in Table 1,

TABLE 1
Relationship Between Terminal List Item Performance and Individual Difference Measures

		Hearing Loss		*Discrimination*		*Lipreading*	
Age	*Speech Score*	*Right*	*Left*	*Right*	*Left*	*Right*	*Left*
(n = 39)	(n = 35)	(n = 9)	(n = 39)	(n = 26)	(n = 29)	(n = 35)	(n = 35)
r = 0.219	r = −0.29	r = 0.164	r = 0.140	r = −0.31	r = 0.078	r = −0.02	r = −0.14
p = 0.180	p = 0.096	p = 0.325	p = 0.396	p = 0.128	p = 0.689	p = 0.896	p = 0.438

None of the correlations reached the 0.05 level of significance.

showed no significant relationships between the difference score for terminal list items and the onset age of hearing loss (point biserial correlation), the ability to discriminate vowels in the right or left ear, lipreading ability, magnitude of hearing loss in either ear, or speech intelligibility as scored by the experimenter.

DISCUSSION

One important characteristic of our data is its implications for deaf readers. It has long been assumed that deaf individuals use sign-language-based codes and visual orthography when they read (Bellugi, Klima, & Siple, 1975). Hanson and Fowler (1987) demonstrated that although sign-based and visual codes may play an important role in reading for the deaf, these individuals are also capable of accessing phonological information. Our confusability index for blocked-letter lists confirms their findings and supports the assertion that the ability to use phonological information need not be tied to the auditory modality.

The results of this study also support the assertion that phonologically mixed lists of stimuli may not be a sensitive measure of phonological coding (Watkins et al., 1974). The data from the mixed-letter lists indicated that only half of our hearing subjects, and only four of 40 deaf subjects, exhibited significant confusion errors. However, in the blocked-letter lists, both deaf and hearing subjects produced significant phonological confusions, and this measure for the deaf corresponded to our clinical labelling of whether or not these subjects were articulators. Thus, it does appear that blocked lists are a more sensitive indicator of phonological coding.

Although Watkins et al. (1974) found a significant modality effect in blocked lists of phonologically similar stimuli, Crowder (1971) showed no such effect. The analysis of our raw data closely resembled the results of Crowder (1971). However, when the data were transformed, a different pattern emerged—one similar to Watkins et al., in which a modality effect was demonstrated with acoustically confusable lists. The finding that acoustic similarity may decrease but not eliminate the modality effect suggests that although echoic memory can represent phonological information, other features of acoustic input may still provide valuable information when integrating STM and echoic memory.

This study was designed to test whether modality effects could be produced with gestural information, in the absence of acoustic feature representation. For the serial tasks, there was no evidence that deaf subjects, who can be presumed to lack the ability to synthesize acoustic information, show the same vocalized superiority over silently read items produced by hearing subjects. Transforming the data to control for baseline differences did not change these conclusions. Modality effects still did not obtain for serial recall of letter lists with deaf subjects.

Crowder (1983) postulated that non-auditory information can access PAS because of early gesture-to-sound associations formed during infancy. Consequently, we suggested that congenitally deaf subjects could not activate such a system. The results of our serial tasks support this notion. Alternatively, adventitiously deaf individuals, who presumably would have formed the necessary gesture-to-sound rules, might be capable of activating PAS auditory feature selection. However, for all of our tasks, we found no relationship between the onset age of hearing loss and the magnitude of the modality effect. One possible explanation for these findings is that the physical damage to the auditory system that resulted in hearing loss may have included those areas associated with PAS.

Although deaf subjects did not produce a modality effect, they did exhibit phonological coding in blocked-letter lists. Moreover, although hearing subjects exhibited both phonological coding and modality effects, these effects showed no predictive relationship. These findings support the notion that echoic memory represents acoustic rather than articulatory information. However, for the free-recall task, both deaf and hearing subjects showed vocalized superiority for recency items. The fact that the two groups also showed the same modality pattern for primacy positions suggests that similar processes were operating to cause the modality effect.

Why the deaf showed modality effects with free recall and not with serial recall is unclear. This study may best be thought of as three independent experiments rather than a single experiment comparing three tasks. It was not designed to test for differences between free and serial recall. The free-recall task differed in many ways from the serial tasks, including rates of presentation, items to be recalled, list lengths, and recall instructions, which probably led to numerous storage and retrieval strategies across subjects.

Previously published findings might lead us to speculate that the important difference between the serial tasks and the free-recall tasks was the nature of the recalled items, letters, or words. Engle (1974) looked at the modality effect and suffix effect in a task requiring either free recall or serial recall of 12-item word lists presented at a one-second rate. The suffix typically eliminates the auditory superiority for recall of short lists of digits or letters but in this study the suffix did not eliminate the auditory superiority in either free recall or serial recall of long lists of words.

Further evidence that the nature of the modality and suffix effects depends on whether letters or words are the recall items was presented by Richardson (1979). He found that auditory superiority with serial recall of short lists of words is not affected by the phonemic similarity of the items, and the effect of the suffix on this recall is not diminished if the suffix and list items are presented by different voices. Both of these effects are quite different from those obtained with letter lists. Richardson argues that words are represented in what he calls a post-lexical store at input, and that neither letters nor digits are so represented. The modality effect with letters and digits is argued to reflect a sensory trace, whereas the effect with words represents a more central and residual code.

By Richardson's logic, the modality effect found with deaf subjects in the free-recall task would not represent the activation of articulatory, gestural, or phonetic codes, but the activation of a more meaning-based code. But, as mentioned previously, our study was not designed to test methodically for differences between serial recall of short lists of letters and free recall of longer lists of words. Why deaf subjects show no modality effects with the serial tasks but do show the effects with free recall must, for now, remain speculation.

REFERENCES

Bellugi, U., Klima, E. S., & Siple, P. (1975). Remembering in signs. *Cognition, 3 (2)*, 93–125.

Campbell, R. & Dodd, B. (1980). Hearing by eye. *Quarterly Journal of Experimental Psychology, 32*, 85–99.

Conrad, R. (1964). Acoustic confusions in immediate memory. *British Journal of Psychology, 55 (1)*, 75–84.

Conrad, R. (1970). Short-term memory processes in the deaf. *British Journal of Psychology, 61*, 179–195.

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

Crowder, R. G. (1971). The sound of vowels and consonants in immediate memory. *Journal of Verbal Learning and Verbal Behavior, 10*, 587–596.

Crowder, R. G. (1972). Visual and auditory memory. In J. F. Kavanagh & I. G. Mattingly (Eds.), *Language by ear and by eye*. Cambridge, MA: MIT Press.

Crowder, R. G. (1983). The purity of auditory memory. *Philosophical Transactions of the Royal Society of London*, B302, 251–265.

Crowder, R. G. (1986). Auditory and temporal factors in the modality effect. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 12 (2)*, 268–278.

Crowder, R. G. & Morton, J. (1969). Precategorical acoustic storage (PAS). *Perception and Psychophysics, 5*, 363–373.

Engle, R. W. (1974). The modality effect: Is precategorical acoustic storage responsible? *Journal of Experimental Psychology, 102*, 824–829.

Greene, R. L. & Crowder, R. G. (1984). Modality and suffix effects in the absence of auditory stimulation. *Journal of Verbal Learning and Verbal Behavior, 23*, 371–382.

Hanson, V. L. & Fowler, C. A. (1987). Phonological coding in word reading: Evidence from hearing and deaf readers. *Memory and Cognition, 15 (3)*, 199–207.

Nairne, J. S. (1988). A framework for interpreting recency effects in immediate serial recall. *Memory and Cognition, 16 (4)*, 343–352.

Nairne, J. S. & Crowder, R. G. (1982). On the locus of the stimulus suffix effect. *Memory and Cognition, 10*, 350–357.

Nairne, J. S. & Walters, V. L. (1983). Silent mouthing produces modality and suffix-like effects. *Journal of Verbal Learning and Verbal Behavior, 23*, 371–382.

Richardson, J. T. E. (1979). Precategorical acoustic storage and postcategorical lexical storage. *Cognitive Psychology, 11*, 265–286.

Spoehr, K. T. & Corin, W. J. (1978). The stimulus suffix effect as a memory coding phenomenon. *Memory and Cognition, 6 (6)*, 583–589.
Watkins, M. J., Watkins, O. C., & Crowder, R. G. (1974). The modality effect in free and serial recall as a function of phonological similarity. *Journal of Verbal Learning and Verbal Behavior, 55 (1)*, 75–84.

Revised manuscript received 25 July 1988