Author: Philip M. Corsi

Short Title: The Effects of Contralateral Noise upon Verbal Perception

The Effects of Contralateral Noise upon the Perception and Immediate Recall of Monaurally-Presented Verbal Material

Philip M. Corsi
Psychology M.A.
4 August 1967

I would like to thank P. A. Corsi for his assistance in the preparation of tape-recorded materials and J. Dudley for his technical advice.

Author: Philip M. Corsi

Title: The Effects of Contralateral Noise upon the Perception and Immediate Recall of Monaurally-Presented Verbal Material

Department: Psychology

Degree: M.A.

Stimulus conditions necessary for the observation of laterality effects in the perception and recall of verbal stimuli were investigated. Recorded material for three auditory tests was delivered monaurally to 24 female subjects. In the experimental condition of each task, noise was simultaneously channeled to the ear opposite the one receiving a relevant signal; in the control condition noise was absent. Contralateral noise as competing input impaired overall performance on all tests. For the two tasks involving the perception and immediate recall of digit sequences, a right-ear advantage was observed with noise present. Differential ear effects were not obtained for any of the tasks with noise absent. Possible mechanisms underlying these findings are discussed. It is concluded that binaural rivalry is required to detect a right-ear effect and that this laterality effect becomes more probable as the competing input becomes more homologous to the relevant verbal message.

Table of Contents

Studies by Kimura (1961a; 1961b) have shown that when different verbal stimuli are presented simultaneously to the two ears, more accurate or efficient report is obtained from the ear which is contralateral to the dominant hemisphere for speech. Thus, when different digits reach each ear at the same time, normal subjects correctly report more digits from the right ear than from the left. Subsequent investigations have confirmed and extended the generality of this finding. Using dichotic listening tests with large groups of normal subjects, Bryden (1963) and Satz, Achenbach, Pattishall, & Fennel (1965) have verified the right-ear superiority for competing digit series and have further demonstrated this ear effect after the report order of digits from the right and left ears was properly controlled. Moreover, Broadbent and Gregory (1964) have found that the right-ear effect holds not only for the recall of dichotically-presented digits, but also for the multiple-choice recognition of digits. Results similar to those cited above have been obtained when filtered, phonetically-balanced (PB) words (Dirks, 1963), balanced nonsense "words" (Curry, 1966), and nonsense syllables (Kimura, 1967) were utilized instead of digits. Furthermore, Shankweiler and Studdert-Kennedy (1967) have recently observed laterality effects at the level of speech sound structure. These investigators have noted a significant right-ear advantage for the identification of stop consonants embedded in single pairs of synthetic consonant syllables (CV) which were dichotically channeled to the right-handed subjects. Taken together, these dichotic studies indicate that normal listeners are more successful in recognizing and recalling verbal stimuli presented to the right ear, which is the ear contralateral to the cerebral hemisphere dominant for language in most right-handed persons. From clinical observation, it has been established that for the great majority of right-handed people verbal activities are predominantly mediated by the left hemisphere (Milner, 1958 and 1967; Milner, Branch and Rasmussen, 1964 and 1966; Penfield and Roberts, 1959; Russell and Espir, 1961).

On the other hand, studies involving the monaural presentation of verbal stimuli to normal listeners have failed to provide conclusive or even consistent evidence for a functional asymmetry in the auditory system. Several workers, some of whom have only incidentally been concerned with perceptual differences between the two ears, have reported separate speech-reception thresholds (spondee words) for the right and left ears. In a comprehensive audiometric survey, Glorig et al. (1954) found significantly lower right-ear thresholds for speech, particularly among adult males. In contrast, Corso (1957) has reported slightly lower left-ear thresholds for speech reception in a mixed group of adult subjects. Still other workers have found little or no disparity between right and left-ear thresholds (Jerger, Carhart, Tillman and Peterson, 1959). Most recently, Palmer (1964) has employed such threshold comparisons in an attempt to analyze the influence of cerebral dominance upon the relative efficiency of the two ears. Palmer's study of male undergraduates revealed lower mean right-ear thresholds than mean left-ear thresholds for the reception of spondaic words in this group, but the difference between ears was minimal and not statistically significant. Investigators using verbal materials presented monaurally at normal conversational levels have found no significant differences between mean scores for the right and left ears (Dirks, 1964; Curry, 1966). The same result was obtained when interrupted or filtered speech was employed with normal subjects (Calearo and Antonelli, 1963).

It is apparent from the research cited thus far that an asymmetry between ears has been consistently observed only under dichotic listening conditions, and has not been evident when subjects attended to only one ear at a time. On the basis of neurophysiological and clinical evidence, Kimura (1961a; 1961b; 1967) has offered hypotheses to account for these behavioral findings. In brief, it has been suggested that the right-ear superiority for dichotically-presented verbal stimuli is a consequence of the dominant role taken by the left hemisphere in the perception of speech as well as the greater efficiency of the crossed auditory pathways when compared with the uncrossed pathways. Furthermore, in Kimura's view, some form of competition between pathways ipsilateral and contralateral to the hemisphere dominant for speech is necessary in order to demonstrate an asymmetry in the auditory system for the reception of verbal material. With interaural rivalry between the ascending auditory connections, it is assumed that at points of overlap between the contralateral and ipsilateral pathways impulses passing along the crossed paths tend to occlude impulses arriving along the uncrossed paths. Likewise, at the cortical level, it is presumed that the contralateral input is further augmented over the ipsilateral input through central competition.

Electrophysiological studies of cat and dog provide supporting evidence for this position. Although both cochleae are represented in each cortical projection area, it has been found that unilateral cochlear stimulation evokes responses of higher amplitude in the contralateral than in the ipsilateral cortex (Bremer and

Dow, 1939; Tunturi, 1946; Rosenzweig, 1951). In particular, Rosenzweig (1951) has taken these findings to indicate that more cortical units in each hemisphere are fired by contralateral stimulation than by ipsilateral, and that in those units which fire to both contralateral and ipsilateral stimulation, the crossed input occludes the uncrossed. Additional, though less direct, evidence for the greater effectiveness of the crossed connections comes from investigations of unilateral temporal-lobe dysfunction in man. Bocca and his coworkers (1955), studying patients with temporal-lobe tumors, have demonstrated that recognition of distorted words and accelerated speech is significantly impaired in the ear contralateral to the tumor. Sinha (1959) has shown a contralateral ear deficit when words masked in white noise were monaurally presented to patients who had undergone unilateral temporal-lobe removals. Impairments in performance for the ear opposite a lesion of the auditory cortex also have been found by Jerger and Mier (1960) when irrelevant speech was delivered to the ipsilateral ear. The research of Kimura (1961a; 1961b) has revealed that unilateral temporal lobectomy on either side produces a deficit in the recognition of dichotically-presented digits arriving at the ear contralateral to the removal. It should be further noted that impairment of overall performance, independent of the ear to which stimuli were channeled, was greatest when damage occured to the temporal lobe dominant for language. Further evidence for the greater strength of the crossed pathways comes from a recent study of patients with surgical disconnection of the cerebral hemispheres (midline section of the corpus callosum, anterior commissure, and hippocampal commissure). It has been observed (Milner, Personal communication) that these patients show a very marked right-ear effect for Kimura's (1961a) dichotic digits task. In fact, under dichotic conditions, they frequently denied hearing any signal in the left ear and only reported the right-ear input, whereas, with monaural presentation, accurate report was obtained from both the left and right ears. These findings, coupled with the analysis of the effects of unilateral cortical lesions, indicate that in man the crossed auditory connections from ear to cortex are functionally more efficient than the uncrossed.

The studies reviewed earlier suggest that at least some minimal amount of competing input in the auditory system is necessary for the appearance of ear differences in the perception of verbal material. However, questions concerning the nature of the stimulus parameters prerequisite for the observation of differential ear effects to date have received little research attention. For example, with verbal tasks is it necessary that the competing input be meaningful speech or at least some form of patterned auditory stimulation? Or, would random noise channeled to the ear contralateral to the one receiving a simultaneous and relevant verbal signal do just as well? Right-ear superiority has been noted when normal listeners, under dichotic conditions, were instructed to attend to and report the verbal stimuli from one ear only (Kimura, 1967; Dirks, 1964). In this case the verbal signals delivered to the other ear were "irrelevant", but they were, nevertheless, effective in producing the observed auditory asymmetry.

The objective of the present research was to investigate further the stimulus conditions necessary for the detection of a difference between ears in the perception of verbal material. More specifically, the effects of contralateral noise (i.e., narrow-band noise delivered to one ear coincident with the delivery of a relevant verbal signal to the other ear) upon the perception and immediate recall of spoken material were analysed. If at least some degree of binaural rivalry is required for the appearance of functional asymmetries in the auditory system, then, on the basis of past research, it was expected that verbal stimuli delivered to the ear opposite the dominant hemisphere for speech would be more often correctly identified and immediately recalled than stimuli channeled to the same side. On the other hand, this differential effect was not anticipated under strictly monaural conditions (i.e., no noise in the channel contralateral to the relevant signal).

Method

Three auditory tasks were presented to each subject. These tasks will be described in detail below. The general experimental paradigm was identical for all three tests and is represented in Figure I. Tape-recorded verbal material for each task was delivered monaurally and in randomized order to the right and left ears through stereophonic earphones. In the experimental condition of each test, narrow-band noise within speech frequencies was simultaneously delivered to the ear opposite the one receiving the relevant verbal signal. In the control condition, noise was absent in the contralateral ear. Observations were made on every subject in the sample under all the noise-ear treatment conditions, and, thus, subjects served as their own controls.

Subjects

The subjects for this study were 24 female student and postgraduate nurses, ages 19-33 (mean age 24.5). Volunteers were not accepted as subjects if they perceived their hearing as other than "normal" or if they reported ever having a punctured eardrum, a "running ear", serious infection of the inner ear or specialized medical attention for an ear ailment. Furthermore, only right-handed persons were accepted as subjects in order to minimize the probability of right-sided speech representation (Milner, Branch and Rasmussen,1966). This determination was made on the basis of what they considered their handedness to be, as well as their reported hand usage in writing, eating, combing hair and cutting with scissors. Each subject had a memory span of at least six digits.

Apparatus

The test material was recorded on magnetic tape ($7\frac{1}{2}$" per second) through the use of a Tandberg (Model 6) dual-channel tape recorder and a Shure crystal microphone (Model 777S-X). Narrow-band noise (range 180 to 320 CPS, centered at 250 CPS) was transferred to tape from a Rudmore Diagnostic Audiometer (Model ARJ-R). The Tandberg tape recorder and a Koss Stereophone Headset (Model PRO-4) were utilized to present the test stimuli to the subject.

Materials and Procedure

The tasks described below were administered to each subject individually, in a single, one-hour testing session. All of the experimental tests were carried out in a small, quiet room. In order to counter-balance against the possibility of inequality between earphones, channel recordings, and test materials, a procedure was followed whereby earphones were reversed for one-half of the sample. As a result of this procedure, material in one channel was delivered to the left ear of half the subjects, while the others heard the same material in the right ear.

Plosive Discrimination Test. This task is similar to one designed by Stitt (1961). The subject was required to identify a stop consonant (P,B,T,D,K, or G) embedded in a two-syllable nonsense "word". The first syllable consisted of the vowel /a/ followed by one of the six consonant phonemes noted above and the second syllable was composed of a specified nasal, fricative, or sibilant consonant phoneme followed by the vowel /a/. The nonsense words were presented in groups of 24 trials with a three-second interval between words. For each group, the second syllable was invariant, but the stop consonant in the first syllable was variable. Subjects were instructed as follows:

> You will now hear some nonsense words in one ear or the other. Each word will begin with the sound /a/, then the sound of one of these six letters (P,B,T,D,K,G - printed on a card and given to the subject) and, finally the sound /ma/. For example, you might hear /AGMA/. In each case I want you to tell me which of the six letters you heard between the /a/ sound and the /ma/ sound. Sometimes you will hear noise in one ear and nonsense words in the other.

Each one of the six stop consonants was delivered twice to the right and left ears in a randomized series of 24 trials. Altogether 60 presentations of nonsense words (12 presentations with the second syllable ending /ma/, 12 with /na/, 12 with /sa/, 24 with /tha/) were made to each ear under the experimental (noise to the contralateral ear) and control conditions. The experimental and control conditions alternated every 24 trials, with half the subjects receiving the experimental treatment first and the other half receiving the control first. The intensity level at which subjects heard the nonsense words was approximately 40 dB SPL (Re. 0.0002 dynes/cm^2). In the experimental condition, the level of the contralateral noise was 50 dB SPL. The onset and termination of the noise was simultaneous (within 10 milliseconds) with the spoken duration of each nonsense word.

Digit Recognition Test. In this test, six or eight digits were presented two at a time (in two different voices of similar intonation) to the same ear. Therefore, each presentation consisted of three pairs of six digits or four pairs of eight digits separated by intervals of one second. After each series of six or eight numbers (one trial), the subject reported all the numbers she heard in any order she desired. Ten groups of six digits and five groups of eight digits were randomly delivered to either the left or right ear. These combined for a total possible score of 100 for each ear under the experimental and control conditions. Experimental and control treatments alternated every ten trials, with the experimental condition preceding the control condition for one-half of the subjects (and vice-versa for the remaining one-half). The intensity level of verbal material was approximately 55 dB SPL (Re. 0.0002 dynes/cm^2) for this test. In the experimental condition, the level of narrow-band noise channeled to the contralateral ear was 65 dB SPL. The onset and termination of the noise was simultaneous (within 10 milliseconds) ~~of~~ WITH the onset and termination of each digit group. In this way, noise covered all the digits and also the intervals between digits for each trial.

Digit Span Test. For this task the subject heard a series of digits (6 to 10) channeled to one ear or the other at the rate of one digit per second. At the completion of each series (one trial), the subject was required to repeat the digits in exactly the same order that they were heard (digit span). A total of 15 trials were conducted under each noise-ear treatment condition with three observations being made at each digit-span length (i.e., a six-digit number was presented three times, a seven-digit number three times, etc.). Digit series of varying lengths were randomized and randomly channeled to the right and left ears. Experimental and control treatments alternated every 15 trials. The maximum score possible for each ear was 120, this being the total number of digits arriving at each ear during the test. The intensity levels of the verbal material and the contralateral noise were the same as those described for the Digit Recognition test (approximately 55 dB SPL for digits and 65 dB SPL for noise). In the experimental condition, noise began in one ear within 10 milliseconds of the delivery of the first digit in the series to the other ear and terminated within 10 milliseconds after the arrival of the last digit in the series.

Upon completion of the Digit Span test, all subjects were presented with a brief "shadowing" test. Series of digits (from 6 to 10) were channeled to one ear (at approximately 55 dB SPL) with noise in the contralateral ear (65 dB SPL) as above. A total of six numbers were delivered to each ear, one number at each digit length. In this situation, subjects were simply instructed to repeat each digit immediately after they heard it. Digits were presented at the rate of one per second.

Data Treatment

For the Plosive Discrimination test, recognition errors were tallied to provide a separate error score for each subject under each treatment condition. In the two digit tests, the total number of digits correctly reported (in any order) by each subject from each ear for the experimental and control treatments was calculated. In addition, for the Digit Span test, a score which reflected memory span under each ear-noise condition was computed. The score was the sum of the digit series which were reported in correct or nearly correct order. (If a subject made one omission error, one commission error or one serial-order error in a particular series, then one credit was subtracted from the total possible score for that series - e.g., if the series "5862719" was presented and the subject reported "5862_19" or "5862419" or "58672219", then a score of six, instead of seven, was assigned for that trial.)

The data for each of the tests were submitted to a three-way analysis of variance (ear treatment X noise treatment X subjects) and, where appropriate, individual means across subjects were compared through the use of t tests for correlated samples.

Results

A three-way analysis of variance of recognition error-scores for the plosive discrimination task (Table I) yields a significant F ratio ($F = 5.72$, $p < .05$) for the contralateral noise treatment; however, no other sources of variation approach significance. Table II presents the mean error-scores for the left and right ears under the control and experimental conditions. As evident from the table, the only significant difference between these means ($t = 2.08$, $p < .05$) occurs for the right ear between the experimental and control treatments (i.e., recognition of stop consonants is poorer for the right ear with noise present in the contralateral ear than with noise absent). It should be noted that the same comparison of cell means for the left ear ($t = 1.69$, $p < .10$) approaches an acceptable level of significance.

For the digit recognition task, an analysis of variance of the number of digits correctly reported Table III) reveals substantial variation across both the ear treatment ($F = 14.42$, $p < .001$) and the noise treatment ($F = 25.31$, $p < .001$). Furthermore, a significant interaction effect between these two sources is apparent ($F = 10.32$, $p < .01$). An inspection of the mean number of digits correctly reported under the various treatment conditions (Table IV) indicates no difference between ears when noise is absent, but a large difference when noise is present in the contralateral ear ($t = 4.64$, $p < .001$) with significantly more digits reported from the right ear than from the left. In fact, the mean number of digits reported from the left ear with noise simultaneously presented to the right is significantly below all other treatment means. No difference is observed between mean scores for the right ear under the experimental and control conditions.

Both sets of scores for the digit-span task were subjected to a three-way analysis of variance. Table V indicates the sources of variation for the number of digits accurately reported without respect to order. From this analysis, it is evident that both the ear and contralateral noise treatments produced significant effects upon performance. For the ear effect, the F value is 18.15 ($p < .001$) and for the noise effect it is 71.88 ($p < .001$). A comparison of cell means across subjects (Table VI) once again reveals no difference between ears in the control condition ($t = 1.11$, NS), but significantly superior report from the right ear under the experimental condition ($t = 4.12$, $p < .001$). Both the left-ear and right-ear scores with contralateral noise present were significantly lower than those obtained in the control situation. The t value for the left-ear comparison is 7.65 ($p < .001$), and for the right-ear comparison, 3.59 ($p < .005$). An analysis of variance of the span scores (sum of digits series in correct sequence) in Table VII shows significant variation for the ear ($F = 15.08$, $p < .001$) and noise ($F = 30.29$, $p < .001$) treatments. An interaction between the ear and noise treatments is also present ($F = 7.11$, $p < .05$). The differences between mean span scores are displayed in Table VIII. Essentially, these differences are in the same relation as those observed for the simple digit recognition scores already analysed for this task. There is no significant difference between means for each ear in the control condition, whereas, in the experimental condition, the left-ear span score is well below the right-ear score. ($t = 4.66$, $p < .001$). It should be pointed out that the variance of the span scores is considerably greater than the variance of the digit recognition scores for this test. Finally, for the brief "shadowing" task which was appended to the digit span test, all 24 subjects achieved perfect identification scores and most of them complained mildly that the test was "too easy".

The important aspects of the analyses offered above are summarized in Figure II. A right-ear advantage in the experimental condition is present for the digit tests, but not for the Plosive Discrimination test. Laterality effects were not observed for any of the tasks in the control condition (noise absent in the contralateral ear).

Discussion

It is clear from the present investigation, as well as from other research reviewed earlier, that some form of interaural rivalry is necessary in order to demonstrate an asymmetry in the auditory system. The principal new finding of this study is the apparent effectiveness of random noise as competing input in producing a right-ear advantage for verbal material. For the two tests involving the perception and immediate recall of digit series, a definite right-ear superiority was evident when narrow-band noise was channeled to the ear contralateral to the ear tested, while, consistent with previous work, no significant differences between right and left-ear scores were found for any of the experimental tasks under monaural presentation conditions.

Stimulus Factors and Laterality Effects

On the basis of these findings what, then, can be said about the nature of the stimulus parameters prerequisite for the observation of differential ear effects in the perception and recall of verbal material? One important factor seems to be the complexity of the stimulus utilized as "competing input" under conditions of binaural rivalry. As noted earlier, contralateral noise as competing input in the Plosive Discrimination test was not effective in producing a right-ear effect. On the other hand, Shankweiler and Studdert-Kennedy (1967) have shown a significant right-ear advantage in the recognition of stop consonants embedded in consonant-vowel syllables which were dichotically delivered in single pairs. A comparison of two other studies provides some further information about the relative effectiveness of contralateral noise as competing input in speech recognition. Dirks (1964) has reported distinctly greater right-ear efficiency in the perception of dichotically-presented PB words, while no ear differences have been noted for the intelligibility of PB words when noise is utilized as the contralateral input (Weston, Miller, and Hirsh, 1965). Apparently, then, the observation of laterality effects for the perception of verbal stimuli becomes more probable as the competing input to the opposite ear becomes more complex and more similar in quality to the relevant verbal message. Evidence from recent investigations (Kimura, 1967; Oxbury, Oxbury and Gardiner, 1967) in which it has been found that irrelevant verbal stimuli delivered to the side contralateral to the test ear were sufficient for the appearance of a right-ear advantage strengthens this interpretation.

In the present research, another stimulus factor related to the emergence of a functional asymmetry in the auditory system is the nature of the verbal task presented to the subject. For the plosive task, subjects were simply required to discriminate between one of six specified stop-consonant phonemes embedded in nonsense syllables, but, for the two digit tasks in which ear differences were noted, greater cognitive demands were made upon the listener. In the digit tasks, the subject was obliged to recognize and recall (sometimes in correct order) several bits of information per trial. Furthermore, there is evidence to indicate that the requirement to recall a series of items may give rise to greater difficulties in the perception of the individual items in the series (Aaronson, 1967). In this connection, it has been demonstrated that the requirement to recall a series of items increases the time needed for perception (Aaronson, 1965; ~~Christovitch~~ Chistovich, Alyahrinskii and Abul'yan, 1960). Thus, such conditions make veridical report more difficult and, by enlarging the area of perceptual uncertainty may presumably permit more sensitive measurement with the resulting detection of definite ear effects. The ease with which all subjects performed the digit shadowing task further supports this argument, for, in the shadowing situation, the listener was required to repeat aloud only one digit at a time immediately after it was heard.

Mechanisms Underlying Binaural Rivalry

A consistent finding for all the experimental tests was the loss of efficiency for both ears in the recognition of verbal stimuli with contralateral noise present. One plausible explanation of this result is suggested by the fact that both ears are represented in each cortical projection area and by the evidence that binaural interaction takes place at each level up through the medial geniculate body (Galambos, Rose, Bromeley, and Hughes, 1952; Rosenzweig and Wyers, 1952; Rosenzweig and Sutton, 1958). It is conceivable that at supposed points of overlap between the crossed and uncrossed pathways and at sites in the auditory cortex, the narrow-band noise input may have partially "jammed" the relevant verbal signals. In this sense, it is possible that the presence of contralateral noise tended to degrade or attenuate the verbal input and thereby increased the likelihood of recognition errors.

At this point, it should be re-emphasized that, for the perception and recall of digit series, the interfering effect of the noise input was significantly less marked when digits were presented to the right ear than to the left ear. The right-ear superiority for verbal material observed under dichotic listening conditions has been explained by Kimura (1967) in terms of the dominant role taken by the left hemisphere in language function as well as the greater efficiency of the neural connections which the left hemisphere makes with the contralateral ear than with the ipsilateral ear. More specifically, Kimura suggests that through the processes of "afferent occlusion" and "central competition", the crossed input is favored over the uncrossed. Thus, verbal stimuli arriving at the right ear would more effectively activate the trace sequences in the left cerebral hemisphere than those stimuli arriving at the left ear. The finding that performance for the digit recognition and digit span tasks was significantly better when digits were delivered to the right and noise to the left ear than under the converse channeling conditions is consistent with Kimura's interpretation.

Thus far, emphasis has been given to the perceptual processes presumably involved in the tasks under discussion. It may be argued that performance on the digit tests was dependent on both perceptual and short-term mnemonic factors and that a consideration of errors in recall as well as perceptual errors induced by the presence of contralateral noise is necessary. If the listener is to report digit series correctly, he must not only "hear" accurately, but must also recall what he has heard. From the present analyses, it is not possible to weigh the relative contribution of perceptual confusions and short-term memorial or serial-order confusions; for there appears to be no adequate way of separating performance errors into discrete and meaningful categories. Although two separate scores were obtained for the digit span task, one for the total number of digits correctly reported and another for the number of digits reported in correct sequence, the pattern of results for both measures was the same, and it is most probable that both scores reflect the interpenetration of perceptual and short-term retention components. Conceivably, the noise input may have generated random "neurological noise" (Conrad, 1964) which interfered with sequencing and subsequent recall of digit series in addition to the prior, increased perceptual stresses which it produced.

An alternate, and perhaps more meaningful way of interpreting the effects of noise upon digit recognition and recall is suggested by a comparison of the digit span and digit shadowing test results. It will be recalled that the performance for the shadowing task was errorless for all subjects, indicating that the listener was able to "hear" the individually presented digits. On the other hand, with the same noise conditions in effect, a marked decrement in performance was observed for the span test. It may be that the additional effort required to recognize the digits under conditions of degraded input decreased the "spare capacity" (Broadbent, 1958) available to perform further cognitive operations or, more simply, reduced the opportunities for rehearsal. The recent findings of Rabbitt (1966) lend support to this suggestion; for Rabbitt has shown that recognition memory for words which were correctly heard in white noise was significantly inferior to recognition for words not so masked. Yet, whatever the mechanisms involved, it appears most likely from the observations reported here that contralateral noise was disruptive during both the perceptual and recall stages of the digit tasks for which a right-ear effect was obtained.

Summary and Conclusions

The purpose of the present research was to investigate the stimulus conditions necessary for the observation of differential ear effects in the perception and immediate recall of verbal stimuli. Three auditory tests employing spoken material were administered to normal, female subjects. In one test (Plosive Discrimination), subjects were required to recognize one of six stop consonants embedded in a two-syllable, nonsense word. In another (Digit Recognition), six or eight digits were presented two at once (in two different voices of similar intonation) to the same ear, and subjects were required to repeat all of the numbers they heard in any order. In the third test (Digit Span), the listener heard a series of from six to ten digits channeled to one ear or the other, and, at the end of each series, was obliged to recall the digits in correct sequence. In addition, a brief digit-shadowing task for which subjects were requested to repeat each digit as it was heard was appended to the span test. The tape-recorded material for each of the three tests was delivered monaurally to the right and left ears through stereophonic earphones. In the experimental condition of each task, narrow-band noise was simultaneously channeled to the ear opposite the one receiving the relevant verbal signal, whereas, in the control condition, noise was absent in the contralateral ear.

Each subject was tested under all conditions, and, thus, subjects served as their own controls.

Contralateral noise as competing input was found to impair overall performance on all three experimental tests, irrespective of the ear to which stimuli were presented. For both digit tasks, a significant right-ear advantage was observed under the noise condition, whereas, for the Plosive Discrimination test, no significant ear difference was obtained. Differential ear effects were not present for any of the tests in the control condition and performance on the shadowing task was errorless for all subjects. With respect to these results it is concluded that some minimal form of binaural competition is required in order to detect a stable right-ear effect for the report of verbal material. It is suggested that the observation of a right-ear advantage becomes more probable as the competing input becomes more complex and homologous to the relevant verbal message. On the basis of electrophysiological and clinical evidence, it is proposed (after Kimura, 1967) that contralateral noise as competing input acted to degrade the verbal input through the mechanisms of afferent and cortical occlusion, and that, as a result of the greater efficiency of the crossed auditory connections, this effect became maximal when noise was delivered to the ear opposite the dominant hemisphere for speech. Although the observed laterality effect for the digit tests can be most plausibly interpreted in terms of perceptual rivalry in the auditory system, it is further suggested that the interfering effects of the noise input were also operative during the recall stages of these tasks.

References

Aaronson, D. Perception and immediate recall of auditory sequences. Paper read at Eastern Psychological Association, Atlantic City, 1965.

Aaronson, D. Temporal factors in perception and short-term memory. Psychol. Bull., 1967, 67, 130-144.

Ades, H. "Central auditory mechanisms," in Field, J., Magoun, H.W., & Hall, V.E. (Ed.), Handbook of Physiology, Section I: Neurophysiology, vol. I. Washington, D.C.: American Physiological Society, 1959.

Bocca, E., & Calearo, C. "Central hearing processes," in Jerger, J. (Ed.), Modern Developments in Audiology. New York: Academic Press, 1963.

Bocca, E., Calearo, C., Cassinari, V., & Migliavacca, F. Testing "cortical" hearing in temporal lobe tumours. Acta Oto-Laryngol., 1955, 45, 289-304.

Branch, C., Milner, B., & Rasmussen, T. Intracarotid Sodium Amytal for the lateralization of cerebral speech dominance. J. Neurosurg., 1964, 21, 399-405.

Bremer, F., & Dow, R.S. The acoustic area of the cerebral cortex in the cat. J. Neurophysiol., 1939, 2, 308-318.

Broadbent, D.E. The role of auditory localization in attention and memory span. J. exp. Psychol., 1954, 47 191-196.

Broadbent, D.E. Immediate memory and simultaneous stimuli. Quart. J. exp. Psychol., 1957, 9, 1-11.

Broadbent, D.E. Perception and Communication. London: Pergamon Press, 1958, Pp. 68-80.

Broadbent, D.E., & Gregory, M. Accuracy of recognition for speech presented to the right and left ears. Quart. J. exp. Psychol., 1964, 16, 359-360.

Bryden, M.P. Ear preference in auditory perception. J. exp. Psychol., 1963, 65, 103-105.

Calearo, C., & Antonelli, A.R. "Cortical" hearing tests and cerebral dominance. Acta Oto-laryngol., 1963, 56, 17-26.

Chistovich, L.A., Alyakrinskii, V.V., & Abul'yan, V.A. Vremennie zadezhki pri povtorenii slishimoi rechi. Voprosi Prikhologii, 1960, 6, 64-70.

Conrad, R. Acoustic confusions in immediate memory. Brit. J. Psychol., 1964, 55, 75-84.

Corso, J.F. Confirmation of the normal threshold for speech on C.I.D. auditory test W-2. J. acoust. Soc. Amer., 1957, 29, 368-370.

Curry, K.W. A comparison of left-handed and right handed subjects on five verbal and non-verbal dichotic listening tasks. Unpublished doctoral dissertation, Northwestern University, 1966.

Dirks, D. Perception of dichotic monaural verbal material and cerebral dominance for speech. Acta Oto-laryngol., 1964, 58, 73-80.

Galambos, R. "Studies of the suditory system with implanted electrodes", in Rasmussen, G.L., & Windle, W.F. (Ed.), Neural Mechanisms of the Auditory and Vestibular Systems. Springfield, Ill: Charles C. Thomas Publisher, 1960.

Galambos, R., Rose, J.E., Bromiley, R.B., & Hughes, J.R. Micro-electrode studies on medial geniculate body of cat. II. Response to clicks. J. Neurophysiol., 1952, 15, 359-380.

Glorig, A., Wheeler, D., Quiggle, R., Grings, W., & Summerfield, A. 1954 Wisconsin State Fair Hearing Survey. Rochester, Minn: American Academy of Ophthalmology & Oto-laryngology, 1957.

Inglis, J. Dichotic listening and cerebral dominance. Acta Oto-laryngol., 1965, 60, 232-238.

Jerger, J.F. Observations on auditory behavior in lesions of the central auditory pathways. Archives of Otolaryngology, 1960, 71, 797-806.

Jerger, J.F., Carhart, R., Tillman, T.W., & Peterson, J.L. Some relations between normal hearing for pure tones and for speech. J. Speech & Hearing Res., 1959, 2, 126-140.

Jerger, J.F., & Mier, M. The effect of brain stem lesions on auditory responses of humans. Paper read at First Annual Meeting of Psychonomic Society, Chicago, 1960.

Kimura, D. Cerebral dominance and the perception of verbal stimuli. *Canad. J. Psychol.*, 1961, *15*, 166-171. (a)

Kimura, D. Some effects of temporal-lobe damage on auditory perception. *Canad. J. Psychol.*, 1961, *15*, 156-165. (b)

Kimura, D. Speech lateralization in young children as determined by an auditory test. *J. comp. physiol.* Psychol., 1963, *56*, 899-902.

Kimura, D. Left-right differences in the perception of melodies. *Quart. J. exp. Psychol.*, 1964, *16*, 355-358.

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

Milner, B. Psychological defects produced by temporal lobe excision. *Publ. Assoc. Res. Nerv. Ment. Dis.*, 1958, *36*, 244-257.

Milner, B. "Laterality effects in audition," in Mountcastle, V.B. (Ed.), *Interhemispheric Relations and Cerebral Dominance*. Baltimore: The Johns Hopkins Press, 1962.

Milner, B., Branch, C. & Rasmussen, T. "Observations on cerebral dominance," in de Reuck, A.V.S., & O'Connor, M. (Ed.), *Disorders of Language*. Boston, Mass: Little, Brown and Company, 1964.

Milner, B., Branch, C., & Rasmussen, T. Evidence for bilateral speech representation in some non-right-handers. *Trans. Amer. Neurol. Ass.*, 1966, *91*. 306-308.

Neff, W.D. "Neural mechanisms of auditory discrimination," in Rosenblith, W.A. (Ed.), Sensory Communication. Cambridge, Mass: The M.I.T. Press, 1961.

Oxbury, S., Oxbury, J., & Gardiner, J. Laterality effects in dichotic listening. Nature, 1967, 214, 742-743.

Palmer, R.D. Cerebral dominance and auditory asymmetry. J. Psychol., 1964, 58, 157-167.

Penfield, W., & Roberts, L. Speech and Brain Mechanisms. New Jersey: Princeton University Press, 1959.

Peterson, L.R., & Kroener, S. Dichotic stimulation and retention. J. exp. Psychol., 1964, 68, 125-130.

Rabbitt, P. Recognition: Memory for words correctly heard in noise. Psychonomic Science, 1966, 6, 383-384.

Rosenzweig, M. Discrimination of auditory intensities in the cat. Amer. J. Psychol., 1946, 59, 127-137.

Rosenzweig, M. Representations of the two ears of the auditory cortex. Amer. J. Physiol., 1951, 167, 147-158.

Rosenzweig, M. Cortical correlates of auditory localization and of related perceptual phenomena. J. comp. physiol. Psychol., 1954, 47, 269-276.

Rosenzweig, M.R., & Sutton, D. Binaural interaction in lateral lemniscus of cat. J. Neurophysiol., 1958, 21, 17-23.

Rosenzweig, M.R., & Wyers, E.H. Binaural interaction at the inferior colliculi. J. comp. physiol. Psychol., 1955, 48, 424-431.

Russell, W.R., & Espir, M. Traumatic Aphasia. London: Oxford University Press, 1961.

Satz, P., Achenbach, K., Pattishall, E., & Fennel, E. Order of report, ear asymmetry and handedness in dichotic listening. Cortex, 1965, 1, 377-396.

Sinha, S.P. The role of thetemporal lobe in hearing. Unpublished Master's Thesis, McGill University, 1959.

Shankweiler, D. & Studdert-Kennedy, M. Identification of consonants and vowels presented to left and right ears. Quart. J. exp. Psychol., 1967, 19, 59-63.

Stitt, C.L. Relationship between certain measures of auditory abilities and judgments of articulation proficiency. Unpublished doctoral dissertation, Stanford University, 1961.

Tunturi, A.R. A study on the pathway from the medial geniculate body to the acoustic cortex in the dog. Amer. J. Physiol., 1946, 147, 311-319.

Weston, P., Miller, J., & Hirsh, I. Release from masking for speech. J. acoust. Soc. Amer., 1965, 38, 1053-1054.

TABLE I

Analysis of Variance for Plosive Discrimination Test Data

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	F VALUE
Ear Effect (E)	11.34	1	11.34	2.44
Noise Effect (N)	31.51	1	31.51	5.72*
Subjects (S)	1841.16	23	80.05	
Interaction: ExS	106.91	23	4.65	1.30
Interaction: NxS	126.74	23	5.51	1.54
Interaction: ExN	0.01	1	0.01	0.003
Interaction: ExNxS	82.24	23	3.57	
Total	2199.91	95		

* $P < .05$

TABLE II

Plosive Discrimination Test: Mean Number of Recognition Errors for the Perception of Stop Consonants under Various Treatment Conditions

EAR TREATMENT

NOISE TREATMENT	Mean Errors for Left Ear		Mean Errors for Right Ear
Control Condition	11.25 (SD=5.38)	$t=1.17$ NS	10.54 (SD=4.59)
	$t=1.69$ NS		$t=2.08$ $p < .05$
Experimental Condition	12.38 (SD=5.36)	$t=1.18$ NS	11.71 (SD=3.92)

NOTE: One-tailed t tests for correlated samples were computed.

TABLE III

Analysis of Variance for Digit Recognition Test Data

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	F VALUE
Ear Effect (E)	84.38	1	84.38	14.42**
Noise Effect (N)	121.51	1	121.51	25.31**
Subjects (S)	4573.33	23	198.84	
Interaction: ExS	134.63	23	5.85	1.18
Interaction: NxS	110.50	23	4.80	0.97
Interaction: ExN	51.08	1	51.08	10.32*
Interaction: ExNxS	113.90	23	4.95	
Total	5189.33	95		

* $P < .01$
** $P < .001$

TABLE IV

Digit Recognition Test: Mean Number of Digits Corectly Reported under Various Treatment Conditions (N=24)

EAR TREATMENT

NOISE TREATMENT	Mean Score for Left Ear		Mean Score for Right Ear
Control Condition	80.08 (SD=7.43)	t=.67 NS	80.50 (SD=7.51)
	t=6.55 $p < .001$		t=1.13 NS
Experimental Condition	76.38 (SD=7.60)	t=4.64 $p < .001$	79.71 (SD=6.71)

NOTE: One-tailed t tests for correlated samples were computed.

TABLE V

Analysis of Variance for Digit Span Test Data

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	F VALUE
Ear Effect (E)	121.50	1	121.50	18.15**
Noise Effect (N)	442.04	1	442.04	71.88**
Subjects (S)	2783.00	23	121.00	
Interaction ExS	154.00	23	6.70	.92
Interaction NxS	141.46	23	6.15	.85
Interaction ExN	70.04	1	70.04	9.67*
Interaction ExNxS	166.46	23	7.24	
Total	3878.50	95		

* $P < .01$

** $P < .001$

TABLE VI

Digit Span Test: Mean Number of Digits Correctly Reported under Various Treatment Conditions (N=24)

NOISE TREATMENT	EAR TREATMENT: Mean Score for Left Ear		EAR TREATMENT: Mean Score for Right Ear
Control Condition	107.50 (SD=5.88)	t=1.11 NS	108.04 (SD=5.70)
	t=7.65 $p < .001$		t=3.59 $p < .005$
Experimental Condition	101.50 (SD=6.20)	t=4.12 $p < .001$	105.45 (SD=5.94)

NOTE: One-tailed t tests for correlated samples were computed.

TABLE VII

Analysis of Variance For Digit Span Test Data (Digit Series Reported in Correct Sequence)

SOURCE	SUM OF SQUARES	df	VARIANCE ESTIMATE	F VALUE
Ear Effect (E)	590.04	1	590.04	15.08**
Noise Effect (N)	1600.67	1	1600.67	30.29**
Subjects (S)	30,812.83	23	1339.69	
Interaction: ExS	899.96	23	39.13	.74
Interaction: NxS	1215.33	23	52.84	1.00
Interaction: ExN	376.04	1	376.04	7.11*
Interaction: ExNxS	1216.96	23	52.91	
Total	36,711.83	95		

* $P < .05$

** $P < .001$

TABLE VIII

Digit Span Test: Mean Number of Digits Reported in Correct Sequence under Various Treatment Conditions (N=24)

EAR TREATMENT

	Mean Score for Left Ear		Mean Score for Right Ear
Control Condition	49.79 (SD=20.21)	$t=.50$ NS	50.79 (SD=18.24)
NOISE TREATMENT	$t=5.99$ $p < .001$		$t=1.94$ $p < .05$
Experimental Condition	37.67 (SD=19.97)	$t=4.66$ $p < .001$	46.58 (SD=18.57)

NOTE: One-tailed t tests for correlated samples were computed.

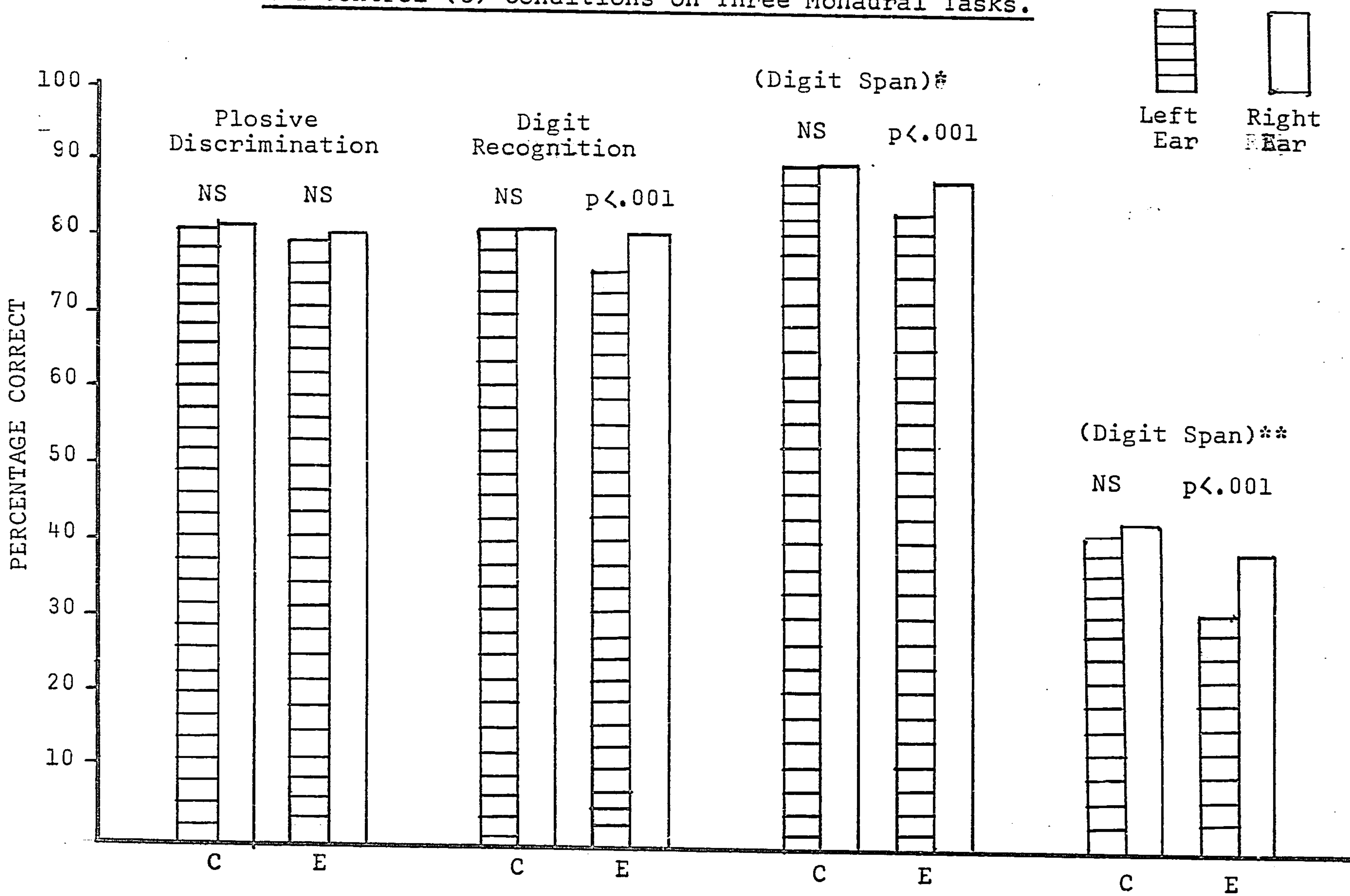
FIGURE I

General Experimental Design: Intra-Individual Analysis of Differences in Task Performance across Treatment Conditions

NOISE TREATMENT	EAR TREATMENT: Verbal Signal to Left Ear	EAR TREATMENT: Verbal Signal to Right Ear
Control Condition	Performance Score for Left Ear ——— Noise Absent in Contralateral Ear	Performance Score for Right Ear ——— Noise Absent in Contralateral Ear
Experimental Condition	Performance Score for Left Ear ——— Contralateral Noise Present	Performance Score for Right Ear ——— Contralateral Noise Present

FIGURE II

Comparisons of the Percentages of Correct Responses from the Left and Right Ears under Experimental (E) and Control (C) Conditions on Three Monaural Tasks.



NOTE: * Percentage of correct responses without reference to order.
** Percentage of digits reported in corect order.