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A DEVELOPMENTAL STUDY OF THE LATERALIZATION OF AUDITORY FEEDBACK MONITORING

A Thesis Presented

By

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Abstract

It was hypothesized that the use of one's speech feedback to control continuous speech production changes with age and that the lateralization of speech feedback monitoring is a developmental process.

Preschoolers, fourth graders, and adults participated in a game in which they were required to tell stories under simultaneous feedback and then under delayed auditory feedback. Three male and three female subjects in each age group received delayed auditory feedback to the right ear and simultaneous feedback to the left ear (D-R); three males and three females in each age group received DAF to the left ear and simultaneous feedback to the right ear (D-L); three male and three female _S_s in each age group received binaural delay (D-D). The speech productions of the participants were tape recorded by the _E_.

Two independent raters evaluated the percent of syllable prolongation, percent of syllable repetition, percent of word repetition, word rate, and syllable rate for each speech sample. The difference between the simultaneous feedback condition and the delay condition was computed for each _S_.

The results showed a significantly higher percent of syllables prolonged and syllables repeated under D-R for fourth grade _S_s and significantly greater syllable prolongation under D-D for adults when compared to the D-L condition. Word and syllable rate were significantly decreased by D-R and D-D but not by D-L.

Problems in interpretation of the results due to the small n were noted. However, the significant data and general trends indicated that the effects of lateralized delayed feedback on speech behavior vary as a function of age. Various considerations for future research were suggested.

Numerous investigations of speech behavior have indicated that the speech of the young child differs significantly from that of the adult but, while it is generally agreed that some level of neural "reorganization" probably underlies developmental differences in speech behavior, the nature of these neural changes and their relation to modifications in overt speech behavior remain largely unspecified.

The monitoring and control of continuous speech output appears to be one area of speech development worthy of further investigation. Bradshaw, Nettleton, and Geffen (1971) offer data which suggest that the feedback mechanisms used by adults are lateralized in the adult brain. Other studies, to be reviewed below, have provided evidence that lateralization of the speech function appears to be incomplete for the young child. Furthermore, evidence indicates that the young child does not use the feedback from his own speech in the same way as the older child and the adult. The present study will attempt to establish a developmental relationship between the feedback monitoring of speech and the lateralization of the speech function. It is hypothesized that the functioning of both of these systems is immature for the young child and that the two systems interact during development.

Smith (1961, 1962) has noted that feedback is critical to human behavior. He proposes that feedback mechanisms must be sensitive to both spatial and temporal differences in stimulation for motion to be precisely organized as it is in adult speech. The perceptual and motor components of speech are viewed as an integrated process, in which sensory feedback is an immediate determinant of the properties and timing of motor behavior.

Anecdotal and experimental evidence suggest that this integrated function of the speech feedback mechanism may be different for the child than for the adult. Observers of children have noted confusions among speech sounds which the child seems to be unable to correct himself until he spontaneously "grows out of" the confusion (Brown and Berko, 1960; Menyuk, 1968). For example, the young child may say "fis" instead of "fish." When his error is repeated by another speaker, the child is quite likely to correct him, saying, "no, fis." The reproduction is accepted by the child only when the speaker produces "fish" and the child may follow by saying, "yes, fis." Such instances might imply that the child, unlike the adult, does not always use the sensory feedback from his own speech to alter incorrect productions. It is notable, however, that these errors do not appear to result from sensory deficits, since the child can detect the incorrect use of the sound when it is produced by another speaker.

This observation may relate to examinations of the mechanisms involved in speech feedback. Various investigators have theorized about the functioning of the mature auditory feedback mechanism. Fairbanks (1954) refers to a servo-system analogy, where the mechanism is kept "on target" by modification of an effector unit which is responsible for initiating each new cycle. The effector unit responds to an error signal of a differential between the intended speech unit and the feedback signals. It thus corrects the output error by modifying the direction of the speech mechanism. Lee (1950) and Chase (1958) offer similar servo-system models. In all of these models, as in Smith's (1961, 1962) theory, the continuous monitoring of speech output is viewed as critical to the precision of succeeding speech movements. However, no validation of the fundamental operations of these models is offered and they thus do little to clarify the function of speech feedback in the speech mechanism.

The experimental approach to the study of feedback monitoring has utilized the delayed auditory feedback technique (DAF), which causes severe disruption of speech by inserting a delay interval between the motor and sensory processes in speech. It has been demonstrated that under optimal delays of about .2 seconds (Yates, 1963) and at intensities of about 80 db. (Butler and Galloway, 1957), most adults show increases in phonation time, increases in articulatory errors, and louder speech (Yates, 1963). A tendency toward discrete speech movements is also noted (Smith, 1962) so that, under DAF, the S̲ may use slow, jerky movements. He quickly performs a speech movement and then apparently waits for the sensory feedback to "catch up" before moving ahead. The greater the precision and complexity of the motion, the more disruptive is the DAF. Thus, the greatest disruption seems to occur for fricatives, which demand more sustained muscular control than other speech sounds (Smith, 1962).

It has been suggested (Yates, 1963) that speech disruption under DAF results mainly from the temporal discrepency between the delayed air-conducted auditory feedback and the instantaneous oscular and kinesthetic feedback. He assumes that, under normal speaking conditions, these three feedback systems are integrated at "higher neural levels." The critical role of neural integration in continuous speech is also implied by Fairbanks (1954). Smith (1962) postulates the existence of neural detectors which are sensitive to differences between the efferent output of the central motor neurons and the sensory feedback related to movement produced by these neurons. Such vague and unvalidated references to the role of neural function in controlling speech behavior unfortunately do little to elucidate the underlying relationships. However, there is general agreement among theorists that some level of neural processing and integration of the various elements of speech behavior is operative in the mature speech feedback mechanism.

The DAF technique has been used with children by several investigators in attempts to clarify the development of the use of speech feedback. Chase, Sutton, First, and Zubin (1961) obtained story-telling speech samples from children 4-9 years old under conditions of simultaneous auditory feedback followed by delayed (.216 sec.) auditory feedback for each S. Several problems in methodology are noted. The speech samples used in the analysis were quite small, with as few as 29 words elicited from at least one, and probably more, of the younger Ss under the synchronous feedback condition. For all S groups the median sample size was under 100 words and the older group (7-9) had a median of only 55 words under DAF.

No mention is made of the minimum speech sample size under DAF. The relatively small number of words included in many of the speech samples rather severely limits the generality of the findings. Chase (1958) noted that, under delayed auditory feedback, he was able to speak fairly accurately until he made one error, and then he was unable to continue with normal speech. It is therefore questionable whether the shorter speech samples included in Chase's et. al. results are illustrative of the effects of DAF on continuous speech. Furthermore, the authors do not specify any analysis of speech changes by more than one rater, casting additional doubt on the conclusions. The authors found, however, that speech disruption under DAF was significantly greater for the 7-9 year old group than for the 4-6 year old group. All Ss demonstrated slowing of speech under DAF from a median of 1.77 words per second under synchronous feedback to a median of .77 words per second under DAF. All but one S showed an increase in the percent of syllables prolonged under DAF, which appeared to be the largest alteration in speech (0% words prolonged under synchronous feedback, 24.6% words prolonged under DAF, $p < .01$). An examination of differences in these variables as a function of age indicated that the older children spoke significantly more rapidly under the control condition (median= 1.92 words per second) than under DAF (median= .80 words per second). The younger Ss had a median word rate of 1.48 words per second under synchronous feedback and .75 words per second under DAF. The older Ss demonstrated no prolongation of syllables under the control condition while the younger Ss had a median syllable prolongation rate of .3%. However, under DAF, a median of 33.9% syllables prolonged was noted for older Ss and a median of 21.3% syllables prolonged was found for younger Ss. Thus, while both subject groups demonstrated disruption under DAF, the disruption was significantly greater for the older group when compared to the normally higher word rate and lower incidence of articulatory errors under synchronous feedback for older children. When questioned about what they had heard the younger children expressed practically no awareness of having heard their own voices. The older children knew that they were listening to their own voices and expressed displeasure at what they heard. Chase et. al. concluded that the older child is apparently more dependent on receiving unaltered sensory feedback. Again, methodological considerations (e.g., small speech samples, lack of inter-rater reliability measures, etc.) make the data offered insufficient to fully justify this contention. An attempt will be made to correct these problems in the present study.

Waters (1968) built upon the results cited above to describe age changes in DAF interference. He studied the effects of delay of whispered speech (.2 sec.) in a reading task for 10-18 year olds and found that the younger children (10-12) showed greater speech disruption under DAF than the older children (16-18). It was suggested that such age differences in performance are determined by the ability of the S to shift his mode of responding from continuous to discrete units. Discrete movements are essentially the slow, jerky speech movements typical of the speech of young children (Smith, 1961). According to Waters, the subjects in middle childhood (7-12 years old) have progressed to the use of more continuous speech but have not yet developed sufficient skills to shift to discrete movements to compensate for the disruption caused by the delayed feedback. However, he holds that the older group (16-18) is able to easily shift back and forth from discrete to continuous units and is therefore less disturbed by DAF than the 7-12 year old children are. By equating the results from this experiment with the data of Chase et. al., Waters derived a bow-shaped function of speech disturbance under DAF as a function of age which showed low speech disruption for 4-6 year olds followed by a dramatic rise in speech disruption for 7-12 year olds and then a decrease in disruption for 16-18 year olds. It is questionable, however, whether the results of both studies can reasonably be viewed as jointly suggesting a trend in speech development. Waters examined speech during reading while Chase et. al. used spontaneous speech samples. Since there are no data concerning differences between these two tasks, it may be erroneous to assume that the S's speech behavior is the same in both instances. Even more importantly, Waters used whispered speech, which presumably creates greater demands on the respiratory mechanisms functional in speech. It is, again, unclear that we are examining the same behaviors in whispered and normal speech and that inferences can be made from the combined perusal of experiments using both techniques.

In yet another attempt to clarify the functioning of the speech feedback mechanism, Yeni-Komshian, Chase, and Mobley (1968) had Ss 1 year, 9 months old to 3 years old perform a standard object naming task under an auditory delay of .2 seconds. Average phonation time (total time taken to produce each word) was used as a measure of speech alteration under DAF. No distinction among syllable prolongation, syllable repetition, hesitation, etc. as sources of differences in phonation time was made. Children 2-3 years old exhibited speech disruption but seemed to be unaware of these changes in their speech. The younger children showed no consistent changes in speech under DAF. Since this younger group was unable to perform the object naming task, any verbal response was used and it is unclear how average phonation scores were derived for these Ss. The object naming task differs substantially from the task employed by Chase et. al. (1961) or the task used by Waters (1968). The authors agree that the data give no indication of the extent to which auditory feedback monitoring is used by young children under normal speaking conditions. None of the authors cited above examined data for children relative to an adult group using the same task. Thus, any inferences from the results of these three studies remain quite difficult to interpret. Nevertheless, it is apparent that some type of developmental trend does exist in the utilization of speech feedback to regulate speech production.

Bradshaw, Nettleton, and Geffen (1971) have introduced a potential relationship between the monitoring of auditory feedback and certain neural processes. These authors used the DAF technique to investigate lateralization of the speech function for right-handed adults. The Ss were required to read a connected prose passage. They received dichotic auditory feedback, with simultaneous feedback delivered to one ear and an auditory delay of .2 sec. inserted into the feedback to the other ear. All Ss experienced both left and right ear delay conditions and were instructed to read the material as fast as possible without making mistakes and without correcting themselves. A significant difference, measured by an increase in reading time, was found between delay delivered to the right and left ears. Specifically, right-handed Ss took longer to read the passage when delay was delivered to the right ear (4.7% increase in reading times) as compared to reading time with delay to the left ear. The results seem to suggest that the auditory feedback mechanism for speech is lateralized in the adult brain. This would indicate, as expected, that the monitoring of one's own speech is at least partly represented at higher neural levels. Tsunoda (1966, cited in Kinsbourne, 1970) used a similar procedure but had Ss tap in time with rhythms. When a sudden delay in the rhythm was introduced through one channel, he found that delay to the left ear disrupted tapping performance more than delay to the right ear. Interestingly, this held true only when tapping was in time with pure tones; when tapping was to the vowel "ah", delay to the right channel proved more disruptive. Bradshaw, Nettleton, and Geffen (1972) employed DAF with several different tasks and concluded, in agreement with the preceding findings, that a progressive reduction in meaningfulness of speech material and an increasing emphasis on rhythm results in a decreasing involvement of the left hemisphere. The authors state that the lateralization of speech function can probably best be described "in terms of a continuum extending from left across an increasingly undifferentiated or neutral zone, to right." With this evidence one could argue that the processing of speech feedback probably occurs primarily in the left hemisphere for right-handed adults.

The dichotic listening method employed in the preceding studies demands further explanation. Kimura (1961, 1967) contends that competitive simultaneous inputs to the two ears are necessary and sufficient to produce a laterality effect. For digits, those presented to the right ear were recognized more efficiently than those delivered to the left ear. Kimura suggested that inputs arriving along the contralateral pathway occlude those messages arriving along the ipsilateral pathway. Thus, the verbal message delivered to the ear contralateral to the language-dominant hemisphere would be handled more efficiently. The finding of a right ear superiority for verbal material under conditions of competitive dichotic input is supported by Bryden (1963, 1967, 1969, 1970), Kimura (1963), Satz, Levy, and Tyson (1970), Shankweiler and Kennedy (1967), and Zurif and Bryden (1969). It has also been suggested (Bryden, 1969; Myers, 1970) that it may be generally more difficult to attend to the left ear than to the right ear when presented with verbal materials. Thus, although its basis is uncertain, speech input to the right ear does appear to be handled more efficiently.

Of major interest to the present investigation is the indication that brain lateralization is incomplete in childhood. Basser (1962) found the frequency of speech loss following right hemisphere lesions in right-handed children to be extremely high relative to adults. It seems that, for most children, both hemispheres participate in the development of speech and lateralization seems to occur through a progressive decrease in the right hemisphere's involvement in the speech function (Lenneberg, 1967). Vygotsky (1965) speculated that any function is probably based on the integration of highly differentiated neutral zones which work to accomplish new tasks through new interareal relations and that the relationships between these theoretically separate cortical zones might be changed in the process of development.

The results of dichotic listening experiments with children are generally in accord with the preceding implications, although they are far from definitive. Kimura (1963) found that digits to the right ear were recognized more efficiently than those to the left ear for children 4-9 years old. She nevertheless concluded that language lateralization is probably less rigidly established in children than in adults. Bryden (1970), using second, fourth and sixth grade _S_s, found that the percent of right-ear dominant _S_s increases with grade level in right-handed children and decreases in left-handed children, suggesting that speech lateralization is not yet fully established in young children.

In summary, several aspects of language behavior appear to undergo reorganization with development. Bradshaw et. al. (1971) found lateralization of speech disruption under DAF for adults. The present investigation will explore the development of this lateralized function.

Chase et. al. (1961), Waters (1968), and Yeni-Komshian et. al. (1968) have suggested that a developmental trend exists in the use of one's own speech feedback to control successive speech productions. These investigators have failed to provide reliable data, primarily due to inadequate length of speech sample, lack of inter-rater reliability measures, and failure to use the same experimental methodology over a representative age range.

It has also been claimed (Basser, 1962; Bryden, 1970; Kimura, 1963; Lenneberg, 1967) that a similar developmental trend occurs in the lateralization of the speech function. In the present study each S will be required to produce a speech sample under simultaneous feedback conditions and under conditions of delayed feedback to either the right ear, the left ear, or both ears. Preschool children, fourth graders, and adults will participate in each of these conditions. The speech samples should be of sufficient length to permit detailed analysis and will be evaluated by two independent raters. Changes in syllable prolongation, syllable repetition, word repetition, word rate, and syllable rate under delayed feedback conditions will be analyzed as a function of age, sex, and type of delay condition. The possibility of an interactive effect between the development of the use of auditory feedback and lateralization of the speech function with age will be explored so that, under Bradshaw's et. al. (1971) paradigm, younger children are expected to demonstrate equivalent disruption of speech with delay to either ear, whereas older children and adults are expected to show a progressive lateralization for the disruptive effects of DAF.

Method

Subjects. Subjects were selected from three age groups. Group 1 consisted of 9 male Ss and 9 female Ss who attended the University Day School (i.e., preschool group). The children ranged in age from 3.1 to 4.8 years, with a mean age of 3.9 years. The Ss in Group 2 were students in the Belchertown Elementary School. The 9 males and 9 females ranged in age from 9.1 years to 10.9 years, with a mean age of 9.7 years. Group 3 was comprised of 9 males and 9 females who were graduate students and research assistants at the University of Massachusetts and who were all over 21 years of age.

Hand preference was determined for each S by asking the S to draw a circle on a piece of paper prior to the beginning of the experiment and to pick up a small ball rolled across the table by the E. The S was also questioned as to his preferred hand (Palmer, 1964). The more skilled hand was determined by the E. If the S used the same hand in both tasks and indicated that the same hand was his preferred hand, he was considered to have demonstrated a clear preference for that hand. If the hand indicated by one or more of the criteria differed, the S was considered to have no clear hand preference. Group 1 contained 6 clearly right-handed males and 3 males who showed no clear preference for handedness. Of the females, 2 were clearly right-handed, 2 clearly left-handed, and 5 Ss demonstrated no clear hand preference. All Group 2 Ss were right-handed. Group 3 contained 7 right-handed and 2 left-handed males, and 8 right-handed females and one left-handed female. Since clinical evidence suggests that the left cerebral hemisphere plays a primary role in speech for right-handed people as well as for the majority of left-handed people (Bradshaw, Geffen, and Nettleton, 1972b), no distinction was made between right and left-handed _S_s. All _S_s were required to be monolingual and no _S_ was used who had any history of serious speech or auditory impairment.

Apparatus. A Revox Model A77 tape recorder was used to deliver auditory feedback and to record the speech output of each _S_. A modification of the tape recorder made it possible to present instantaneous auditory feedback through one channel and to insert a .175 second delay at a tape velocity of 7.5 inches per second into the other feedback channel. A selection switch allowed the _E_ to shift the delay to either or both channels. The output was fed into a pair of Lafayette SP-55 stereo headphones and the volume controls were adjusted according to a 454A Oscilloscope, using an EICO Model 377 audio generator to give approximately equal intensity at each ear. This resulted in peaks of 90-100 db., on the average, under experimental speaking conditions. For the two groups of children, both the microphone (Wollensak A-0454) and the headphones were mounted inside a toy space helmet which was intended to prevent the children from removing the headphones during the experiment and to keep the microphone at a constant 3 inches from the _S_'s mouth. For adult _S_s, the microphone was mounted in a holder which hung around the _S_'s neck and held the microphone 3 inches from the mouth of the _S_. A Sony TC-900A tape recorder was used to deliver the instructions, introduction, and prompts, if needed.

Procedure. Each S was seated at a table in a quiet room, facing a wooden constructed dog head which bore the name "SPOT" in block letters at the base. The constructed head was fitted with an aluminum foil replica of a space helmet. It was explained to adult Ss that the presentation was intended for children. The E sat behind a large screen opposite the S. Both tape recorders were hidden from the S's view, under the table, and the E held a hand control for the Sony tape recorder. The tape was started and a voice, supposedly "Spot's", introduced itself to the S. Spot asked the S if he would like to play a game about a trip to the moon. If the S agreed to play, Spot explained the game, stressing that the most important aspect of the game was to keep on telling stories all the time they were on the moon. Spot also mentioned that sometimes everything sounds different on the moon, thus preparing the S for the delayed auditory feedback condition (see Appendix A for a complete transcription of the recorded instructions). The E held a set of 20 storybook illustrations mounted on cardboard. Spot told the S that as soon as the game began, they would be able to see some wonderful pictures and instructed the S to tell him "lots and lots" of stories about the pictures. Each S was then tested for handedness as previously described. The S was asked if he was ready to play and the E helped the child to put on the space helmet. Reassurance and further explanations were offered if the S seemed reluctant to continue. The tape recorder was started and the E placed the first illustration on the table in front of the S while Spot asked the S to tell a story. The E remained behind the screen while the S was speaking and presented each illustration, in random order, as soon as the *S* stopped speaking. If the *S* was hesitant to speak at any time during the session Spot prompted by saying "Great, keep on going, let's hear some more," etc.

All *Ss* heard immediate auditory feedback through both earphones for approximately the first two minutes of speech (control condition), with the requirement that the speech be fairly continuous. Thus, the interval between the end of one picture description and the beginning of the next was omitted from consideration as part of this two minute segment of the experiment if it fell within the two minutes. Following the simultaneous feedback condition the feedback was switched to dichotic delivery for two of the subject groups, with delayed feedback through one channel and instantaneous feedback through the other channel. For 6 *Ss* in each age group (3 males and 3 females), delay was presented to the right ear (D-R) and for 6 *Ss* in each age group (3 males and 3 females), delay was presented to the left ear (D-L). The third *S* group (3 males and 3 females from each age group) received binaural delay (D-D) following the two minutes of simultaneous feedback. Each *S* was required to speak for approximately two minutes under the appropriate delay condition (D-R, D-L, or D-D).

At the completion of the experimental session, Spot informed the *S* that they had returned from the trip to the moon and thanked the *S* for a wonderful time. The *E* helped the *S* to remove the space helmet and then asked the *S* whether he had enjoyed the game and what he had heard during the game. The responses to these questions and any other comments offered by the *S* were recorded by the *E*.

Design and Analysis. Two independent raters listened to each recording and counted the number of syllables prolonged, the number of syllables repeated, and the number of words repeated for control and delay conditions. The total number of words and syllables and the total time in seconds for each condition were evaluated by one rater.

In order to determine whether the speech samples were of adequate length to permit further evaluation, the mean number of words in the individual speech samples was calculated for each age group. For the control condition (simultaneous feedback), means of 288.611 words, 300.944 words, and 193.556 words were noted for adults, fourth graders, and preschoolers respectively. The delay conditions yielded means of 281.833 words for adult *S*s, 287.222 words for fourth grade *S*s, and 204.611 words for preschool *S*s. The total number of words in the recorded speech samples ranged from 164 to 448 words under the control condition and from 144 to 622 words under delay conditions for adults; from 99 to 610 words under the control condition and from 132 to 494 words under delay conditions for fourth grade *S*s; from 71 to 368 words under the control condition and from 86 to 389 words under delay conditions for preschool *S*s.

The percentage scores for the dependent variables were calculated as follows to adjust for differences in size of speech samples (Chase et. al., 1961):

Variable 1, % syllables prolonged = $\dfrac{\text{\# syllables prolonged}}{\text{\# syllables}} \text{ X } 100$

Variable 2, % syllables repeated = $\dfrac{\text{\# syllables repeated}}{\text{\# syllables}} \text{ X } 100$

Variable 3, % words repeated = $\frac{\#\text{ words repeated}}{\#\text{ words}} \times 100$

Variable 4, words per minute = $\frac{\#\text{ words}}{\text{time in seconds}} \times 60$

Variable 5, syllables per minute = $\frac{\#\text{ syllables}}{\text{time in seconds}} \times 60$

A score was computed for the control condition and for the delay condition for each S for each of the dependent variables. Difference scores for Variables 1, 2, and 3 were obtained by subtracting the score for the control condition from the score for the delay condition. The difference scores for Variables 4 and 5 were obtained by subtracting the score for the delay condition from the score for the control condition, in order to produce a majority of positive difference scores.

The data were investigated using a 4-way Analysis of Variance for each of the dependent variables. Age (preschool, fourth grade, adult), sex (male, female), delay condition (D-R, D-L, D-D) were the between-subject variables and treatment condition (simultaneous or delayed feedback) was the within-subjects variable. The Tukey Multiple Comparison method was used to further evaluate the results of the analyses.

Results

The reliability measures between the two independent raters for difference scores for individual speech samples were r = .94 for Variable 1, r = .98 for Variable 2, and r = .98 for Variable 3. The difference scores for Variables 4 and 5 were computed by a single rater since they did not involve subjective judgements. These reliability data were considered adequate to permit further analysis. Where the scores provided by the raters differed, the score used in the analysis was an average of the two scores for an individual.

Percent syllables prolonged. The raw score data for Variable 1 are presented in Table 1. An analysis of variance using these data yielded a significant treatment effect, F (1, 36) = 37.8, $p < .001$, and a significant delay X treatment interaction, F (2, 36) = 3.3, $p < .05$. Further comparison of these results indicated that the right-ear delay condition (D-R) produced significantly greater syllable prolongation than left-ear delay (D-L). Because of these significant results using raw scores, an analysis of the difference score data was performed which confirmed the preceding results and also yielded a significant delay X age interaction, F (4, 26) = 3.6, $p < .025$. The significant differences between the control and delay conditions held only for fourth grade Ss under the D-R condition and for adult Ss under binaural delay (D-D). Furthermore, the differences between syllable prolongation under D-R and under D-L reach significance only for fourth grade Ss. Figure 1 indicates that both D-R and D-D resulted in greater speech disruption than D-L for adults and fourth graders but not for preschoolers, although these differences were significant only for fourth graders under D-R and for adults under D-D. Preschool S̲s were more disrupted by D-L than either adult or fourth grade S̲s but the differences were not significant.

Insert Figure 1 about here

Percent syllables repeated. The analysis of the raw score data (see Table 2) yielded a significant age effect, F (2, 36) = 3.7, $p < .05$, demonstrating a difference in syllable repetition between adults and preschoolers regardless of treatment condition. A significant treatment effect, F (1, 36) = 9.9, $p < .005$, and the significant delay X age X treatment interaction, F (4, 36) = 3.4, $p < .025$, was confirmed by the results of the analysis of difference scores. A comparison of means showed that the difference between the control and delay conditions was significant for fourth graders under D-R but failed to reach significance for other experimental groups. D-R was found to be more disruptive for fourth grade S̲s than for preschool S̲s and an examination of the combined scores for adults and fourth grade S̲s showed that D-R caused significantly greater syllable repetition than D-L. Figure 2 indicates a similar trend to Figure 1. Syllable repetition was significantly greater for fourth graders under D-R than for adults or preschoolers. Adults showed greater disruption under D-D and preschoolers showed greater disruption under D-L than the other two subject groups but these differences were not significant.

Insert Figure 2 about here

Percent words repeated. The analysis of variance for Variable 3 resulted in a significant age effect, F (2, 36) = 8.0, $p < .005$ using raw scores (see Table 3). Preschool Ss repeated a significantly greater percent of words under all conditions than adult Ss but other comparisons between age groups failed to reach significance.

Words per minute. The raw score data for word rate are shown in Tables 4 and 5. These data yielded a significant age effect, F (2, 36) = 15.8, $p < .001$, with adults evidencing a significantly higher word rate than fourth graders, and fourth graders demonstrating a significantly higher word rate than preschoolers, regardless of experimental manipulation. A significant age main effect for difference scores, F (2, 36) = 6.0, $p < .01$, indicated that delayed feedback significantly reduced word rate for adult and fourth grade but not for preschool Ss. This effect was greater for adults than for fourth graders or preschool Ss (see Table 4). The raw score data also yielded a significant effect of treatment, F (1, 36) = 58.8, $p < .001$, and a significant delay X treatment interaction, F (2, 36) = 7.2, $p < .005$. Further comparisons using difference scores showed that delay significantly reduced word rate for D-R and D-D but not for D-L conditions.

Insert Figure 3 about here

The delay X age X sex X treatment interaction was found to be significant, F (4, 36) = 2.6, $p < .05$, only for adult males under D-D (see Table 5). However, this result is difficult to interpret due to the small number of subjects in each group (n = 3).

Syllables per minute. The raw score data for Variable 5 are shown in Tables 6 and 7. A significant effect of age, F (2, 36) = 20.7, p < .001, is noted as well as an age main effect using difference scores, F (2, 36) = 7.2, p < .01. Adults displayed a higher syllable rate under both control and experimental conditions than fourth graders or preschoolers. Adults and fourth graders showed a supressed syllable rate under delay but preschool Ss showed no effect of delay (see Table 6). The raw score data yielded a significant treatment effect, F (1, 36) = 19.7, p < .001, and a significant delay X treatment interaction, F (2, 26) = 7.1, p < .005, which was confirmed by the results of the difference score analyses. Syllable rate was reduced under both D-R and D-D but not under D-L. A significant delay X sex interaction using difference scores, F (2, 36) = 3.4, p < .05, indicated that the reduction in syllable rate was significant for males but did not reach significance for female Ss. Finally, the significant interaction of delay X age X sex X treatment, F (4, 36) = 2.7, p < .05, showed a reduction in syllable rate only for adult males under D-R and under D-D (see Table 7), but, as noted previously, an interpretation of this result is difficult due to the small n.

Insert Figure 4 about here

Discussion

The results imply that the effects of delayed auditory feedback change with age and that the lateralization of this auditory feedback behavior is a developmental process. Right-ear delay produced significantly greater syllable prolongation and syllable repetition than left-ear delay but this difference reached significance only for fourth grade Ss. Adult Ss demonstrated significantly greater syllable prolongation under D-D than under D-L. D-R and D-D reduced word rate and syllable rate for adults and fourth graders but not for preschool Ss. In addition, several differences between subject groups were noted which were not related to experimental manipulation. Preschool children repeated significantly more words and syllables than adults. Adults were found to have a higher word rate and syllable rate than fourth graders and fourth graders demonstrated a significantly higher word and syllable rate than preschool Ss.

Unfortunately, the conclusions based on these results are somewhat limited by the small size of the subject population. While many trends were observed (see Tables 1 - 7), few of the differences between means actually reached significance. Delayed auditory feedback disrupted the speech of all S groups, but the disruptive effects appeared to be less for preschoolers than for adults or fourth graders (see Figures 1 - 4). D-R and D-D were generally more disruptive than D-L for adults and fourth graders but not for preschoolers. Of particular interest is the indication that for Variable 1 (% syllables prolonged) and for Variable 2 (% syllables repeated), preschool Ss displayed slightly more disruption under D-L than under D-R or D-D. Since these two measures have previously been cited as the aspects of speech behavior most disrupted by delayed auditory feedback (Chase, 1958; Chase et. al., 1961; Yeni-Komshian et. al., 1968), these differences may be indicative of developmental changes in feedback monitoring. However, the differences are too slight to have any predictive value and further investigation of this trend would be advised.

In contrast to previous studies, the same experimental methodology was employed for all age groups, rendering a more complete picture of the effects of DAF on spontaneous speech behavior. The present study showed, in agreement with Chase et. al. (1961), that preschool subjects repeated more words and syllables and uttered fewer words and syllables per minute than older subjects, regardless of experimental manipulation. Fourth graders demonstrated greater speech disruption under DAF than preschool Ss, which further confirmed Chase's et. al. results. Waters (1968) found greater disruption of whispered speech for 10 - 12 year olds than for 16 - 18 year olds. This trend was supported for the percent syllables prolonged and for the percent syllables repeated measures under the D-R condition but not under the D-L or D-D conditions. Thus, the D-R curves for Variables 1 and 2 (see Figures 1 and 2) conform to Waters' bow-shaped function derived from the combined results of his task and Chase's et. al. results.

The preceding observations of basic differences in speech patterns as a function of age may be important. It has been suggested by Cullen, Fargo, Chase, and Baker (1968) that the specific effects of DAF on speech behavior may vary with the child's developmental stage and with the type of vocal behavior involved. They found that when infant crying was subjected to delay, a significant decrease in average crying duration occurred, a result in direct contrast to the finding that average reading and speaking time for adults is increased under DAF. Webster, Schumacher, and Lubker (1970) found that when stutterers (14 - 18 years old) read a passage under DAF their fluency was greatly improved. In the present study, the E noted that some preschoolers also seemed to exhibit an improvement in fluency under DAF instead of the decrement observed in adult speech. In many instances, syllable repetition was reduced and words became more distinct and less jumbled. The explanations offered by Webster et. al. concerning these effects on stuttered speech do not appear to be applicable to young children's speech. This approach may, nevertheless, be important in re-evaluating previous results in DAF studies. The speech of young children may actually be affected by DAF but the effect may be quite different from the effect on adult speech. The measures used to evaluate speech alterations under DAF (i.e., word duration, syllable prolongation, etc.) may simply not reflect the changes caused by DAF in the preschooler's speech behavior. An extensive observation period would be recommended prior to DAF studies using young children to determine appropriate measures, since it seems apparent that the types of changes in speech under DAF vary with age and that the feedback mechanisms may actually function differently at different ages.

Bradshaw et. al. (1971, 1972) have been the only authors to compare the effects of delay to the right ear and delay to the left ear.

These studies used reading and musical tasks and used total reading time/playing time as their measure of speech or performance disruption for adult Ss. Both the task and the measures used in the present study were quite different. However, in spite of these differences, a significantly greater decrease in word rate was found for D-R than for D-L, comparable to the increases in reading times under D-R found by Bradshaw et. al. It appears that, for various types of speech behavior, delay to the right ear results in a greater slowing of speech than delay to the left ear, supporting the theory of hemispheric lateralization of speech feedback monitoring.

In agreement with the observations of Chase et. al. and Yeni-Komshian et. al., most of the preschoolers in the present study said that they found nothing disturbing in the DAF segment of the experiment and did not seem to be aware of any changes in their speech. The children did not appear to realize that they were hearing their own voices, as evidenced by such remarks as "Someone's talking to me" and "Be quiet, Spot." None of the younger Ss were able to specify what they had heard in terms of changes in their own speech. On the other hand, all of the fourth grade and the adult Ss could detect some peculiarity in their speech, even if they were unable to identify the exact nature of the changes.

In conclusion, the hypotheses of changes in the utilization of speech feedback with age and of a developmental hemispheric dominance for speech feedback monitoring are supported. The effects of lateralized DAF appear to be quite different for the speech of preschool children when compared to the effects on the speech behavior of older children and adults. This observation as well as basic differences in speech behavior at various ages bear further investigation. Future researchers are advised to use large sample sizes and, more importantly, to attempt to develop new approaches in studying the effects of the delayed auditory feedback technique on the speech of young children. The application of new measures and observational methods to the speech samples of young children and their evaluation relative to adult speech behavior under delayed auditory feedback may bring us closer to an understanding of an important aspect of speech development.

References

Basser, L. S. Hemiplegia of early onset and the faculty of speech with special reference to the effects of hemispherectomy. *Brain*, 1962, 85, 427-460.

Berko, J., and Brown, R. Psycholinguistic research methods. In Handbook of Research Methods in Child Development, New York: John Wiley & Sons, Inc., 1960, 527-531.

Bradshaw, J. L., Nettleton, N. C., and Geffen, G. Ear differences and delayed auditory feedback: Effects on a speech and a music task. *Journal of Experimental Psychology*, 1971, 91, 85-92.

Bradshaw, J. L., Nettleton, N. C., and Geffen, G. Ear asymmetry and delayed auditory feedback: Effects of task requirements and competitive stimulation. *Journal of Experimental Psychology*, 1972a, 94, 269-275.

Bradshaw, J. L., Nettleton, N. C., and Geffen, G. Our two brains. *New Scientist*, 1972b, 15, 628-630.

Bryden, M. P. Ear preference in auditory perception. *Journal of Experimental Psychology*, 1963, 65, 103-105.

Bryden, M. P. An evaluation of some models of laterality effects in dichotic listening. *Acta Oto-Laryngologica*, 1967, 63, 595-604.

Bryden, M. P. Binaural competition and the division of attention as determinants of the laterality effect in dichotic listening. *Canadian Journal of Psychology*, 1969, 23, 101-113.

Bryden, M. P. Laterality effects in dichotic listening: Relations with handedness and reading ability in children. *Neuropsychologica*, 1970, 8, 445-450.

Butler, R. A., and Galloway, F. T. Factorial analysis of the delayed speech feedback phenomenon. *Journal of the Acoustical Society of America*, 1957, 29, 632-635.

Chase, R. A. Effects of delayed auditory feedback on the repetition of speech sounds. *Journal of Speech and Hearing Disorders*, 1958, 23, 583-590.

Chase, R. A., Sutton, S., First, D., and Zubin, J. A developmental study of changes in behavior under delayed auditory feedback. *Journal of Genetic Psychology*, 1961, 99, 101-112.

Cullen, J. K., Fargo, N., Chase, R. A., and Baker, P. The development of auditory feedback monitoring: I. Delayed auditory feedback studies on infant crying. *Journal of Speech and Hearing Research*, 1968, 11, 85-93.

Fairbanks, G. Systematic research in experimental phonetics: A theory of the speech mechanism as a servosystem. Journal of Speech and Hearing Disorders, 1954, 19, 133-139.

Kimura, D. Cerebral dominance and the perception of verbal stimuli. Canadian Journal of Psychology, 1961, 15, 166-171.

Kimura, D. Speech lateralization in young children as determined by an auditory test. Journal of Comparative and Physiological Psychology,1963, 56, 899-902.

Kimura, D. Functional asymmetry of the brain in dichotic listening. Cortex, 1967, 3, 163-178.

Kinsbourne, M. The cerebral basis of lateral asymmetries in attention. In A. F. Saunders, Attention and Performance III, Acta Psychologica, 1970, 33, 193-201.

Lee, B. S. Effects of delayed speech feedback. Journal of the Acoustical Society of America, 1950, 22, 824-826.

Lenneberg, E. H. Biological Foundations of Language. New York: Wiley, 1967.

Menyuk, P. Chidren's learning and reproduction of grammatical and non-grammatical sequences. Child Development, 1968, 38, 849-859.

Myers, T. F. Asymmetry and attention in phonic decoding. Acta Psychologica, 1970, 33, 158-177.

Palmer, R. D. Development of a differentiated handedness. Psychological Bulletin, 1964, 62, 257-272.

Satz, P., Levy, M., and Tyson, M. Effects of temporal delays on the ear asymmetry in dichotic listening. Journal of Experimental Psychology, 1970, 84, 372-374.

Shankweiler, D., and Studdert-Kennedy, M. Identification of consonants and vowels presented to left and right ears. Quarterly Journal of Experimental Psychology, 1967, 19, 59-63.

Smith, K. U. The geometry of human motion and its neural foundations II. Neurogeometric theory and its experimental basis. American Journal of Physical Medicine, 1961, 40, 109-129.

Smith, K. U. Delayed Sensory Feedback and Behavior. W. B. Sanders, Philadelphia, 1962.

Vygotsky, L. S. Psychology and localization of functions. Neuropsychologica, 1965, 3, 381-386.

Waters, J. E. A theoretical and developmental investigation of delayed speech feedback. Genetic Psychology Monographs, 1968, 78, 3-54.

Webster, R. L., Schumacher, S. J., and Lubker, B. B. Stuttering frequency and delayed auditory feedback. Journal of Abnormal Psychology, 1970, 75, 45-49.

Yates, A. J. Delayed auditory feedback. Psychological Bulletin, 1963, 60, 213-232.

Yeni-Komshian, G., Chase, R. A., and Mobley, R. L. The development of auditory feedback monitoring: II. Delayed auditory feedback studies on the speech of children between two and three years of age. Journal of Speech and Hearing Research, 1968, 11, 307-315.

Zurif, E. B., and Bryden, M. P. Familial handedness and left-right differences in auditory and visual perception. Neuropsychologica, 1969, 7, 179-187.

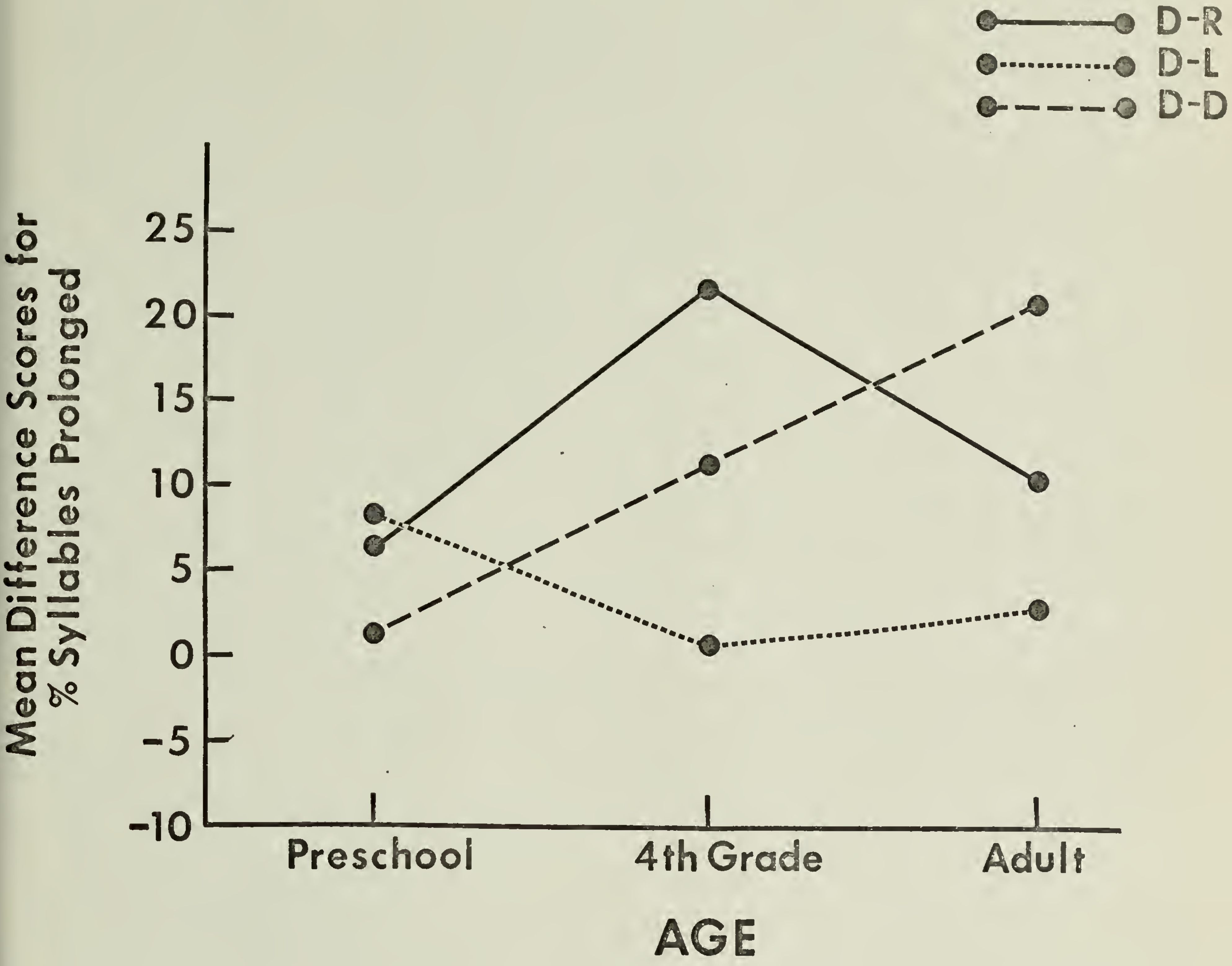

Figure 1. Mean difference scores for percent syllables prolonged for Adult, Fourth Grade, and Preschool subjects under right-ear delay, left-ear delay, and binaural delay conditions.

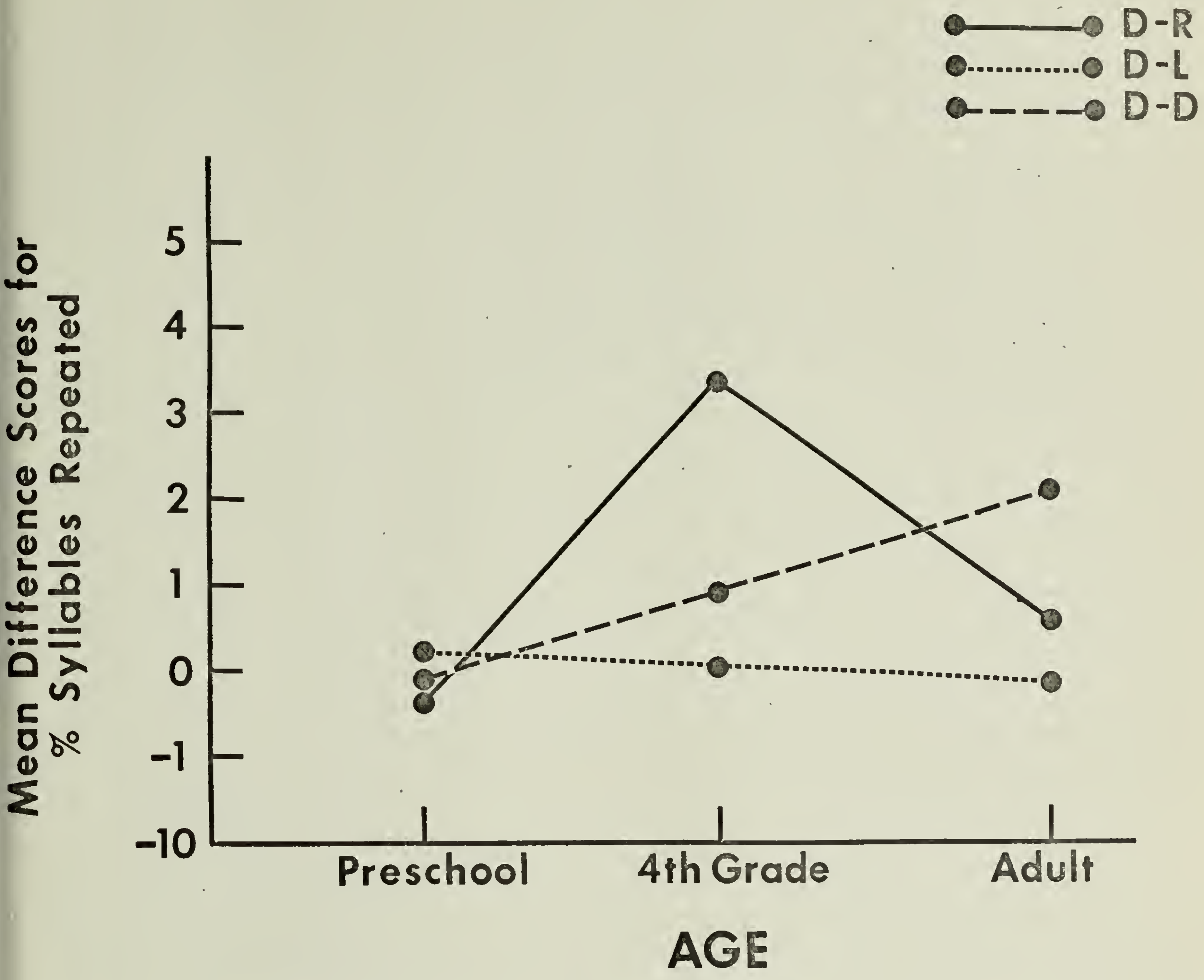

Figure 2. Mean difference scores for percent syllables repeated for Adult, Fourth Grade, and Preschool subjects under right-ear delay, left-ear delay, and binaural delay conditions.

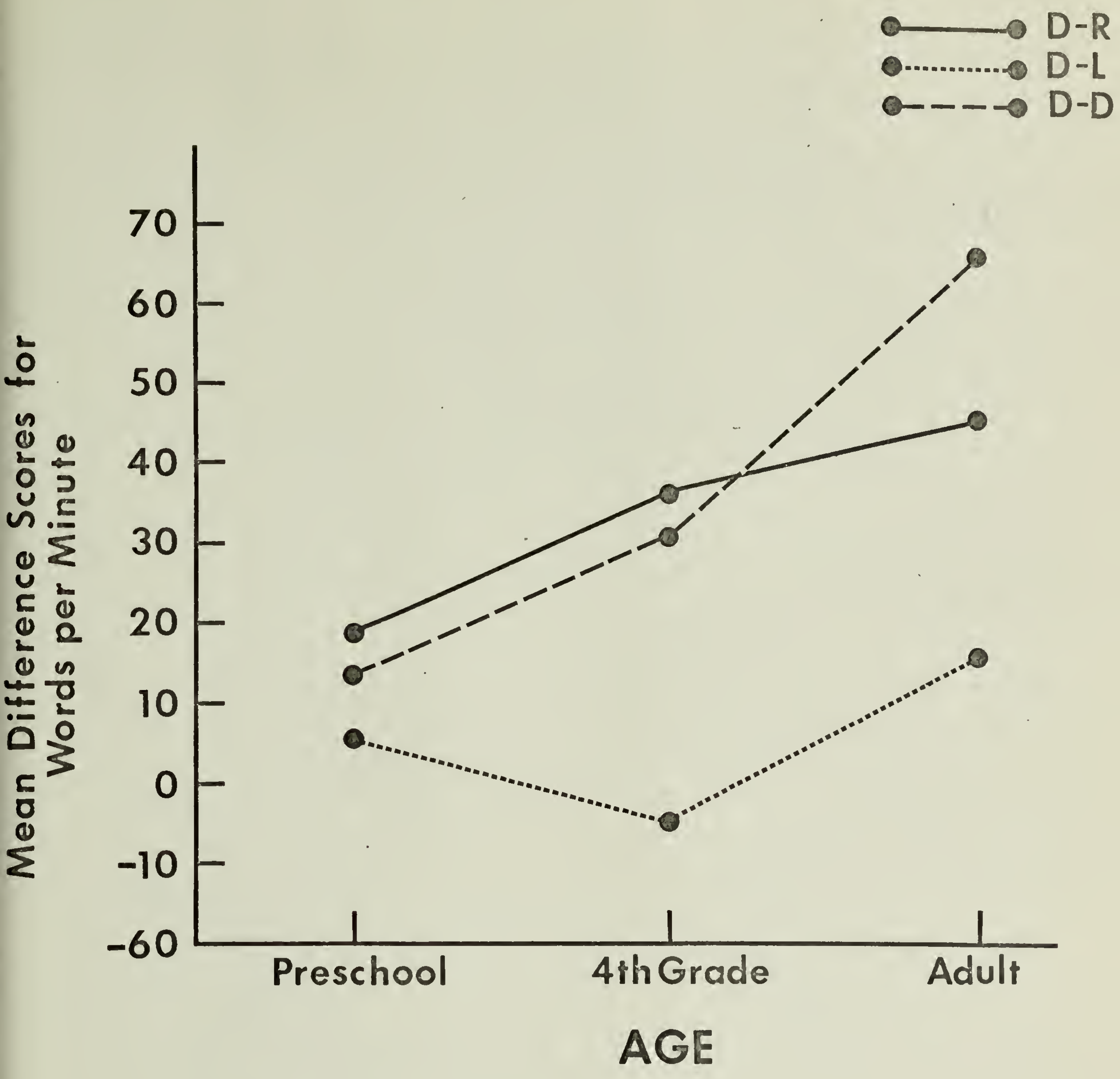

Figure 3. Mean difference scores for words per minute for Adult, Fourth Grade, and Preschool subjects under right-ear delay, left-ear delay, and binaural delay conditions.

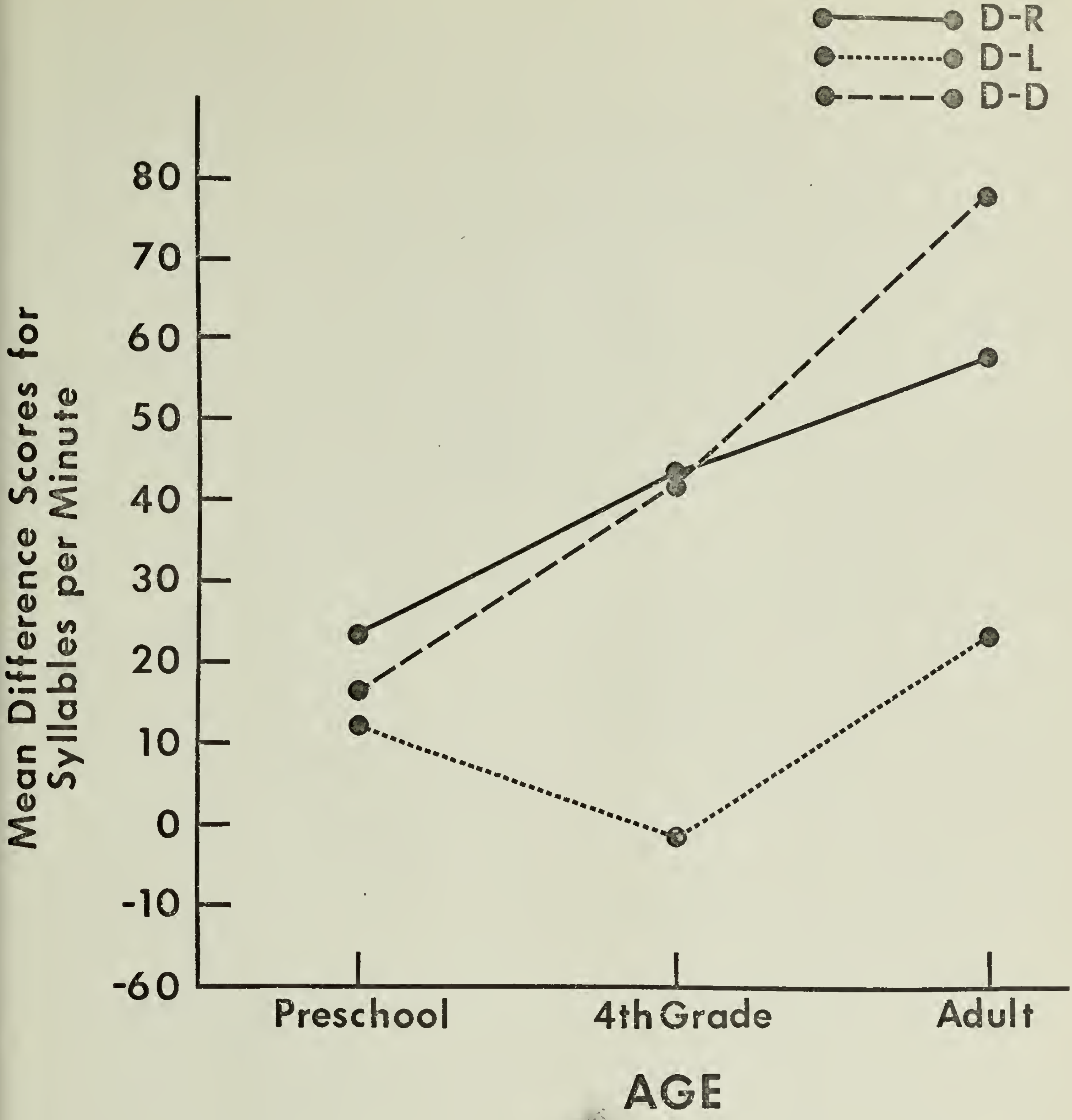

Figure 4. Mean difference scores for syllables per minute for Adult, Fourth Grade, and Preschool subjects under right-ear delay, left-ear delay, and binaural delay conditions.

Table 1

Mean percent syllables prolonged for the delay X age X treatment interaction using raw scores

	D-R		D-L		D-D	
	control	delay	control	delay	control	delay
Adults	11.28	21.44	13.74	16.33	12.40	33.13[a]
4th gr.	11.46	33.65[b]	11.01	11.65	11.11	22.65
Presch.	16.39	22.78	13.85	22.49	14.39	15.35
$\bar{X}$ [1]	13.04	25.96[c]	12.87	16.82	12.63	23.71

[a] delay condition significantly greater than control condition for adult Ss under D-D, $p < .01$.

[b] delay condition significantly greater than control condition for 4th grade Ss under D-R, $p < .01$.

[c] delay condition significantly greater than control condition under D-R, $p < .05$.

[1] means for delay X treatment interaction.

Table 2

Mean percent syllables repeated for the delay X age X treatment interaction using raw scores

	D-R		D-L		D-D		$\bar{X}$ [1]
	control	delay	control	delay	control	delay	
Adults	10.19	10.53	10.95	10.76	10.46	12.67	10.92
4th gr.	11.05	14.24[a]	11.07	11.10	10.93	11.71	11.68
Presch.	12.28	11.91	11.98	12.39	11.84	12.24	12.11
M [2]	11.14	12.26	11.33	11.42	11.08	12.21	

[a] delay condition significantly greater than control condition for fourth grade Ss under D-R, $p < .05$.

---

[1] means for age main effect.

[2] means for delay X treatment interaction.

Table 3

Mean percent words repeated for the age main effect using raw scores

Adults	4th grade	Preschool
10.31	10.88	11.43[a]

[a] preschool Ss repeated significantly more words than adult Ss, $p < .05$.

Table 4

Mean words per minute for the age X treatment interaction using raw scores

	control	delay	$\overline{X}$ [1]
Adult	148.46	106.85[a]	127.66
4th grade	115.31	94.43[b]	104.87
Preschool	93.50	79.00	86.25[d]
M [2]	119.09	93.43[c]	

[a] word rate significantly reduced under delay conditions for adults, $p < .05$.

[b] word rate significantly reduced under delay conditions for fourth grade Ss, $p < .05$.

[c] word rate significantly reduced under delay, $p < .05$.

[d] word rate significantly lower for preschool Ss than for adult Ss, $p < .05$.

[1] mean word rate for age main effect.

[2] mean word rate for treatment main effect.

Table 5

Mean words per minute for the delay X age X sex X treatment interaction using raw scores

		D-R		D-L		D-D	
		control	delay	control	delay	control	delay
M	Adult	161.58	100.01^a	128.10	136.92	159.95	69.43^b
	4th gr.	99.61	72.21	101.57	113.11	110.68	88.55
	Presch.	82.76	74.18	83.88	82.89	101.94	89.18
	$\bar{X}^1$	114.66	82.13^c	104.52	110.98	124.19	82.39^d
F	Adult	145.41	112.52	169.61	126.89	126.13	95.33
	4th gr.	146.98	102.55	109.07	107.19	123.92	82.98
	Presch.	97.91	68.62	89.12	67.78	105.36	91.37
	$\bar{X}^1$	130.10	94.57^e	122.60	100.62	118.47	89.89^f
	M^2	122.38	88.35^g	113.56	105.80^h	121.33	86.14^i

[a] control condition significantly greater than delay condition for adult males under D-R, $p < .05$.

[b] control condition significantly greater than delay condition for adult males under D-D, $p < .05$.

[c] control condition significantly greater than delay condition for males under D-R, $p < .05$.

Table 5 (cont'd)

[d] control condition significantly greater than delay condition for males under D-D, $p < .05$.

[e] control condition significantly greater than delay condition for females under D-R, $p < .05$.

[f] control condition significantly greater than delay condition for females under D-D, $p < .05$.

[g] control condition significantly greater than delay condition for D-R, $p < .05$.

[h] delay condition significantly greater for D-L than for D-R or D-D, $p < .05$.

[i] control condition significantly greater than delay condition for D-D, $p < .05$.

[1] means for delay X sex X treatment interactions.

[2] means for delay X treatment interactions.

Table 6

Mean syllables per minute for the age X treatment interaction using raw scores

	control	delay	$\bar{X}$ [1]
Adult	189.02	135.53[a]	162.28[b]
4th grade	140.59	113.27[c]	126.93[d]
Preschool	113.35	95.98	104.67
M [2]	147.65	114.93[e]	

[a] syllable rate significantly reduced under delay conditions for adults, $p < .05$.

[b] syllable rate significantly greater for adults than for 4th grade or preschool *S*s, $p < .05$.

[c] syllable rate significantly reduced under delay conditions for 4th graders, $p < .05$.

[d] syllable rate significantly greater for 4th grade *S*s than for preschoolers, $p < .05$.

[e] syllable rate significantly reduced under delay conditions, $p < .05$.

[1] mean syllable rate for age main effect.

[2] mean syllable rate for treatment main effect.

Table 7

Mean syllables per minute for the delay X age X sex X treatment interaction using raw scores

		D-R		D-L		D-D	
		control	delay	control	delay	control	delay
M	Adult	195.97	122.65[a]	163.96	171.70	207.48	88.79[b]
	4th gr.	121.25	86.47	126.42	138.00	139.85	107.67
	Presch.	96.69	89.62	105.78	100.59	123.72	106.92
	$\bar{X}$[1]	137.97	99.58[c]	132.06	136.77	157.02	101.13[d]
F	Adult	180.16	138.78	220.31	165.81	166.25	125.43
	4th gr.	171.92	121.86	134.33	125.61	149.74	100.00
	Presch.	120.95	86.83	108.02	87.36	124.93	104.56
	$\bar{X}$[1]	157.68	115.82[e]	154.22	126.26	146.97	110.00[f]
	M[2]	147.82	107.70[g]	143.14	131.51[h]	151.99	105.56[i]

[a] control condition significantly greater than delay condition for adult males under D-R, $p < .05$.

[b] control condition significantly greater than delay condition for adult males under D-D, $p < .05$.

[c] control condition significantly greater than delay condition for males under D-R, $p < .05$.

[d] control condition significantly greater than delay condition for males under D-D, $p < .05$.

[e] control condition significantly greater than delay condition for females under D-R, $p < .05$.

[f] control condition significantly greater than delay condition for females under D-D, $p < .05$.

[g] control condition significantly greater than delay condition for D-R, $p < .05$.

[h] delay condition significantly greater for D-L than for D-R or D-D, $p < .05$.

[i] control condition significantly greater than delay condition for D-D, $p < .05$.

[1] means for delay X sex X treatment interactions.

[2] means for delay X treatment interactions.

Appendix A

Transcription of Instruction Tape

Hi there. My name is SPOT. What's your name? (pause) That's a nice name. Do you know what? (pause) When I'm happy my nose lights up... whoops! just like that! (light bulb nose is switched on and off several times by the _E_.) And when children play with me and talk to me my nose lights up lots and lots.

I have a great idea...let's play a game! It's my very very favorite game and it's all about a trip to the moon. Would you please please play with me? (pause) Wonderful! Here's how we play our game. Do you see this hat on my head? (pause) Well, this hat is my space helmet. You have one too. (_E_ shows the _S_ the space helmet.) As soon as we take off for the moon we'll be able to look at some great pictures. You can tell me lots and lots of stories about the pictures. Of course, sometimes everything sounds different up on the moon. The most important thing is to keep on telling stories all the time that we're up in space. Remember, keep on talking and telling me stories. Are you ready?

Great! Here we go!

Tell me a story...Great, keep on going!...I want to hear more stories... Wonderful, let's hear some more...We're almost home. Tell me one more story.

Well, we're home again. Did you have fun? (pause) Would you play with me sometime again? Great! Thanks for playing. Bye!

Key for Appendices B - K

D - Delay Condition (D-R, D-L, D-D)

A - Age (preschool, fourth grade, adult)

S - Sex (male, female)

T - Trial (simultaneous auditory feedback, delayed auditory feedback)

N - Number of Subjects

Appendix B

Analysis of Variance for Raw Scores for Syllables Prolonged

Source	SS	df	MS	F
Delay condition	413.74	2	206.87	2.36
Age	23.19	2	11.60	.13
Sex	114.01	1	114.01	1.30
Treatment	2343.66	1	2343.66	37.84[1]
Delay X Age	893.20	4	223.20	2.55
Delay X Sex	174.36	2	87.18	.99
Delay X Treatment	403.09	2	201.54	3.25[2]
Age X Sex	345.18	2	172.59	1.97
Age X Treatment	214.79	2	107.39	1.73
Sex X Treatment	25.93	1	25.93	.41
Delay X Age X Sex	365.82	4	91.45	1.47
Delay X Age X Treatment	885.32	4	221.33	3.57[3]
Delay X Sex X Treatment	161.50	2	80.75	1.31
Age X Sex X Treatment	278.97	2	139.49	2.26
N/DAS	3156.10	36	87.67	
DAST	266.13	4	66.53	1.08
NT/DAS	2230.01	36	61.95	

T =

[1] significant at $p < .001$.

[2] significant at $p < .05$.

[3] significant at $p < .025$.

Appendix C

Analysis of Variance for Raw Scores for Syllables Repeated

Source	SS	df	MS	F
D	2.13	2	1.06	.32
A	25.81	2	12.90	3.67[1]
S	3.83	1	3.83	1.08
T	15.33	1	15.33	9.92[2]
DXA	23.72	4	5.93	1.70
DXS	1.07	2	.53	.14
DXT	6.13	2	3.07	2.07
AXS	3.26	2	1.63	.46
AXT	6.34	2	3.17	2.13
SXT	1.11	1	1.11	.73
DXAXS	4.06	4	1.02	.28
DXAXT	20.99	4	5.25	3.40[3]
DXSXT	4.46	2	2.23	1.46
AXSXT	2.31	2	1.15	.80
N/DAS	126.53	36	3.52	
DXAXSXT	7.68	4	1.92	1.26
NT/DAS	55.61	36	1.55	

[1] significant at $p < .05$.

[2] significant at $p < .005$.

[3] significant at $p < .025$.

Appendix D

Analysis of Variance for Raw Scores for Words Repeated

Source	SS	df	MS	F
D	.15	2	.08	.07
A	22.54	2	11.27	8.01[1]
S	1.74	1	1.74	1.21
T	.03	1	.03	.04
DXA	2.80	4	.70	.50
DXS	.20	2	.10	.07
DXT	.06	2	.03	.04
AXS	2.53	2	1.26	.93
AXT	3.49	2	1.74	2.54
SXT	.26	1	.26	.38
DXAXS	1.29	4	.32	.23
DXAXT	6.64	4	1.66	2.46
DXSXT	.47	2	.23	.35
AXSXT	.21	2	.11	.17
N/DAS	50.66	36	1.41	
DXAXSXT	2.57	4	.64	.94
NT/DAS	24.73	36	.69	

[1] Significant at $p < .005$.

Appendix E

Analysis of Variance for Raw Scores for Words Per Minute

Source	SS	df	MS	F
D	678.80	2	339.40	.35
A	30963.68	2	15481.84	15.81[1]
S	1048.44	1	1048.44	1.07
T	17777.84	1	17777.84	58.79[2]
DXA	6305.09	4	1576.27	1.61
DXS	841.19	2	420.60	.43
DXT	4331.10	2	2165.55	7.16[3]
AXS	947.55	2	473.78	.19
AXT	3618.73	2	1809.36	5.98[4]
SXT	249.07	1	249.07	.82
DXAXS	2702.02	4	675.51	.69
DXAXT	1775.17	4	443.79	1.47
DXSXT	1984.85	2	992.43	3.28[5]
AXSXT	1144.23	2	572.12	1.89
N/DAS	35260.04	36	979.45	
DXAXSXT	3157.68	4	789.42	2.61[6]
NT/DAS	10886.34	36	302.40	

[1] significant at $p < .001$.

[2] significant at $p < .001$.

[3] significant at $p < .005$.

[4] significant at $p < .01$.

[5] significant at $p < .05$.

[6] significant at $p < .05$.

Appendix F

Analysis of Variance for Raw Scores for Syllables Per Minute

Source	SS	df	MS	F
D	1986.49	2	993.24	.68
A	60767.34	2	30383.67	20.66[1]
S	1617.23	1	1617.23	1.09
T	28917.81	1	28917.81	19.67[2]
DXA	7156.51	4	1789.13	1.22
DXS	1599.58	2	799.79	.54
DXT	6189.67	2	3194.84	6.98[3]
AXS	693.24	2	346.62	.23
AXT	6268.35	2	3134.18	7.07[4]
SXT	222.24	1	222.24	.50
DXAXS	4026.71	4	1006.68	.67
DXAXT	2459.99	4	614.99	1.39
DXSXT	3011.23	2	1505.61	3.40[5]
AXSXT	1579.97	2	789.99	1.78
N/DAS	52937.53	36	1470.49	
DXAXSXT	4856.43	4	1214.11	2.74[6]
NT/DAS	15958.41	36	443.29	

[1] significant at $p < .001$.

[2] significant at $p < .001$.

[3] significant at $p < .005$.

[4] significant at $p < .005$.

[5] significant at $p < .05$.

[6] significant at $p < .05$.

Appendix G

Analysis of Variance for Difference Scores for Syllables Prolonged

Source	SS	df	MS	F
D	810.52	2	405.26	3.28[1]
A	432.72	2	216.36	1.75
S	52.06	1	52.06	.42
DXA	1774.95	4	443.74	3.60[2]
DXS	322.89	2	161.45	1.31
AXS	558.58	2	279.29	2.26
DXAXS	537.69	4	134.42	1.09
N/DAS	4443.15	36	123.42	

[1] significant at $p < .05$.

[2] significant at $p < .025$.

Appendix H

Analysis of Variance for Difference Scores for Syllables Repeated

Source	S	df	MS	F
D	12.27	2	6.13	1.99
A	12.68	2	6.34	2.05
S	2.23	1	2.23	.71
DXA	41.99	4	10.50	3.40[1]
DXS	8.92	2	4.46	1.45
AXS	4.61	2	2.31	.74
DXAXS	15.37	4	3.84	1.23
N/DAS	111.21	36	3.09	

[1] significant at $p < .025$.

Appendix I

Analysis of Variance for Difference Scores for Words Repeated

Source	SS	df	MS	F
D	.12	2	.06	.04
A	6.97	2	3.48	2.54
S	.52	1	.52	.38
DXA	13.28	4	3.32	2.42
DXS	.93	2	.47	.34
AXS	.42	2	.21	.15
DXAXS	5.13	4	1.28	.93
N/DAS	49.43	36	1.37	

Appendix J

Analysis of Variance for Difference Scores for Words Per Minute

Source	S	df	MS	F
D	8664.09	2	4332.04	7.16[1]
A	7237.33	2	3618.66	5.98[2]
S	499.05	1	499.05	.83
DXA	3548.01	4	887.00	1.47
DXS	3971.51	2	1985.75	3.28
AXS	2287.82	2	1143.91	1.89
DXAXS	6312.98	4	1578.24	2.61
N/DAS	21781.02	36	605.03	

[1] significant at $p < .005$.

[2] significant at $p < .01$.

Appendix K

Analysis of Variance for Difference Scores for Syllables Per Minute

Source	SS	df	MS	F
D	12109.70	2	6054.85	6.75[1]
A	12849.82	2	6424.91	7.17[2]
S	388.64	1	388.64	.43
DXA	5176.87	4	1294.22	1.44
DXS	6272.75	2	3136.38	3.50[3]
AXS	3068.63	2	1534.31	1.71
DXAXS	9592.47	4	2398.12	2.68
N/DAS	32275.38	36	896.54	

[1] significant at $p < .01$.

[2] significant at $p < .01$.

[3] significant at $p < .05$.