PHONEMIC RESTORATION
IN NURSERY SCHOOL CHILDREN

by

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ACKNOWLEDGMENTS

I would like to thank Dr. Rainbolt, my adviser, for his assistance and advise. I would also like to thank the other members of my committee, Dr. Ahmed and Dr. Flanagan.

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Finally, I would like to thank my husband, Dwight, for his support throughout the period this study took place.

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INTRODUCTION

Auditory perceptual skills of children has become increasingly important to educators as they become aware of the vital role it can play in the development of a number of skills. Auditory perception has been found to influence reading (Wepman, 1960; Flynn & Bryne, 1970), spelling (Bannatyne & Wichiarjote, 1969), and articulation (Wepman, 1960). In addition to these skills, overall achievement in school (Morency & Wepman, 1973), and level of mental functioning (McNinch & Hafner, 1971) are highly correlated to auditory perceptual abilities. The auditory skills studied include what the authors term as the following: auditory discrimination, blending or phonemic synthesis, auditory memory, dichotic listening skills, auditory sensitivity, auditory attending, auditory-visual integration, auditory closure, auditory figure-ground, and speech-in-noise functioning.

The speech-in-noise problem is probably one of the most important because of the need for a child to function efficiently in a noisy environment. Katz and Illmer (1971) state: "We have noted about 60% of the children referred for learning problems had poor performance in speech-in-noise tasks." This extremely high incidence of problems with speech-in-noise tasks points to a need for greater understanding of how a normal child functions in this type situation to serve as a basis of comparison.

The traditional method of analyzing performance in speech-in-noise situations include presenting phonetically balanced word lists in the presence of a masking noise, or requiring discrimination of words presented against backgrounds such as cafeteria or playground noises. These methods can give information on how well individual speech sounds are discriminated, but this may not be the only or the most efficeint methodology for determining level of performance. The processes involved in speech-in-noise tasks may be evaluated more efficiently by another methodology. One of the possible methodologies has recently been reported bases on a different view of the processes involved.

Warren and Warren (1970) and Warren (1970) reported on a phenomenon they called phonemic restoration (PhR). A phoneme was removed from a recorded sentence by removing a portion of the tape. Enough of the surrounding phonemes were also removed to eliminate transitional cues. A recorded cough of the same duration as the deleted portion was then spliced into the tape to replace the deleted segment. When the tape was played to a listener, the phoneme was perceived as being present. The illusion was so strong that even when the listeners were informed that a sound was missing they were unable to distinguish between the real and illusory sounds. Subsequent studies have shown that the PhR perceptual process that allows accurate perception when we are faced by ambiguities caused by loud noises masking portions of words. It seems that the PhR presents a different way of viewing the major processes operating in speech-in-noise tasks and thus has potential for aiding in identifying the specific problem a child in a noisy environment may have.

To date, the only work located with PhR tasks has been with young adults. This study will attempt to determine if the PhR occurs in normal children. Further, it will attempt to create a foundation for further investigations of the PhR with children.

Review of Literature

A. Literature dealing directly with the PhR.

The PhR was first reported by Warren and Warren (1970) and Warren (1970). A cough replaced a phoneme in a sentence and was presented to twenty undergraduate psychology students. The task was to indicate on a typewritten copy of the statement the exact position of the cough. Two things occurred: (1) the missing phoneme was clearly perceived; and, (2) the cough was mislocalized beyond the boundaries of the word containing it. It was found that other sounds such as a tone or a buzz could also elicit the PhR; however, the noise had to be at least as loud as the loudest sound in the sentence. If a silent space replaced the phoneme, the silence was accurately located and the PhR did not occur. Warren (1970) comments on this: "Of course, unlike extraneous sounds, a silence would not occur normally unless produced by the speaker. Also, silent intervals have functions akin to phonemes, requiring their accurate identification and localization for speech comprehension."

The PhR response depends on the surrounding context; therefore, different contexts will result in different PhR responses. For example: "It was found that the _eel was on the ______." The context at the end of the sentence would furnish the context to resolve the previous ambiguity. The PhR for "axle" would be "wheel"; for "orange" the PhR would be "peel."

The inability to localize the sound has been reported before and is seems that the systematic errors that occur are caused by various features of sentence structure. (Ladefoged & Broadbent, 1960; Beaver, Lackner, Kirk, 1969; Bever, Lackner, Stolz, 1969). Warren and Obusek (1971) summarize these studies in this way: "The general conclusion of these investigators were that the direction and magnitude of the displacement of the click reflected aspects of sentence deep structure, sentence surface structure, and transitional probabilities within clauses, as well as interactions between these variables in a rather complex fashion."

Warren and Obusek (1971) report on further studies on PhR and expand the concepts previously presented. Again undergraduate college students were used as subjects, and the task remained that of identifying the position of the noise in the sentence. The deleted phoneme was replaced with either a cough, a tone, or a buzz. The intensity levels ranged from approximately equal to the loudest sound in the sentence to ten decibels above this level. The PhR occurred with all noises and intensity levels; however, it rarely occurred when the deleted phoneme was replaced with silence. Repeated judgments, or practice, seemed to have no effect on the PhR response.

Warren, Obusek, and Ackroff (1972) describe the PhR as a specialized form of auditory induction (AI). They describe AI by this general rule: "If there is contextual evidence that a sound may be present at a given time, and if the peripheral units stimulated by a louder sound include those which would be stimulated by the fainter sound, then the fainter sound may be heard as present." The two other types of AI involve "(1) inducing and induced sounds of identical spectral composition (differing only in intensity; (2) sounds of differing spectral composition (e.g. a tone and a louder noise band)."

Sherman (1971) and Warren and Sherman (1974) examine the PhR responses when the resolving context follows the deleted phoneme. Again undergraduate students were used as subjects, and the task was to repeat the sentence and identify the position of the noise in the sentence. The deletion for the stimulus sentences (Warren & Sherman, 1974) was accomplished by electronically removing the portions by use of an electronic switch. The phoneme to be deleted was deliberately mispronounced in the initial tape in order to eliminate transitional cues.

The results of these studies support all aspects of the previous experiments. In addition they analyze the direction and extent of localization errors and interpret the results in terms of the amount of time required for perceptual synthesis in PhR. A directional bias was observed with a significant number of noises being localized to a position in the sentence previous to where it actually occurred. Warren and Sherman (1974) explain this in the following statement: "It seems that Ss listening to a sentence may store the auditory input in some partially processed form until confirmation of a particular verbal organization is achieved. Long storage may be required if a portion is missing--especially if the prior context does not identify unambiguously the absent portion, requiring information occurring after the missing speech sound to complete the identification....The delay in completion of perceptual processing of the verbal signal near the noise burst would cause the noise to appear to occur with an earlier portion of the sentence, as was observed."

There is evidence from Warren and Sherman (1974) that the duration of the noise-filled gap must apprriximate the normal duration of the restored in an ambiguous sentence can be changed by changing the length of the noise burst.

Dykman, et. al. (1971) imply that the PhR is a Gestalt process of closure. Warren and Sherman (1974) comment on this: "Phonemic restorations are more than Gestalt-type closures or completion of gaps. If this filling-in were all, it would be anticipated that the silent gap would elicit responses not appreciably different from those with a noise-filled gap, but it was found that Ss could localize the silence (and identify the missing phoneme) more accurately."

The literature that deals directly with the PhR response can be summarized by several statements on the nature of the PhR:

1. The PhR is a normal mechanism in young adults that aids in the veridical perception of speech sounds.

2. The PhR requires certain conditions to occur: a) the noise must be as loud or louder than the peak intensity level of the sentences; b) the noise must be approximately the same length as the deleted phoneme; c) a wide variety of noises can be used; and d) the PhR does not occur if a silence replaces the missing phoneme.

3. The PhR consists of two separate phenomena: a) perception of the illusory phoneme; and, b) mislocalization of the noise.

4. The context can effect both the perception of the illusory phoneme and the mislocalization of noise.

5. The PhR is not just a Gestalt-type closure process.

B. Related Literature.

Karlin (1942) performed a factorial analysis of the results of twenty-seven auditory tests and identified eight auditory factors. The following is the description he gave of Factor D: "This factor seems to underlie both the domains of auditory synthesis and analysis. Instead of one auditory ability enabling the organism to resist distortion of words due to temporal disarrangement, and another ability for resistance to masking noises obscuring meaning, there is apparently a more central ability which serves both purposes. This factor will be known as the AR (auditory resistance) factor. This functional system is probably widely operative in most auditory environments in social life." This is one of the first studies that specifically points out the ability of a normal person to function in a noisy environment. The descriptions of auditory synthesis and analysis are similiar to the PhR phenomenon. It is unfortunate that the descriptions of the tests used are not detailed enough to determine if PhRs could have occurred: however, it seems likely that the PhR is related to Karlin's AR factor.

Cherry and Wiley (1967) and Holloway (1970) judge the intelligibility of speech with strongly voiced components removed and either silent gaps or noise separating the remaining components. When noise was used, the signal had a greater intelligibility. Powers (1973) also reported increased intelligibility when noise was added to silent intervals of regularly interrupted speech. It seems plausible to believe that multiple PhRs are occurring in these situations and can account for the increased intelligibility.

Oller and Eilers (1975) discuss the implication of the PhR in a clinical setting. Both PhR and phonetic expectations can cause serious doubt as to the validity of transcriptions of taped language samples.

The literature related to the PhR can be summarized by the following statements:

1. The PhR response may be only one of several auditory resistance (AR) abilities.
2. There is a possibility that multiple PhR responses can

be elicited under appropriate circumstances.

3. There exists the possibility that the PhR response affects transcription validity.

Hypothesis

It will be assumed in this study that phonemic restorations are part of the normal process for adults that aids in veridical perception of speech sounds in noisy situations. It is hypothesized that PhRs occur for children. It is possible that factors such as maturity, health, educational background, socio-economic background, etc. could influence the PhR and cause a developmental progression; however, this study will not attempt to analyze the influence of these factors or to make definitive statements on exactly when and/or how the PhR process develops. An attempt will be made to assess whether or not PhR responses occur in nursery school children. If the data do indicate differential responding as a function of age, some tenative statements on when the PhR response first occurs and how it progresses will be proposed.

METHOD

Population

Twenty-six children, ranging in age from four years, zero months to five years, six months from Forsythe Nursery School at Fort Riley, Kansas participated in this study. All of the children were screened at 25 dB HL at .5, 1, 2, 4, and 8 KHz. All of the children passed this screening and were assumed to have normal hearing sensitivity.

Computer Program

The stimuli for this study were spoken sentences of a duration of two seconds or less. This speech was initially recorded on an analog tape recorder. It was then palyed back through a low pass filter and converted to digital form by an analog to digital converter as shown in Figure 1. The Nova minicomputer was programmed to sample these data at 9000 samples per second and simultaneously transfer it to a magnetic disk. With the speech signal stored on disk it was then possible to display all or part of the sentence on a CRT graphics terminal, modify the signal and then play it back out on a digital to analog converter. To eliminate frequency aliasing and other undesirable effects the low pass filter was set to cutoff at about 4000 Hz thus limiting the bandwidth of the signal to below 4500 Hz.

The main objective of the program was to replace a specific phoneme within a sentence by a noise signal, thereby eliminating any audible trace of the phoneme but without disturbing the rest of the signal. This was accomplished by first displaying the sentence on the CRT. The phoneme in question was located and a previously sampled noise signal was retrieved from disk and inserted in its place. Since in many cases it was found to be very hard to locate the exact position and extent of a consonant this took many trials until a satisfactory result was obtained.

To avoid transients the magnitude of the noise was linearly increased from zero to its full amplitude. Simul-

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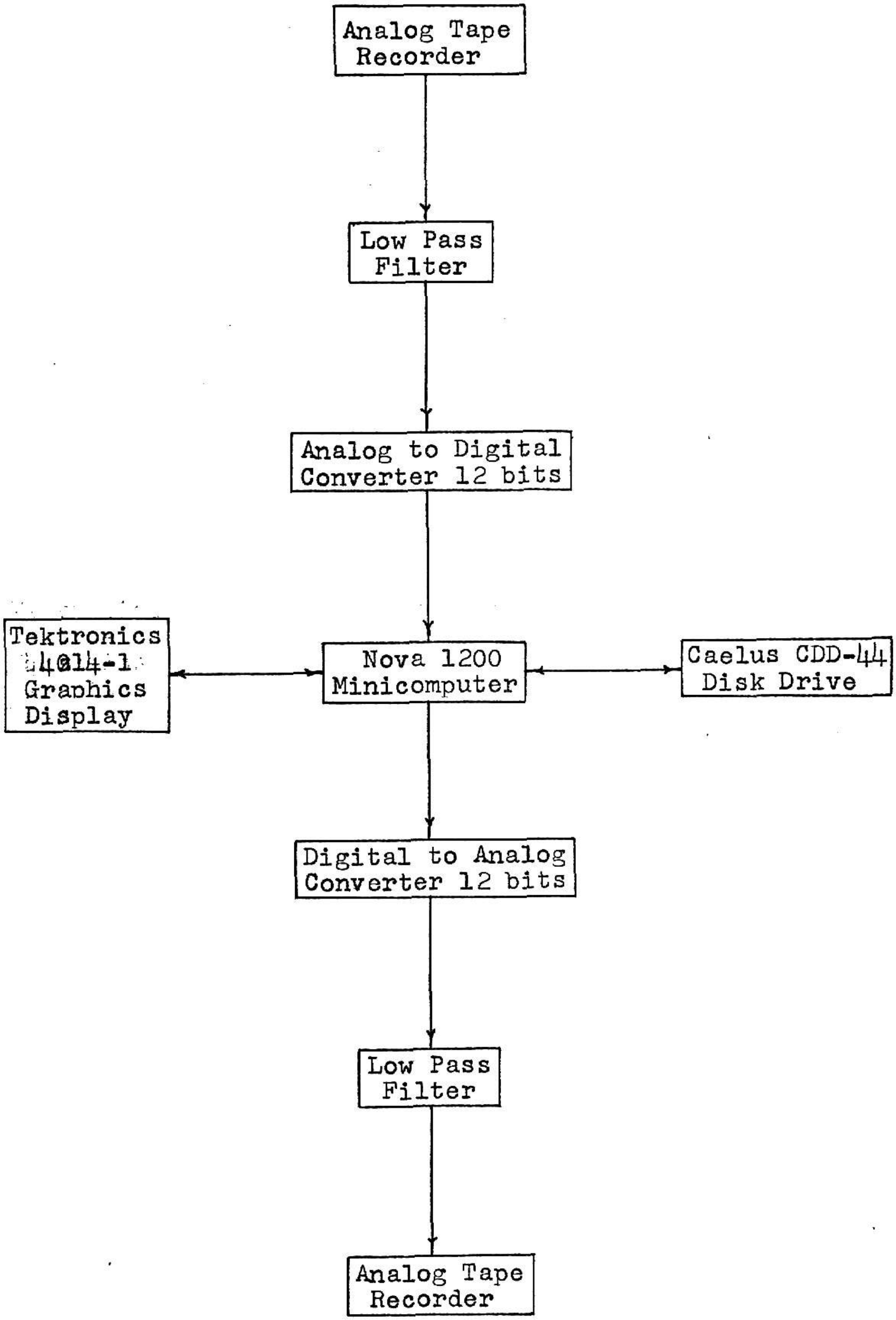

Figure 1. Block diagram of computer system.

taneously the original speech signal was linearly decreased to zero in the same manner. The trailing edge of the noise was treated in a similar fashion. The envelopes of the speech and the noise are depicted in Figure 2.

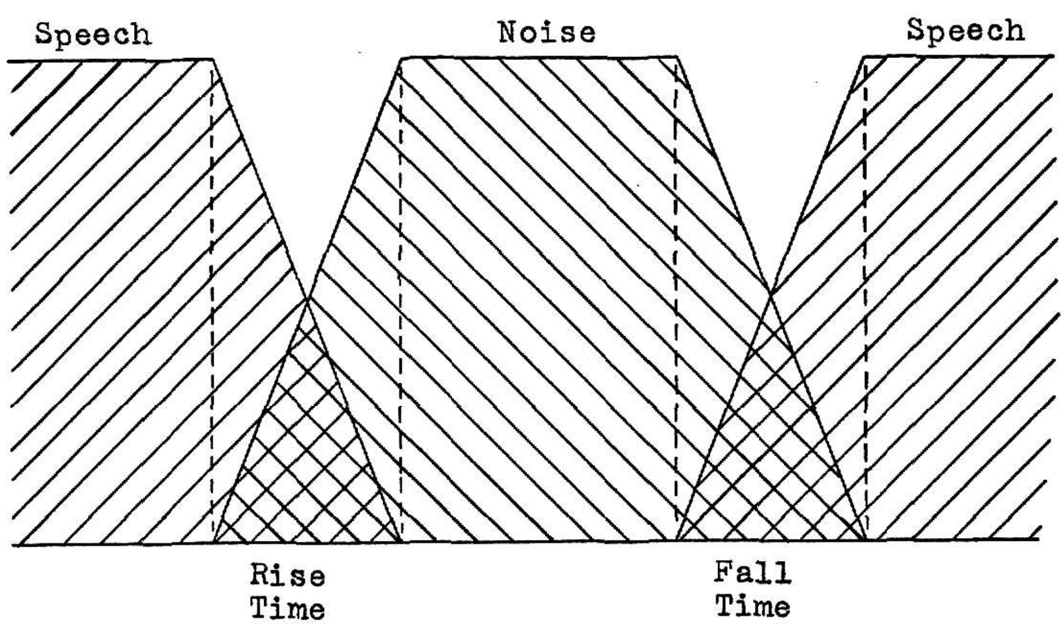

Figure 2. Diagram of envelopes of speech and noise in stimuli sentences.

The rise time and fall times were taken to be 10 msec. in all cases and the duration of the noise varied for each sentence. The specific duration of the noise for each sentence will be indicated later. The gradual mixing of the noise and speech eliminated the audible transient that was heard when a finite rise time was not used.

Since the output of the digital to analog converter is a steplike signal, this must be filtered to eliminate the upper harmonics produced. The cutoff of this low pass filter was experimentally chosen so as to produce the most natural sounding output.

Tape Preparation

All the sentences were taped in a quiet environment using a woman's voice on a Tandberg Cross Field, Series 9200XD tape recorder with a AKG D-1000E microphone. Four sentences were taped, one control and three test. All the sentences were limited to 4-5 words. Simple sentence structures were used to ensure that young children would be able to repeat the sentences. The computer program was utilized to delete the desired portions of the test sentences and replace the deletion with a sample of cafeteria noise. The phoneme that was to be deleted was purposefully mispronounced so that coarticulation cues would not be available to aid in the perception of the deleted phoneme. All signal to noise ratios were 0-5 dB. The sentences and the duration of the deleted portion for each one are listed below:

Control: "He has a big nose."

Test Sentence 1: "I had a birth(m/d)ay party." Deleted portion was 178.0 msec.

Test Sentence 2: "The night was (m/d)ark." Deleted portion was 154.6 msec.

Test Sentence 3: "I get toys on Chri(v/s)tmas." Deleted portion was 155.0 msec.

The speech wave form of each of the above sentences can be found in Appendix 1.

For communicative simplicity, the test sentences will hereafter be designated as follows:

Test Sentence 1: Sent. 1 "birthday"

Test Sentence 2: Sent. 2 "dark"

Test Sentence 3: Sent. 3 "Christmas"

Procedures

The hearing of the subjects was screened prior to listening to the test tape. The following instructions were read to the subjects and any questions were answered before earphones were placed in position: "I am going to put these earphones on your head. You will hear a lady's voice. I want you to tell me what the lady says. If the lady says, 'We saw a boy,' you would say the same thing, 'We saw a boy.' Let's try it. I'll say a sentence and you say the same thing. 'The dog sat down.' (Wait for response.)"

The sentences were presented through Sennheiser HD-424 earphones from a Tandberg Cross Field, Series 9200XD tape recorder in a quiet environment. If the subjects repeated the control sentence, the test sentences were presented. If the control sentence was not responded to correctly, the directions and control sentence were repeated up to three times. If the control was still not repeated, it was assumed that the task was too difficult for the child. All the subjects in this study were able to perform the task.

In judging the correctness of the response, the following guidelines were used:

1. The word containing the deleted phoneme must have been repeated.
2. The other words in the sentence could have been missed (not repeated exactly) or omitted.
3. Articulation errors were disregarded.

RESULTS AND DISCUSSION

All twenty-six subjects were able to perform the task of repeating the sentences. The results indicated that the three sentences used as test stimuli were qualitatively different. Sent. 1 "birthday" and Sent. 3 "Christmas" contain a very strong context effect with the PhR occurring within the word. Sent. 2 "dark" had some context present, but it was a weaker context than the other test sentences. The main reason for the difference was the position in the word of the deletion; Sent. 1 "birthday" and Sent. 3 "Christmas" had deletions in the medial position while Sent. 2

"dark" had the deletion in the initial position. The sentence context for Sent. 2 "dark" may have been weaker than the other sentences but it is difficult to make a judgment about relative strengths of sentence contexts. The results will be discussed in light of the context effect.

For the sentences with a strong context effect, virtually all responses showed a PhR that was correct based upon context. (See Table 1) This indicates that the PhR response does occur in four and five year old children at least when there is a strong context.

Table 1 also shows the results obtained on Sent. 2 "dark", the sentence with the weaker context. The correct PhR based on context (dark) only occurred for 27 per cent of the children. "Park" or "parked" was the most prevalent response with 30 per cent of the children reporting this PhR. The other responses were scattered among several other responses. Twenty-three per cent reported words that ended with "ork" rather than "ark." One child reported simply "ark," thus indicating that no PhR had occurred. Since the correct PhR based upon context did occur for some children, it was assumed that results were not a function of the tape's preparation (i.e. the deletion and replacement with noise was appropriate). Rather it seems that the results indicate that the children did not adequately use the contextual information available in the PhR response.

Age	Control Sentence	Sent. 1 "Birthday"	Sent. 2 "dark"	Sent. 3 "Christmas"
4:0	C	C	park	C
4:2	C	C	C	NR
4:2	C	C	work	C
4:2	C	C	klark	C
4:4	C	C	parked	C
4:5	C	C	NR	C
4:5	C	C	work	C
4:7	C	C	ark	C
4:7	C	C	nork	C
4:8	C	C	C	C
4:10	C	C	park	C
4:11	C	C	pork	C
4:11	C	C	C	C
4:11	C	C	C	C
5:0	C	C	C	C
5:0	C	C	C	C
5:0	C	C	park	C
5:2	C	C	NR	C
5:2	C	C	C	C
5:2	C	C	worked	C
5:2	C	C	park	C
5:3	C	C	bark	C
5:4	C	C	park	C
5:4	C	C	parked	C
5:5	C	C	park	C
5:5	C	C	work	C

Key: C-Correct PhR based upon context.
NR-No response.

Table 1. Responses of Ss to control and test sentences, arranged chronologically.

It is interesting to note that out of 78 responses to all the sentences, only four responses showed no PhR. Of course, not all the responses were correct based upon context, but the overwhelming occurrence of the PhR points to the importance and prevalance of the PhR in auditory perception of speech.

The results were analyzed to determine if differential responding occurred as a function of age. Sent. 1 "birthday" and Sent. 3 "Christmas" could provide no information for this since virtually all the children responded correctly on these sentences. Table 1 shows the responses to Sent. 2 "dark" as a function of age. The results do not indicate any consistent dependency on age. The population was so small that no statistical tests could practically be applied. It is possible that if more information was available on the subjects, such as mental age, maturity, health, educational background, etc. the results would show differential responding.

The results can be summarized as follows:

1. The PhR response does occur in four and five year old children.

2. Contextual influences are apparent in the results.

3. The overwhelming occurrence of the PhR, disregarding correctness based on context, indicates the importance and prevalance of the PhR as a mechanism that aids in auditory perception of speech.

4. On the basis of the population studied, it is impossible to indicate whether or not there is any differential responding as a function of age. Further investigations are currently being carried out to clarify this.

The present study had as one of its goals to create a foundation upon which further work on the PhR phenomenon with children could be based. The study has established that the PhR does occur in four and five year old children, and that responses are dependent to some degree on the contextual effects of the sentence. On the basis of these results and other information concerning the PhR, some suggestions for further research can be made.

The computer preparation was adequate for the tape preparation. Changing the printout to a spectrograph form, rather than amplitude vs. time, would facilitate location of the points to be deleted and replaced with noise. The program is presently being modified so that the sampling of the speech occurs at a higher rate than 9000 time per second, thus raising the cutoff of frequencies sampled effectively.

One area that warrants further study is the context effect. A method of grading the strength of the context of a sentence should be developed so that responses could be examined as a function of the context effect.

The population sample studied was too small to determine if responses varied as a function of age. A larger sampling of four and five year olds could indicate some differences within these age groups. Extension of the sampling up to ten years of age could also result in significant differences in responding as a function of age. Obtaining information on mental age, maturity, educational background, etc., could also indicate differential responding.

Once the effects of context, age, and any other factors of interest are explored more fully it would be of interest to compare the results with traditional speech-in-noise tasks; i.e. discrimination of phonetically-balanced words in noise.

It is possible that multiple PhRs can occur within sentences. This possibility could be explored in detail to determine if an increased number of PhRs is a more difficult task and/or if it discriminates between groups or age levels more effectively than a single PhR.

Examination of responses to PhR tasks by children with some type of disability would also be of interest. It is possible that learning disabled children, poor readers, poor spellers, children with articulation problems, etc. would respond in quantitatively and/or qualitatively different ways. If differences are found it is possible that an auditory perceptual test would be developed that would aid in differentiating these children and also point to a specific skill that would require remediation.

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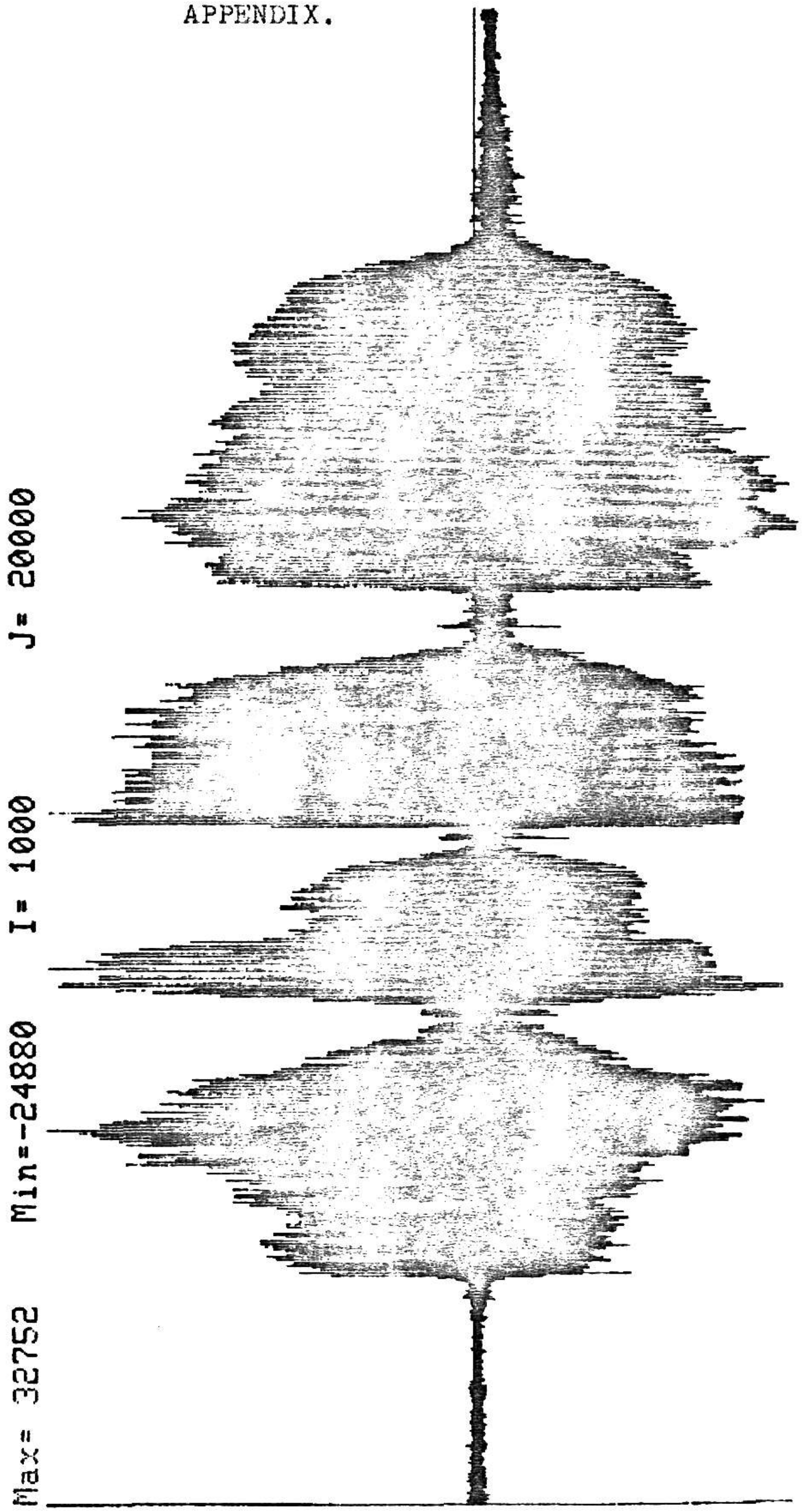
APPENDIX.

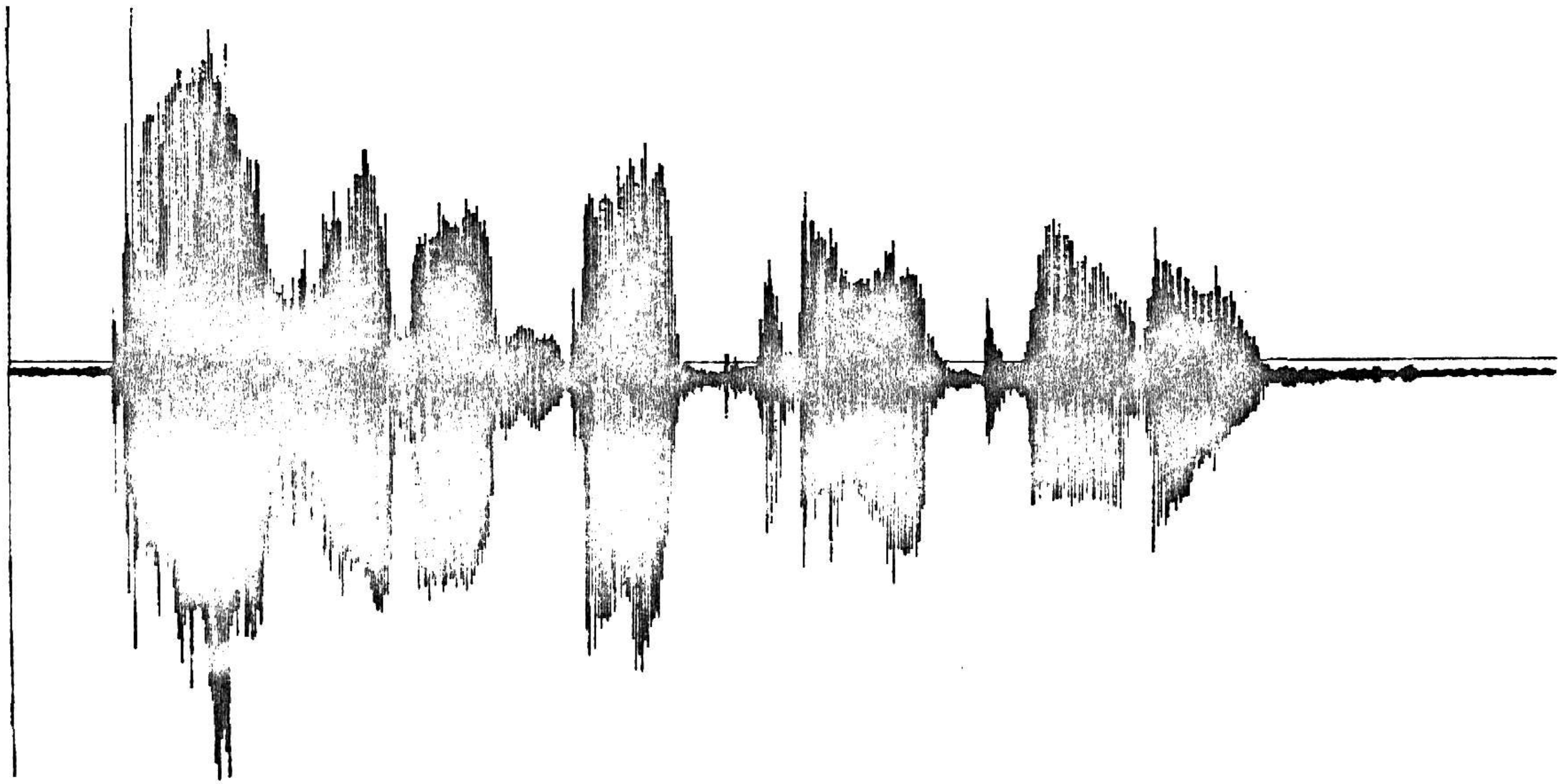
FIGURE 3: Computer output of control sentence,
"He has a big nose."



SENT14

FIGURE 4: Computer output of test sentence 1, without noise, "I had a birthmay party."

Max= 23536 Min=-27920 I= 1000 J= 20000



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*SEU
COMMAND ERROR
*SENT14 NOISE
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FIGURE 5: Computer output of test sentence 1, with noise, "I had a birth*ay party."

Max= 23536   Min=-29776   I= 1000   J= 20000

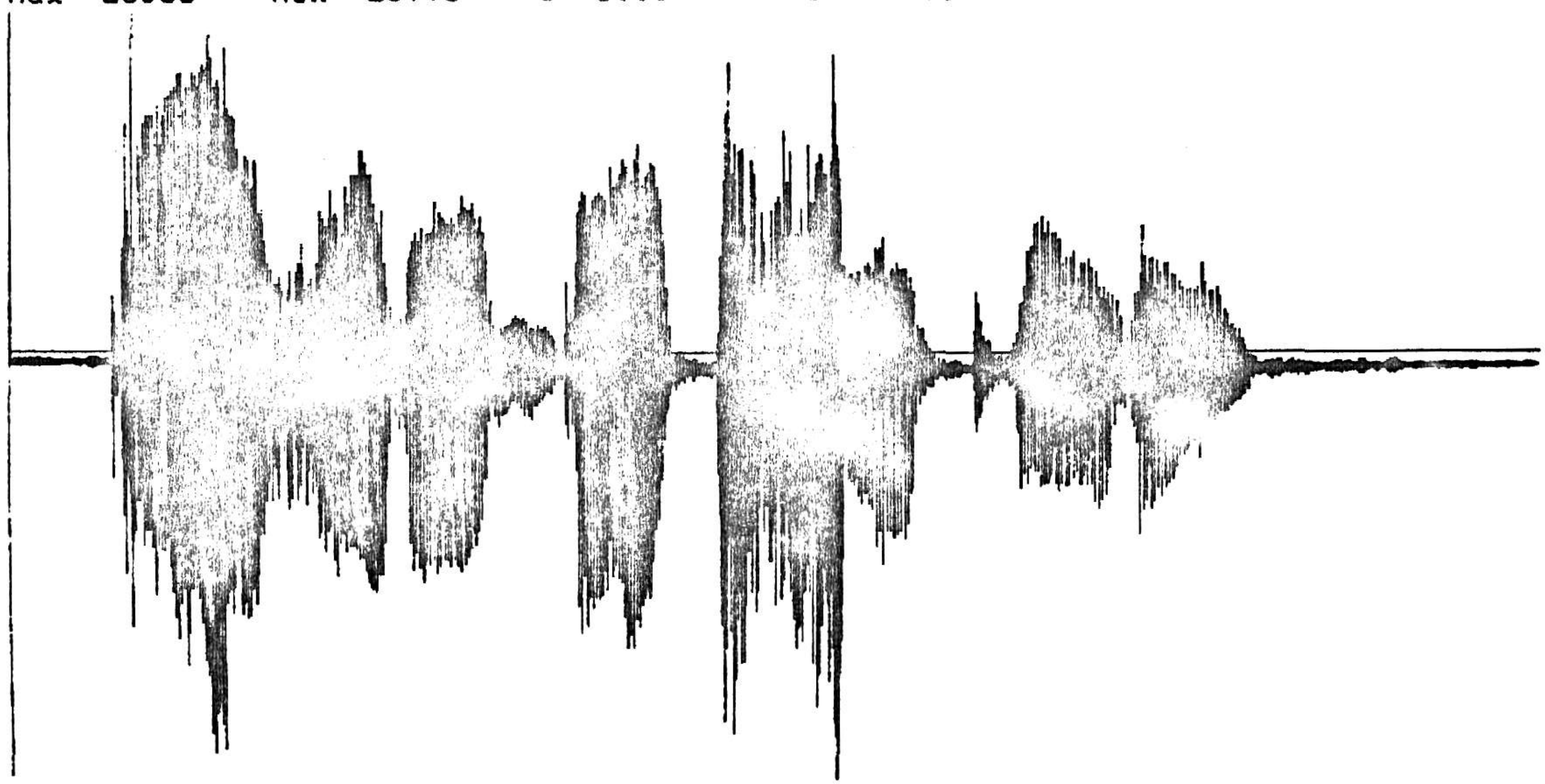


FIGURE 6: Computer output of test sentence 2, without noise, "The night was mark."

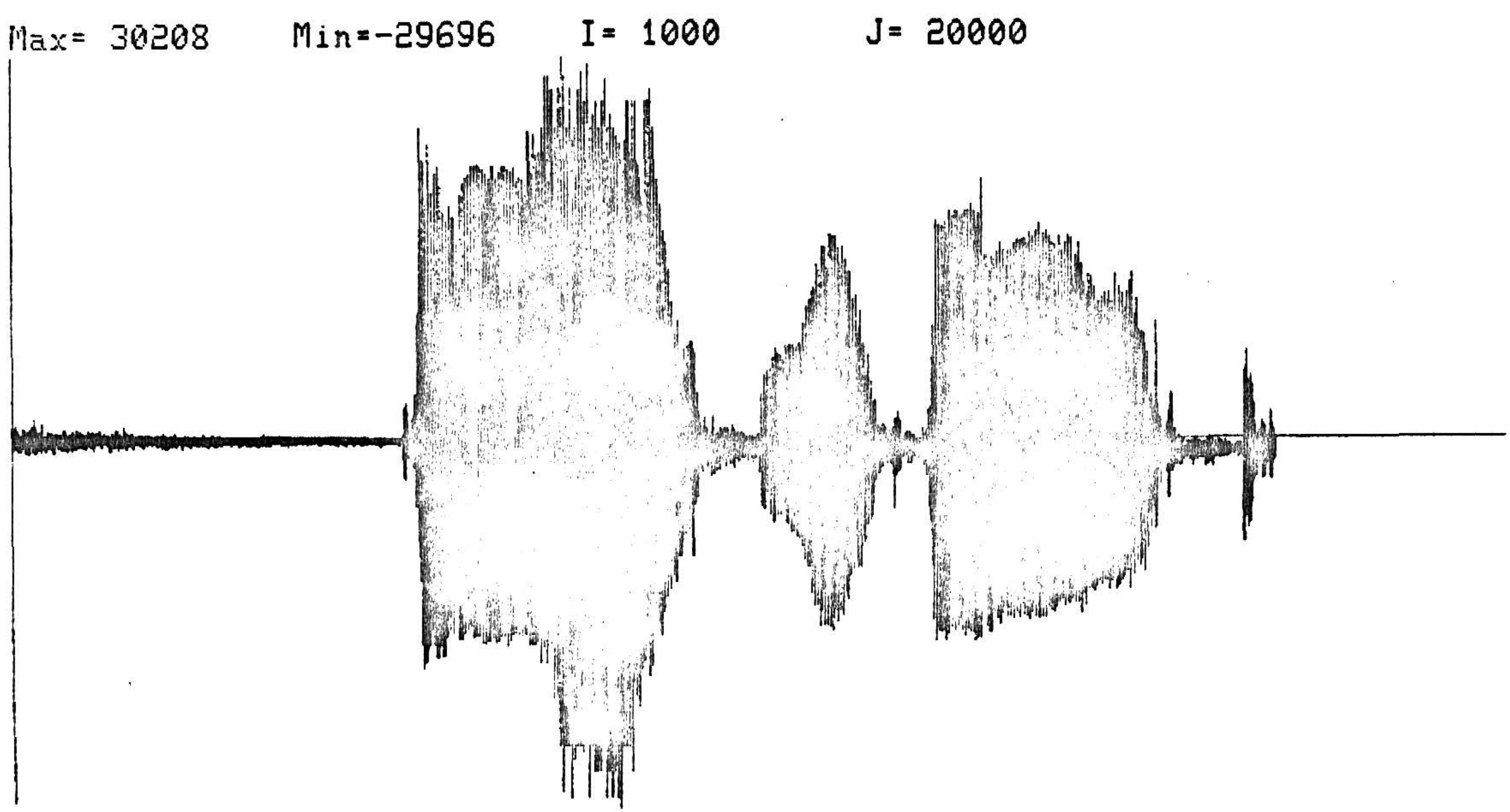


FIGURE 7: Computer output of test sentence 2, with noise, "The night was *ark."

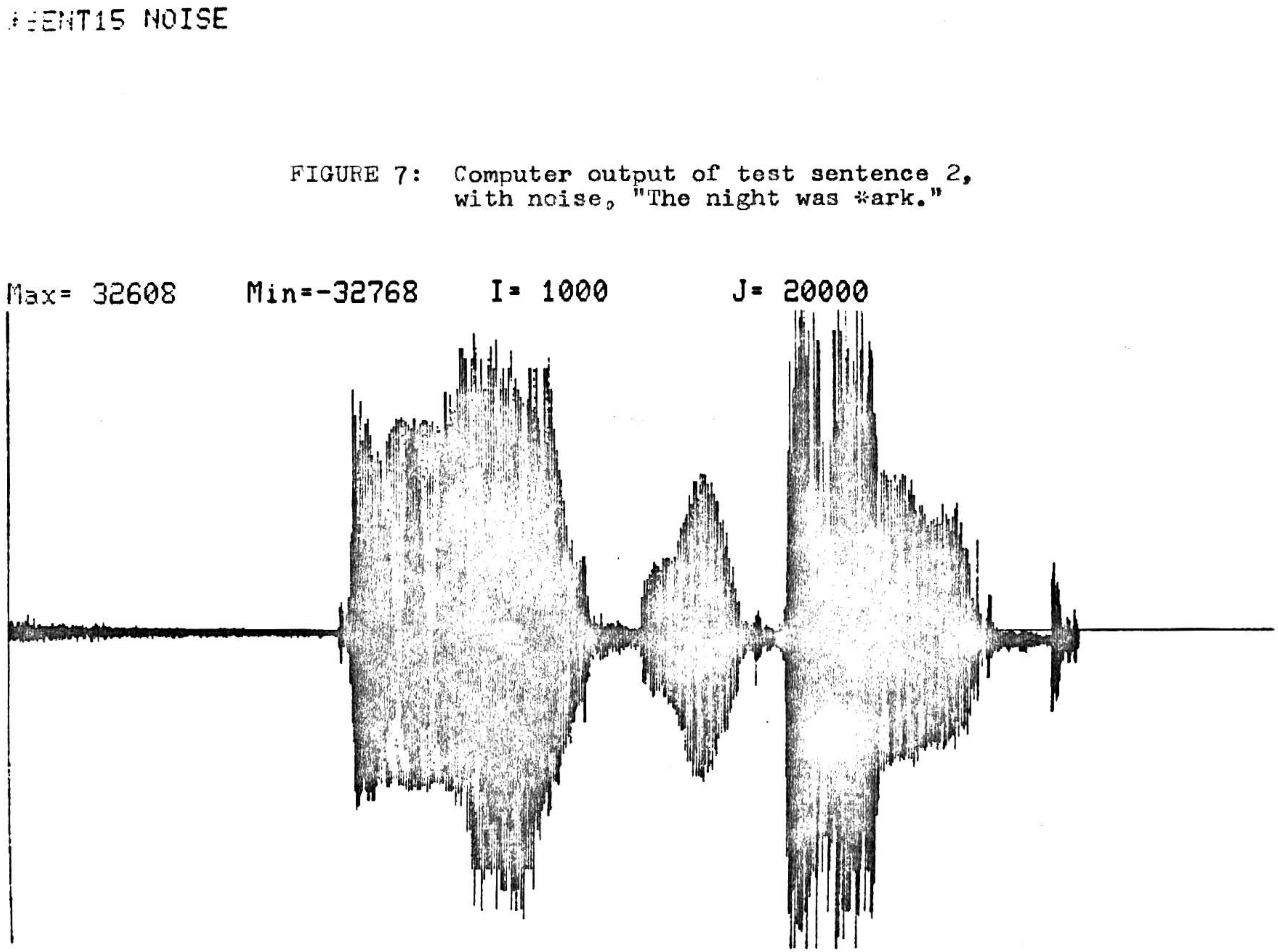


FIGURE 8: Computer output of test sentence 3, without noise, "I get toys on Chrivmas."

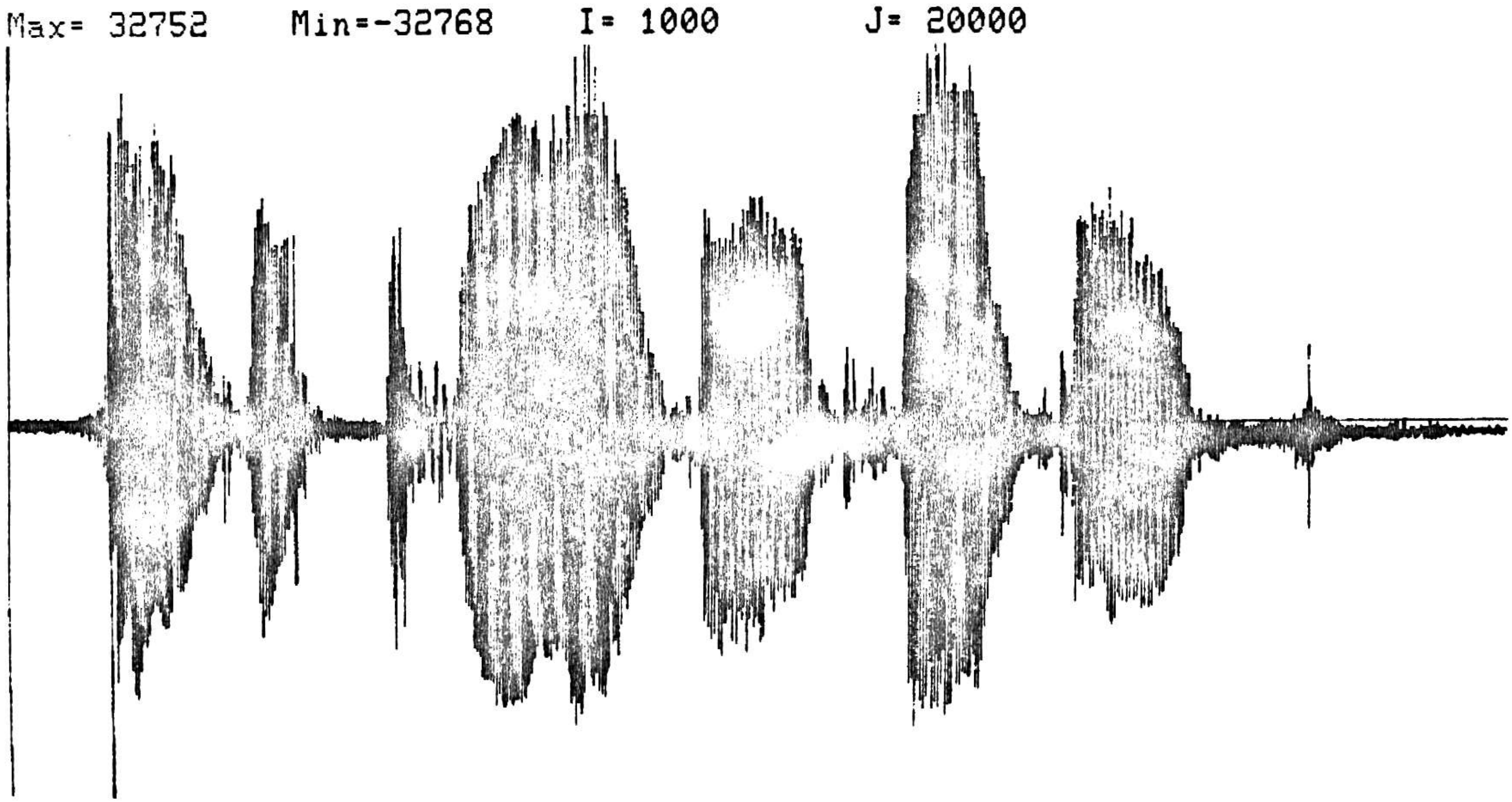
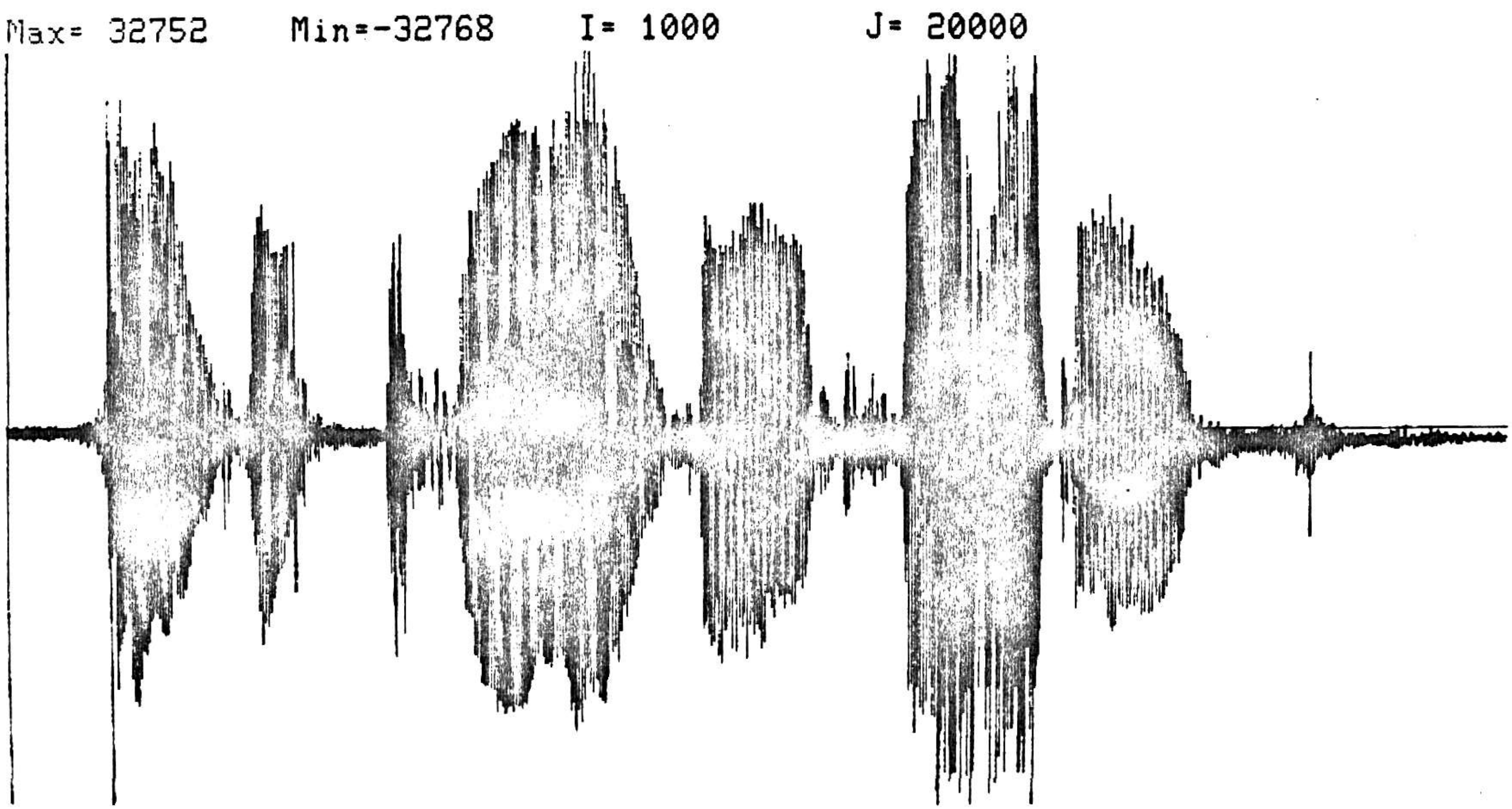


FIGURE 9: Computer output of test sentence 3, with noise, "I get toys on Chri*mas."



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1976

ABSTRACT

When a speech sound is removed from a sentence and replaced with a noise, the missing speech sound is perceived as being present. This effect is called phonemic restoration (PhR). This phenomenon is a normal perceptual mechanism that allows veridical perception of speech in noisy situations. This study has examined the responses of twenty-six nursery school children, ages four to five to PhR tasks. The stimuli consisted of three test sentences and one control sentence that were prepared by a computer program that sampled the speech wave form and converted it to a digital form. The program then allowed location of and removal of one specific phoneme. After the phoneme was removed the gap was replaced with a noise. The task was to repeat the sentences.

The results showed a qualitative difference in the sentences. The two sentences with a strong context effect produced virtually all correct responses based upon context. The sentence with a weaker context produced only 27 per cent correct responses based upon context.

PhR responses occurred in 95 per cent of all responses, although not all the PhRs were correct based upon context. This points to the prevalance and importance of the PhR in the auditory perception of speech. Examination of responses for differential responding due to age revealed no

consistent trends. This is probably attributable to the statistically small population used in this study.

Areas pointed out as needing further research include the effect of context, effect of age in a larger population, relationship of PhR to traditional speech-in-noise tasks, effects of educational background, maturity, etc., and responses to PhR tasks by children with some type handicap or disability.