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A REVIEW AND PRELIMINARY EVALUATION OF METHODOLOGICAL FACTORS IN PERFORMANCE ASSESSMENTS OF TIME-VARYING AIRCRAFT NOISE EFFECTS

By

Glynn D. Coates

and

Earl A. Alluisi

Final Report

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
Grant NSG 1092
August 1, 1974 - September 30, 1975

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INTRODUCTION

This is the final progress report to be submitted under National Aeronautics and Space Administration (NASA) Research Grant No. NSG-1092. This research on "A Review and Preliminary Evaluation of Methodological Factors in Performance Assessments of Time-Varying Aircraft Noise Effects" has been conducted for the Noise Effects Branch of the NASA Langley Research Center, Hampton, Virginia, under the direction of Dr. Earl A. Alluisi (University Professor of Psychology), principal investigator, and Drs. C. J. Adkins, Jr. and G. D. Coates (Professor and Associate Professor of Psychology, respectively)--all of Old Dominion University.

This report covers work completed during the grant period of 1 August 1974 through 30 September 1975. The research has progressed along the three lines of attack initially proposed: (1) a review of the literature has been completed to identify the methodological and stimulus parameters involved in the study of noise effects on human performance, (2) a theoretical framework has been developed to provide working hypotheses as to the effects of noise on complex human performance, and (3) data collection has begun on the first of several experimental investigations designed to provide tests of the hypotheses generated by the theoretical framework. Progress made along each of these is described below.

1. REVIEW OF THE LITERATURE

The review of the literature was conducted to identify specifically (a) the various performance methodologies that have been employed in the study of noise effects, (b) the pertinent results as to the effects of noise on human performance, and (c) the principles involved in the specification of interactions of the various methodologies and results. In general, the organization of the 300 articles reviewed for this project centered around the following classifications:

(a) Performance methodologies employed in the assessment of noise effects,
(b) Identified effects of noise on human performance,
(c) Methodologies employed in the assessment of subjective reactions to noise,
(d) Physiological responses to noise, and
(e) Physical characteristics of aircraft noise.

A technical report summarizing the findings of this review has been completed. The report also contains an exposition of the theoretical framework developed and an annotated bibliography of relevant papers involving assessments of human performance as affected by noise. The technical report is attached to this final report as Appendix I, "A Review of Methodological Factors in Performance Assessments of Time-Varying Aircraft Noise Effects", and will be published within the next quarter as an Old Dominion University Performance Assessment Laboratory Interim Technical Report.

2. DEVELOPMENT OF THEORETICAL FRAMEWORK

The theoretical framework developed was employed to organize the literature review along compatible lines as follows: the human in a performance situation is viewed as an information-processing channel having numerous inputs and numerous outputs, one of which is the output being measured with the performance-assessment task(s). This information-processing channel is hypothesized to have two limiting thresholds: (a) its channel capacity, and (b) its minimum operating level. On the one hand, if the performance situation forces the human to operate at the level of his channel capacity, the addition of further information-processing requirements will result in diminished output and a degradation in performance. On the other hand, if the performance situation forces the human to operate near or below his minimum operating level, the addition of further information-processing requirements will result in an improved information flow that will be associated with improved performance. Auditory noise is an additional input into the human information-processing channel. The impact of the noise as input to the information-processing system will depend upon (a) its relevance to other information being processed and (b) the informational characteristics of the noise. The human information-processing channel (with its two limiting thresholds) interacts with the performance-assessment situation that places specifiable information-processing requirements on the human. The effects of time-varying aircraft noise on human performance can then be predicted on the basis of the hypothesized interaction and specification of the informational characteristics of the noise. Details of the theoretical framework and the resulting hypotheses are contained in Appendix I.

3. EXPERIMENTAL INVESTIGATIONS

A series of experimental investigations has been designed to test the viability of the theoretical framework and the resulting hypotheses. Data collection has begun on the first of these investigations; a report of each of these investigations will subsequently be published as Old Dominion University Performance Assessment Laboratory Interim Technical Reports and will be distributed to all pertinent offices of the National Aeronautics and Space Administration.

4. GRANT RELATED ACTIVITIES

Dr. Alluisi chaired a symposium on "Reactions to Aircraft Noises" as part of the formal program of the Society of Engineering Psychologists at the 83rd Annual Meeting of the American Psychological Association held 30 August to 3 September 1975 at Chicago, Illinois. The participants in the symposium were Dr. Alluisi (Chairman); Dr. Michel Loeb, University of Louisville ("Expected Effects of Aircraft-Type Noises"); Drs. G. D. Coates, C. J. Adkins, Jr., and E. A. Alluisi, Old Dominion University ("Human Performance and Aircraft-Type Noise Interactions"); Drs. F. E. Fiedler and Judith Fiedler, University of Washington ("Verbal and Behavioral Reactions to Airport Related Noise"); and Dr. Walter Gunn, NASA-Langley Research Center (Discussant). The paper presented by Drs. Coates, Adkins, and Alluisi was essentially a report of the review of the literature and theoretical framework presented in Appendix I.

In addition, a paper summarizing this year's work under NASA Research Grant No. NSG-1092 has been accepted for presentation at the Third Interagency Symposium on University Research in Transportation Noise to be held 12-14

November 1975 at the University of Utah. The paper, co-authored by Drs. G. D. Coates, E. A. Alluisi, B. B. Morgan, Jr., and C. J. Adkins, Jr., is entitled "Methodological Factors in Performance Assessments of Time-Varying Aircraft-Noise Effects."

APPENDIX I

A REVIEW OF METHODOLOGICAL FACTORS IN PERFORMANCE ASSESSMENTS OF TIME-VARYING AIRCRAFT NOISE EFFECTS

By

Glynn D. Coates, Earl A. Alluisi, and C. J. Adkins, Jr.
Performance Assessment Laboratory
Department of Psychology
Old Dominion University
Norfolk, Virginia 23508

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A REVIEW OF METHODOLOGICAL FACTORS IN PERFORMANCE ASSESSMENTS OF TIME-VARYING AIRCRAFT NOISE EFFECTS

By

Glynn D. Coates, Earl A. Alluisi, and C. J. Adkins, Jr.

The study of the direct effects of aircraft or aircraft-type noise on human performance has received very little attention in the literature. Although Stevens and his associates conducted several early studies of the effects of aircraft noise on performance (Stevens, Egan, Waterman, Miller, Knapp and Rome 1941), and Miles (1953) conducted later studies of the effects of jet aircraft noises while wearing ear defenders, there have been no systematic studies of the effects of modern aircraft noise on complex human performance typically encountered in work situations. There have been a small number of studies that provide some evidence of an indirect nature as to the effects of extreme aircraft noise (i.e., sonic booms) on performance. For example, Woodhead (1969) investigated the effects of sonic booms on a visual search task. Chiles and West (1972) investigated the *aftereffects* of booms introduced during sleep periods on complex human performance in a synthetic-work situation. Similarly, the startle effects of sonic booms on arm-hand steadiness tasks have been investigated (Thackray, Touchstone, and Bailey, 1973; Thackray, Rylander, and Touchstone, 1973), as have the effects of booms on sleep (Smith and Hutto, 1972; Lukas and Dobbs, 1972; Olivier-Martin, Schieber, and Muzet, 1972; Collins and Iampietro, 1972). These studies, however, only provide data regarding the indirect effects of aircraft noise that, though relevant and important, do not attack the problem of interest to this review--the assessment of the direct effects of aircraft and aircraft-type noise on performance.

In view of the dearth of investigations of the effects of aircraft noise on performance, therefore, it should be noted that the approach taken in this review was to examine and analyze the evidence within the literature of the effects of general noise on human performance. The examination was conducted in an attempt (a) to identify those *characteristics of noise* that have been found to affect human performance, (b) to identify those *characteristics of performance* most likely to be affected by the presence of noise, (c) to identify those *characteristics of the performance situation* typically associated with noise effects, and, finally, (d) to develop a theoretical framework, based on the identified characteristics, that will permit predictions of possible effects of time-varying aircraft-type noise on complex human performance.

It should be further noted that the scope of the review has, of necessity, been limited to the extent that performance effects of noise attributable to the acoustic interference and auditory trauma have been excluded. Consequently, no attempt has been made to examine performance effects directly associated with speech interference, auditory masking, and auditory threshold shift. The exclusion of these areas was decided upon, not to minimize the contribution of such areas, but because the methodologies employed and the results found are more or less orthogonal to the areas of interest in this review. Further, the studies included in this report represent only about 50% of the studies reviewed; studies selected for inclusion were chosen as being representative of the field. The Appendix to this report presents an annotated bibliography of the reviewed studies of effects of noise on human performance.

OVERVIEW OF EFFECTS OF NOISE ON PERFORMANCE

The literature, at first glance, appears to be filled with contradictions as to the effects of noise on human performance (cf. McCormick, 1970, P. 523ff). On the one hand, from one of the first studies of noise effects on performance (Cassel and Dallenbach, 1918) to the most recent reported studies (e.g., Finkelman, 1975), there have been numerous studies indicating that noise produces a *decrement* in human performance. Likewise, however, there have been a considerable number of studies reporting that noise produces an *increment* in performance (e.g., Kirk and Hecht, 1963; Warner, 1969; Warner and Heimstra, 1971). Finally, there are a number of reported (and probably countless unreported) studies indicating that noise has *no* significant effect on performance (e.g., Jerison, 1957; 1959; Cohen, Hummel, Turner, and Duker-Dobos, 1966). The apparent schizophrenic nature of the findings in the area can be attributed, in part, to the wide range of "performance tasks", "performance situations", and the different characteristics of the "noise" employed. Whatever the source of the dissonant findings in the area, it is apparent that no general theoretical framework regarding noise effects on human performance is possible or even desirable without a thorough analysis of the noise, task, and situational variables employed in the investigations leading to the apparent contradictions in the area.

NOISE VARIABLES

Noise Sources

A wide variety of noise sources has been employed in the investigations of noise effects on performance. The previously cited study by Stevens and his associates (Stevens, 1941a; 1941b) utilized simulated *aircraft noise* in the study of choice reaction time as a function of 115 dB and 90 dB noise levels; no significant differences in RT were found in those studies. In a study of the effects of *jet engine noise* at 130 dB while wearing ear defenders, Miles (1953) reported an improvement in simple reaction time when compared with performance unaccompanied by the noise. In a study of the effects of noise on performing arithmetic division problems, recordings of a *low-frequency airhorn* at 98-108 dB had no effect on performance (Park and Payne, 1963). Using a 105 dB presentation of recorded *industrial noises* as compared with 95 dB of *music*, Wolf and Weiner (1972) reported that performance was poorer in the presence of the industrial noise. Broadbent (1957) employed filtered, recorded industrial noises in his study of the effects of noise frequency on performance.

In a series of studies using approximately 1-sec bursts of recorded *low-frequency rocket blast noises*, Woodhead has reported decrements in visual search performance at 100 dB (Woodhead, 1958) and in decision-making at 110 dB (Woodhead, 1959). *Teletype noise*, used in bursts of 66-70 dB against a background noise of 55 dB, was found to have a detrimental effect on proof-reading performance when compared to performance under quiet conditions (Weinstein, 1974). As would be expected, the majority of the studies investigating noise effects on performance has employed *broad-band white noise*; the distinguishing characteristics of those studies for purposes of this review, however, are characteristics other than those related to the source of the noise and will be covered below. In general, the effects of noise on performance as a function of noise source seem to reflect the findings of the total area--some indicate decremental effects, some indicate incremental effects, and some indicate no effects.

Intensity Levels

As suggested above, a wide range of intensity levels have also been employed, ranging from the 66-70 dB used in the Weinstein study (1974), in which decrements in performance were reported as a function of noise, to the 130 dB using ear defenders reported by Miles (1953) which resulted in increments in performance. In general, however, the results tend to indicate that, given an effect regardless of direction, the higher the intensity, the greater the effect. Consequently, if noise was found to affect performance detrimentally, the higher the intensity level, the greater the decrement (cf. Woodhead, 1959). Conversely, if the demonstrated effect of noise on performance is one of enchancement, the greater the intensity, the greater the enhancement (cf. Warner, 1969; Warner and Heimstra, 1972). Of particular interest to this review is a study whose findings apparently run counter to this general trend (Teichner, Arees, and Reilly, 1963). In that study, four groups of 10 subjects each were presented with 150 visual search displays with a background noise level of 81 dB; then, without warning the noise level for each of the four groups was changed to 57, 69, 93, or 105 dB for 50 remaining displays. The results indicated that the change in noise level (regardless of whether increased or decreased) increased the time required for decisions, i.e., the change produced decrements in the percentage gain of information transmission. Thus, we have an example of a *change* (either an increase *or* a decrease) in intensity resulting in a decrement in performance efficiency. As indicated, this study has further implications for this review and will, therefore, be discussed further below. In general, the intensity variable can be a relevant variable to be considered in the development of a theoretical framework, but the effect of the variable is not a simple one.

Frequency

There have been few systematic investigations of the effects of noise on performance as a function of the spectral characteristics of the noise. There is some suggestive evidence, however, that high-frequency noise is more detrimental to performance than is low-frequency noise. For example, Broadbent (1957a; 1957b) investigated the effects of high-frequency (greater than 2,000 Hz) and low-frequency (less than 2,000 Hz) noise presented at 80, 90, and 100 dB on performance of the five-choice serial reaction task. Results indicated that high-frequency noise was associated with a greater number of errors than was the low-frequency noise, but that the effect was limited to the highest level of intensity. Poulton and Edwards (1974) make a strong argument for the beneficial effects of low-frequency noise in their study of the interaction of low-frequency noise and heat stress. In that study, results indicated that on the performance of the five-choice serial reaction task, the low-frequency noise served to reduce the percentage of errors--a finding that appears to be contrary to the results of a large number of studies using that task with broad-band, white noise. As indicated above, these data are only suggestive in that they are only two studies with a single task and the second study made no direct comparison with broad-band, white noise. Nevertheless, the frequency variable is one that should be considered in future investigations.

Temporal Factors

Certain temporal factors associated with the noise source have been shown to be a critical variable in a number of studies. Of particular interest to this review is the continuum defined by the on-off time (with on-time being expressed as a percentage of total time) of an intermittent noise; the continuum ranges from an on-ratio of 100% (continuous noise) at one extreme to an on-ratio of 0% (no noise) at the other extreme with varying degrees of intermittency falling along the continuum. Orthogonal to that continuum is a second temporal-related continuum associated with the periodicity of the intermittency, ranging from a random or aperiodic intermittency on the one hand to a patterned or periodic intermittency on the other. Thus, a noise source that presented 1 sec of noise followed by 1 sec of silence alternately would have an on-ratio of 50% and would be periodic; similarly, the presentation of a 1-sec duration of noise followed by a random duration of silence averaging 1 sec would also have an on-ratio of 50% but would be aperiodic on the periodicity continuum. A third, time-varying factor that appears to be a modification of the continuous/no-noise continuum is one in which there are no "off" periods but there are variations in intensity over time.

While most of the investigations of the effects of noise on performance have employed continuous noise, there is good evidence that these temporal continua are as meaningful for assessing performance effects as are the factors of intensity and/or frequency. Kirk and Hecht (1963), for example, investigated the effects of continuous or "constant" noise at 65 dB, "variable" noise varying in intensity with an average of 65 dB, and "quiet" of 61 dB on vigilance performance using a cathode ray tube display. (It should be noted that the variable noise condition is an example of the third temporal factor mentioned above.) Their results indicated a significant increment in performance under the variable noise condition when compared with either the constant noise or the quiet condition; the constant noise, on the other hand, did not produce performances that differed from the quiet condition. Likewise, Warner and Heimstra (1971) investigated two levels of task complexity on a visual search task as a function of four levels of intermittency (on-ratios of 0%, 30%, 70%, and 100%). Performance on the more complex task was found to be superior for the two intermittent ratios (30% and 70%) when compared to the no-noise (0%) and the continuous-noise (100%) conditions; for the less complex task, only the 30% condition was superior to the controls.

In another temporally related investigation (Theologus, Wheaton, and Fleishman, 1974), performance on a battery of three performance tasks was studied as a function of two conditions of intermittent noise--one periodic, intermittent condition (referred to as "patterned") in which 85 db of noise was presented at an on-ratio of approximately 71% in 5-sec on and 2-sec off periods, and one aperiodic, intermittent condition with noise being presented for random durations of from 1 to 9 sec with 2-sec interpolated silence periods. Their results indicated that, in general, performance was poorer for the aperiodic, intermittent condition. However, the effect of the aperiodic condition was dependent upon the task and the performance measure used with some measures being unaffected. Regardless of the measure or task used, the periodic noise group performed about the same as the quiet control group.

Eschenbrenner (1971) examined performance on the McDonnell Douglas Image Motion Compensation Simulator which yields measures of complex psychomotor performance. Three intensity levels (50, 70, and 90 dB) were combined factorially with three temporal patterns of noise--continuous, periodic intermittent (with a ratio of 50% using 2-sec periods), and aperiodic intermittent (with an average ratio of 50% but varying off-time from 0.5 to 3.5 sec with 2-sec on-time). The three intensity levels produced significant decrements in performance when compared to a control condition. The three temporal patterns of noise also produced significant decrements in performance with the aperiodic intermittent condition producing the greatest decrement followed by the periodic intermittent and the continuous groups in order of greater decrement. Applicable to this area of discussion are a series of studies conducted by Woodhead in which decision-making (Woodhead, 1959), visual search (Woodhead, 1964a), and memory-and subtraction (Woodhead, 1964b) performances were investigated in the presence of 1-sec bursts of recorded rocket fire. Although the author did not specify the durations of the off-periods, it would be safe to classify these situations as aperiodic intermittent. Decrements in performance were reported in all three studies as a function of the noise conditions.

A number of studies (Finkelman and Glass, 1970; Glass and Singer, 1972; 1973; Finkelman, 1975) have been reported using "predictable" and "unpredictable" noise conditions in an attempt to assess the effect of the conditions on multiple-task performance. The "predictable" noise condition in those studies was, in terms of the present review, period intermittent noise; in one study, for example, the predictable noise consisted of periodic intermittent noise of a 75% ratio (9-sec on, 3-sec off) at 85 dB. The unpredictable noise consisted of aperiodic intermittent noise of a 75% ratio at 85 dB with the on-period varying from 1 to 9 sec and the off-period varying from 1 to 3 sec. In their assessments of the effects of noise on performance, the authors reported that performance on the primary task was unaffected by the noise conditions whereas the secondary task was detrimentally affected by the aperiodic intermittent conditions. These studies are of substantial importance to this review and will be discussed further in succeeding pages.

In general, the data related to the temporal characteristics of the noise seem to suggest that intermittent noise produces both increments (cf. Warner and Heimstra, 1971) and decrements (cf. Theologus, Wheaton, and

Fleishman, 1974; Eschenbrenner, 1971) when compared with continuous noise. Aperiodic intermittent noise appears to produce decrements in performance when compared with periodic intermittent noise (cf. Finkelman and Glass, 1970; Glass and Singer, 1972; 1973; Finkelman, 1975). Therefore, the temporal characteristics of the noise appear to be a potentially important variable that must be considered later.

PERFORMANCE VARIABLES

Tasks

No attempt will be made at this time to review all of the different tasks that have been employed in both laboratory and field studies of noise effects on performance. Broadbent (1957a) provides an excellent coverage of the tasks employed in noise-effect research as of that time. Major emphasis in this paper will be directed toward those task situations that have persisted since Broadbent's review and those task situations that have been introduced since that time.

One class of performance situation that was just beginning to be recognized at the time of Broadbent's review but has persisted throughout the literature is that of the vigilance situation. Broadbent (1954; 1957a) reported a comparison of vigilance performance while watching steam guages under condition of 70 and 100 dB of noise; results indicated that subjects performed better under the quiet (70 dB) condition than under the noisy (100 dB) condition. Data from an easier task under the same conditions showed no effect of the noisy condition. Jerison and his associates, in an attempt to replicate Broadbent's findings, found that subjects in a vigilance situation monitoring three clocks for the occurrence of occasional double steps did about as well in noise (114 dB) as in quiet (83 dB) for about 1 1/2 hours at which time subjects performing in noise deteriorated markedly (Jerison and Wing, 1957). Trying to duplicate these results with another vigilance situation, the Mackworth Clock Test, Jerison (1957) found that vigilance performance under conditions of quiet (79 dB) was not different from performance under conditions of noise (113 dB). These studies have set the stage for a large number of investigations of vigilance performance as affected by noise with the majority of the results indicating that noise has no effect on vigilance performance. One exception, previously cited, is the finding of Kirk and Hecht (1963) that variable intensity noise produces improvement as compared to performance under constant noise or quiet conditions.

Another task reported by Broadbent (1957) has proven to be the most reliable task situation in terms of demonstrating noise effects--the five-choice serial reaction task. The five-choice serial reaction task is a self-paced tracking task in which the subject must track a neon indicator lamp by touching the corresponding brass disk with a stylus; the successful response to one lamp presents the succeeding lamp. As stated by Poulton and Edwards (1974), the task has been used in 11 experiments assessing the effects of noise; in 7 of the 11 studies, noise produced reliable decrements in performance through an increase in errors, and in 3 of the remaining 4 studies, the same decrement was observed but not reliably.

Numerous other task situations have been employed with a majority of them reporting some effects attributable to noise. Typically, the more complex the task or task situation, the greater the probability that noise effects will be manifest. For example, all levels of intensity (50, 70, and 90 dB) and three levels of temporal patterns detrimentally affected the complex psychomotor performance on the McDonnell Douglas Image Motion Compensation Simulator (Eschenbrenner, 1971). Likewise, Theologus, et al. (1974) reported that the effects of noise were task-dependent in their examination of a battery of three tasks; the task most reliably affected detrimentally was the time-sharing of two simultaneously presented tasks. Broadbent's task requiring memorization of a 6-digit number and subtraction from it a 4-digit number consistently is reported to be detrimentally affected by noise (Broadbent, 1958; Woodhead, 1964).

One of the most promising task situations for assessing noise effects is that of the subsidiary task technique, developed by Bahrick, Noble, and Fitts (1954); re-introduced by Boggs and Simon (1968), and revitalized by Glass and his associates (Finkelman and Glass, 1970; Glass and Singer, 1972; 1973). This technique requires a subject to perform at a "primary" task and a "secondary" task simultaneously, and underlying the task situation is the assumption that because of the load imposed on the subject by the addition of the secondary task, any external demands will result in a deterioration of performance on the secondary task.

It should be noted that the one task that has consistently demonstrated detrimental effects of noise on performance, the five-choice serial reaction task, and the promising subsidiary technique have a common characteristic not shared by many of the performance tasks previously employed in the study of noise effects. Specifically, in both of these task situations, the subject cannot possibly alter his behavior significantly without the alterations being reflected in the measure(s) of his performance. In the five-choice serial reaction task, for example, shifts in attention will result in either an increase in errors or an increase in "gaps" or failures to respond within 1 1/2 sec. Thus, the subject's performance measures reflects both his erroneous responses as well as his failure to respond. In the subsidiary task technique, on the other hand, any deviation in behavior will be reflected by virtue of the task situation; namely, the primary task is usually a fairly demanding task so that there is a minimum of available time for the secondary task. Consequently, any deviation in behavior will result in time stolen from the subject's performance of the secondary task which typically is a production task so that less time results in less production.

DEVELOPMENT OF A THEORETICAL FRAMEWORK

The Human as an Information Processing Channel

For the purposes of organizing the results of noise-effect research, the human in a performance situation is viewed as an information-processing channel, a channel having numerous inputs and numerous outputs, one of which is the output being measured in the performance assessment. Further, the information-processing channel is viewed as having two limiting thresholds--(a) its channel capacity, and (b) its minimum operating level. The channel capacity of the human performer is defined as the maximum rate of information that can be processed under a given set of circumstances. Under circumstances in which the human channel is not required to operate near or at its channel capacity, the overall rate of information transmission will continue to increase as the demands of the inputs dictate, and all relevant information will be processed. As the channel is required to operate near or at its channel capacity, priorities must be established as to what of the incoming information will be processed first; even at this level of operation, however, the rate of transmission of information may continue to increase with the input demands although there may be an increased variability of the information transmission rate. However, when the channel's capacity is exceeded, the increased demands for setting of priorities paired with the constant overwhelming input of information results in a cessation of the gain in the rate of information transmission; transmission slows down so that output from the channel is reflected in the human's performance in the situation. On the other hand, the human channel is viewed as also having a minimum operating level of input information. If the input information exceeds the minimum operating level, the channel operates at more or less a normal level--all information will be processed and the overall rate of information transmission will grow with increases in input information. However, if input information falls below the minimum operating level, flow within the channel becomes intermittent and with further decreases in information input, transmission of information may cease completely.

The human in the performing situation can, of course, be faced with any or all of the gradations of information demands from the minimum operating level to the excedance of his channel capacity. When first learning a task situation, the human channel has not yet learned to distinguish the relevant from the irrelevant information in the channel and may find itself at, near, or above channel capacity. Likewise, in a very complex tasks situation, the human channel may be forced to operate at channel capacity continuously. At the other extreme, the performing human, in a situation that he has overlearned or in a situation that, by its nature, provides extremely rare input information, finds himself at or even below the minimum operating level.

Noise as Information Input

Noise is seen as additional input into the human information processing channel. As input, the impact of noise on the information processing system will depend upon (a) its relevance to other information being processed and/or (b) the informational characteristics of the noise. Like other information-processing models, this framework sees the human information channel as having the capabilities of distinguishing relevant from irrelevant information and filtering out the irrelevant information. Consequently, there are performance situations in which the concomittant noise is deemed relevant to performance in the situation and will be processed; in this situation, noise will serve as additional input to be processed with other relevant information from the situation. On the other hand, there are situations in which the noise is deemed irrelevant and it will consequently be filtered out when possible. There are circumstances in which noise, because of its relatively high informational content, cannot be filtered out, thereby, providing additional information to be processed in competition with the relevant information being processed at the time. There are a number of determinants of the informational content of noise but of primary interest at this point is the *number of discriminable changes* (either in frequency, intensity, or location) in the noise per unit time--the greater the number of discriminable changes, the higher the informational content.

It should be noted that intensity is not a determinant of informational content unless there is a change in the intensity over time. It should also be noted in this connection that continuous noise is extremely low in informational content, and unless the continuous noise is related in some way to the performance situation, it will very quickly become filtered out as irrelevant information. Likewise periodic intermittent noise of moderately high informational content will eventually be filtered out also as irrelevant over repeated exposure. This view is not incompatible with the physiological adaptation position adopted by Teichner, et al. (1963).

Noise, therefore, is seen as an additional input to the human information processing channel and the degree to which this additional input affects the output of the channel depends upon (a) the degree to which the noise is seen to be relevant to the other relevant information being processed, and/or (b) the informational content of the noise.

Noise as an Enhancer of Performance

From this theoretical point of view, therefore, noise will serve to enhance performance if (1) the human information-processing channel is receiving input at or below the minimum operating level, (2) the noise is relevant to the performance under study, and/or (3) the informational content of the noise is relatively high even though it may be irrelevant information. For example in the typical vigilance situation, relevant information input to the operator is minimal, occurring very infrequently. In such situations, it would be expected that the introduction of noise should serve to enhance performance and the degree to which there is enhancement will be determined by the extent to which the introduced noise is relevant to the performance or the extent to which the introduced noise has high information content. The Kirk and Hecht (1963) study provides an example of noise in this role in that vigilance performance was enhanced by variable intensity noise with an average intensity of only 64.5 dB. Unfortunately, many of the vigilance investigations of the effect of noise have employed continuous noise sources which served to minimize any of the potential enhancing characteristics.

Noise as a Detriment to Performance

Noise would be expected to affect performance detrimentally, on the other hand, if (1) the human information-processing channel is receiving input at, near, or above channel capacity, (2) the noise is relevant but redundant to the performance under study, and/or (3) the informational content of the noise is high even though it may be irrelevant. Eschenbrenner's (1971) study of noise effects on complex psychomotor performance using the McDonnell Douglas simulator provides a good example of the role of noise as a detriment to performance. That task is complex enough so that until it is overlearned, its operator is processing information at or above his channel capacity. Consequently, all noise levels as well as all temporal patterns of the noise produced decremental effects on the simulator performance. Similarly, any of the task situations employing the subsidiary task technique or any form of multiple-task performance (e.g., Boggs and Simon, 1968; Finkelman and Glass, 1970; Glass and Singer, 1972; 1973) will by their nature force the operator to perform at or near his channel capacity, at least until the task situation becomes overlearned.

Role of the Performance Measure in the Study of Noise Effects

No attempt has been made to cite specific measures of performance found to be affected by noise, In most studies, performance was assessed by some measure of accuracy (e.g., errors, number correct, percent correct) and some measure of response speed (reaction time, time to response, problems solved per minute); consequently, noise effects have been reported for either or both of these measures with the majority of the studies reporting changes in only one. In only one case, however, has there been a report of counteracting effects, i.e., a decrement in accuracy but an increment in speed or an increment in accuracy and decrement in speed; the single exception (Smith, 1951) involved performance on two paper-and-pencil tests under 100 dB noise where subjects attempted more, got more correct, made more errors, and had a lower percentage of accuracy. Consequently, since the rate of information transmission takes into account both speed and accuracy, the end results of most studies reporting decremental effects or incremental effects can best be described as demonstrating increments or decrements in the rate of information transmission.

It is suggested that a more efficient measure of noise effects would be a direct measure of the rate of information transmission. A direct measure would have the added advantage of permitting sensitive assessments of noise effects at levels of information processing that falls between the two extremes of channel capacity and minimum operating level. Noise effects are likely to be unnoticed in this range of information processing when only separate measures of accuracy and speed are taken. Teichner, et al., (1963), for example, utilized a measure of information transmission rate to assess the performances of subjects who were performing a memory-identification task under a background or context noise condition of 81 dB prior to being shifted to intensity levels above and below the original context level. The results indicated a decrement in the rate of change of the information transmission as a function of the shift from the context level with the greater the change from the original 81 dB, the greater the decrement. In that study, therefore, subjects were processing information at a level somewhere below channel capacity and above the minimum operating level; yet the change in rate of information transmission was detectable. Related to this study, it should be noted that the change in intensity level from the context or background level of 81 dB to its new background level is viewed as a momentary shift in the informational content of the noise which would be processed by the information-processing channel as possibly relevant. Thus, the processing of the additional information would be expected to increase the overall information transmission rate but could possibly affect the performance transmission rate. (The *particular* effect could only have been predicted from this theoretical framework based on additional assumptions and extensions of the framework which will not be discussed at this point.) It is suggested, however, that without a further change in the intensity level, the performance output as measured by the information transmission rate would return to its earlier level as the new context level became identified as irrelevant input. The authors of that study did not continue measurement beyond the 15-min summary indicating the effect observed above.

CLASSIFICATIONS OF NOISE EFFECTS

Underlying the present conceptualization of the effects of noise on human performance is a classification in which possible effects are viewed as threefold: (1) *simple effects* that are immediate in nature and affect certain performances directly, (2) *stressor effects* that are long-term, cumulative in nature, and more likely to be evidenced following noise exposure or when noise is overlaid with other stresses, and (3) *interactive effects* in which simple and/or stressor effects are found to interact with environmental, situational, or task variables. By far, the type of noise effects for which we have the most data are those of the simple effects which are evidenced in laboratory investigations of discrete tasks in short-term situations. Needless to say, all of the data we have discussed in the present review have been restricted to data on simple effects.

Although there is virtually no performance data reflecting the stressor effects of noise on performance, based on Kryter's (1970, pp. 491-543) review of the general physiological responses to noise, it seems safe to predict that noise will eventually produce a stressor effect in man and that the effect will be decremental in nature resulting in a decrease in man's ability to perform. Because of its long-term nature, however, and its interaction with the "aging" process, the stressor effect of noise will be difficult to demonstrate.

The interactive effects of noise are and will continue to be the most challenging and most elusive effects for the researcher. One example of the interactive effect of noise can be found in Wilkinson's (1963) study of noise and sleep deprivation. In that study, Wilkinson used the five-choice serial reaction task which, as indicated above, has reliably demonstrated the decremental effects of noise on performance. Subjects were deprived of sleep for 36 hours and then tested on the serial reaction task under 100 dB of continuous noise. The results indicated that the noise had no effect on any measure of serial reaction task performance for the sleep-deprived subjects although testing of the subjects after a normal night's sleep revealed the typical decrement in performance as a function of noise. Thus, according to Wilkinson, sleep deprivation reduced the adverse influence of noise.

IMPLICATIONS FOR THE STUDY OF EFFECTS OF AIRCRAFT NOISE ON PERFORMANCE

Based on the review of the literature and the subsequent development of a theoretical framework around which to organize the findings, certain general predictions can be made regarding the anticipated effects of aircraft or aircraft-type noise on human performance.

1. For those performance situations providing limited input to the subject, it is anticipated that aircraft noise will have either an enhancing effect on performance or no effect at all. Therefore, the typical vigilance situation (excluding the auditory vigilance situation) will not be adversely affected by aircraft

noise. If the noise were highly variable or related to the vigilance situation, an enhancing effect would be predicted.

2. For those performance situations that are below the channel capacity but above the minimum operating level of the individual, it would be anticipated that with normal performance measures, no effect of the noise will be detected reliably. However, if moment-to-moment information transmission rate measures were employed, effects of the aircraft noise can be demonstrated, provided that variability of the noise and relevance to the performance situation can be manipulated. Highly variable noise with low relevance to the performance situation can be expected to result in decrements in performance; highly variable noise with high relevance to the performance can be expected to result in increased rates of information transmission.

3. For those performance situations that force the subject to perform at or near channel capacity, it is expected that aircraft noise will result in performance decrements, particularly if the noise is highly variable and irrelevant to the actual performance. In this case, it is suggested that the subsidiary task technique with measures of rate of information transmission would provide for the most efficient assessment of effects.

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Wilkinson, R. T. Interaction of noise with knowledge of results and sleep deprivation. *Journal of Experimental Psychology*, 1963, 66, 332-337.

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Woodhead, Muriel. Effect of brief loud noise on decision making. *Journal of the Acoustical Society of America*, 1959, 31, 1329-1331.

Woodhead, Muriel. Searching a visual display in intermittent noise. *Journal of Sound Vibration*, 1964, 1, 157-161.

Woodhead, Muriel. The effects of bursts of noise on an arithmetic task. *American Journal of Psychology*, 1964, 77, 627-633.

Woodhead, Muriel. Performing a visual task in the vicinity of reproduced sonic bangs. *Journal of Sound Vibration*, 1969, 9, 121-125.

APPENDIX A

ANNOTATED BIBLIOGRAPHY OF STUDIES OF THE EFFECTS OF NOISE ON HUMAN PERFORMANCE

By

Henry G. Luhring III and Glynn D. Coates

Angelino, H. & Mech, E. V. Factors influencing routine performance under noise. II An explanatory analysis of the influence of adjustment. *Journal of Psychology*, 1955, 40, 397-402.

Task: Adding single digit numbers successively to a two place number.
Noise: a. quiet
b. 85 dB--by turning up volume on record player
Results: Inverse relationship between adjustment and routine performance.

Auble, D. & Poritton, N. Anxiety as a factor influencing routine performance under auditory stimuli. *Journal of General Psychology*, 1963, 58, 115-119.

Task: Series of number checking and name checking exercises.
Noise: Recordings of "I can hear it now", Volume I and Speech of Mental Patients--at 80 dB.
Results: Level of anxiety is directly related to routine performance. Under the noise condition the higher the anxiety level of S, the better work performed.

Barnett, C. D., Ellis, N. R. & Pryer, M. W. Absence of noise effects on the simple operant behavior of defectives. *Perceptual and Motor Skills*, 1960, 10, 167-170.

Task: Simple lever pulling
Noise: a. white noise
b. minimal to near pain level (no dB given)
Results: Noise has minimal, if any effects on psychomotor performance.

Boggs, D. H. & Simon, J. R. Differential effects of noise on tasks of varying complexity. *Journal of Applied Psychology*, 1968, 52, 148-153.

Primary Task: 4 choice reaction time, 2 levels of complexity
Secondary Task: Auditory digit-sequence recognition
Noise: .5 sec recorded bursts of a bandsaw cutting aluminum at 92 dB (noise bursts did not overlap any secondary tasks digits).
Results: Noise produced a significantly greater increase in secondary-task errors when the secondary task was paired with the complex primary than when it was paired with the simple primary task. Secondary-task performance provided a more sensitive measure of both task complexity and the effect of noise than did the RT measure.

Broadbent, D. E. Effects of noise of high and low frequency on behavior. *Ergonomics*, 1957, 1, 21-29.

Task: 5 choice serial reaction and simple reaction to onset of noises.
Noise: Broadband noise either above or below 2000 Hz and at either 80, 90, or 100 dB.
Results: The high frequency noise gave more errors in performance, significant only at 100 dB. When reaction times were measured to the same noises, the first reaction of a series with the same type of stimulus was slower when the stimulus was low intensity and low frequency. With high frequency or high intensity stimuli this was not so.

Broadbent, D. E. Effects of noise on an intellectual task. *Journal of the Acoustical Society of America*, 1958, 30, 824-827.

Task: Self-paced mental arithmetic
Noise: 70 and 100 dB, broadband noise
Results: Noise group slowed down at solving the subtractions as time went on, relative to the groups working in quiet. There was an aftereffect of noise such that the subjects who had had noise previously slowed down relative to those who had not.

Brown, R. L., Galloway, W. D. & Gildersleeve, K. R. Effect of intense noise on processing of cutaneous information of varying complexity. *Perceptual and Motor Skills*, 1965, 20, 749-754.

Task: Interpreting messages received cutaneously
Noise:
a. no noise
b. intermittent
c. continuous at 90 dB--white noise

Results: "Neither continuous nor intermittent noise served as a performance disrupter."

Cassell, Edna E. & Dallenbach, K. M. The effect of auditory distraction upon the sensory reaction. *American Journal of Psychology*, 1918, 24, 129-143.

Task: Simple reaction time to auditory stimulus
Noise:
a. continuous tuning fork
b. intermittent electric bell
c. continuous-intermittent metronone

Results:
a. The auditory distractor may inhibit and lengthen the reaction; it may facilitate, and shorten the reaction; or it may become habitual, and have no effect at all.
b. The effect of the distraction is dependent upon: 1) the temporal relations of the distractor, and 2) the conscious attitude of the observer during the distraction.
c. The distractor most resistant to habituation is the intermittent; the least resistant is the continuous.
d. The passive attitude is conducive to a constant sensory reaction of normal length; the active attitude to a slow and variable reaction.

Collins, W. E. & Iampietro, P. F. Simulated sonic booms and sleep: effects of repeated booms of 1.0 psf. *FAA Office of Medicine Report*, 1973, 50.

Task: Sleep
Noise: Sonic boom 1 lb/sq ft
Results: No physical measures showed any statistical significant effect of boom presentations on nightly sleep patterns--(heart rate increased during the minute following the boom by less than 1 beat/minute).

Conrad, D. W. The effects of intermittent noise on human serial decoding performance and physiological response. *Ergonomics*, 1973, 16, 739-747.

Task: Rapid serial decoding
Noise: White noise--93 dB, 20-20,000 Hz
- a. quiet
- b. continuous
- c. periodic
- d. aperiodic

Results: Performance at rapid serial decoding device involving short term memory competence will not be significantly affected by continuous or by periodic or aperiodic intermittent patterns of white noise presented at a level of 93 dB.

Chiles, W. D. & West, G. Residual performance effects of simulated sonic booms introduced during sleep. *FAA Office of Aviation Medicine Report*, 1973, 49, Abstract no. 08268.

Task: Multiple Task Performance Battery given before and after nights sleep.
Noise: Sonic booms--1 lb/sq ft intermittent
Results: No measurable consequences of performance attributable to booms.

Davies, D. R. & Hockey, G. R. J. The effects of noise and doubling the signal frequency on individual differences in visual vigilance performance. *British Journal of Psychology*, 1966, 57, 381-389.

Task: Visual cancellation task
Noise:
- a. white noise--noise 95 dB
- b. white noise--quiet 70 dB

High and low frequency
Results: Introverts made more errors in quiet than in noise. Extroverts made more errors in noise than in quiet.

Eschenbrenner, J. A., Jr. Effects of intermittent noise on the performance of a complex psychomotor task. *Human Factors*, 1971, 13, 59-63.

Task: McDonnell Douglas Image Motion Compensation Simulator.
Noise: White noise
Intensity levels: 50, 70, 90 dB
Duration: Aperiodic, periodic, and continuous
Results: White noise had a detrimental effect on image motion compensation performance. The magnitude of the decrement varied as a function of both the temporal pattern and intensity level of the noise.

Finkelman, J. M. Environmental noise, information processing, and human performance. *Sound and Vibration*, 1975, 9, in press.

Primary Task: Compensatory tracking
Secondary Task: Delayed digit recall
Noise: 80 dB intermittent bursts of white noise presented periodically and aperiodically.
Results: Performance on primary task was not affected by either of the noise conditions. A significant decrement was found in secondary tasks under aperiodic noise conditions.

Finkelman, J. M. & Glass, D. C. Reappraisal of the relationship between noise and human performance by means of a subsidiary task measure. *Journal of Applied Psychology*, 1970, 54, 211-213.

Primary Task: Compensatory tracking
Secondary Task: Delayed digit recall
Noise: 80 dB white noise, presented predictably (9 sec on, 3 sec off) and unpredictably (duration of noise and silence varied).
Results: The use of unpredictable, as opposed to predictable noise resulted in performance degradation on the subsidiary task. Performance on the primary task was unaffected by either types of noise.

Ford, A. Attention-automatization: an investigation of the transitional nature of mind. *American Journal of Psychology*, 1929, 41, 1.

Task: Searching for a single digit number from a row of mixed letters and numerals, then add the numbers as they are found.
Noise:
a. "Klaxton automobile horn placed 2 ft from ear"
b. "record player with loud needle, the amplyfying horn adjusted as closely as possible to S's head"
c. quiet

Results: "...there seems to be no indication of a correlation between number of errors and the presence of distraction. ...there are more errors in the first half of the distraction period than in the last half."

Freeman, G. L. Changes in tension pattern and total energy expenditure during adaptation to "distracting" stimuli. *The American Journal of Psychology*, 1959, 52, 354-360.

Task: Addition problems
Noise: a. quiet
b. noise--50 dB
Results: a. Only a temporary reduction in work output upon introduction of noise distraction
b. The added effort which S exerts to compensate for the distraction expresses itself not only by a rise in total energy expenditure, but also by a shift in the pattern of supporting processes.

Grimaldi, J. V. Sensorimotor performance under varying noise conditions. *Ergonomics*, 1958, 2, 34-43.

Task: Follow patterns with a stylus
Noise: Intermittent-narrow band--70,80,90, and 100 dB varying
Results: Intermittent noise may have a reducing effect on capacity for quick and precise execution of coordinated movements.

Hack, J. M., Robinson, H. W. & Lathrop, R. J. Auditory distraction and compensatory tracking. *Perceptual and Motor Skills*, 1965, 20, 228-230.

Task: Compensatory tracking
Noise: Intermittent noise of 60 dB to half of subjects
Results: "...auditory distraction causes an initial decrement in performance, which is followed by an adaption to distraction condition."

Hartley, L. R. Effects of prior noise or prior performance on serial reaction. *Journal of Experimental Psychology*, 1973, 101, 255-261.

Task: Serial reaction
Noise: a. Continuous broad-band noise at 100 dB
b. Continuous broad-band noise at 70 dB.
Results: a. Noise has a cumulative adverse effect on performance
b. Amount of impairment is determined by duration of exposure to noise
c. Impairment caused by noise and performance is additive

Hartley, L. R. & Adams, R. G. Effect of noise on the Stroop Test. *Journal of Experimental Psychology*, 1974, 102, 62-66.

Experiment 1:
Task: Stroop Test
Noise: a. continuous noise--100 dB
b. quiet--70 dB
c. Broad band noise--50-4,000 Hz
Results: S's tested under both conditions showed increased interference in noise. No increased interference in long as compared to short exposure.

Experiment 2:
Task: Modified Stroop Test
Noise: continuous
a. noise--95 dB
b. quiet--70 dB
Results: Brief exposure to noise decreased interference, long exposure to noise increased interference.

Jerison, H. J. Paced performance on a complex counting task under noise and fatigue conditions. *American Psychologist*, 1954, 9, 339.

Task: To maintain 3 different counts simultaneously and to press key every Nth time a specified number appeared
Noise: a. 110 dB--white noise
b. quiet
Results: Ability to keep a mental count suffers under the conditions of this experiment--performance deteriorates more in noise than in quiet.

Jerison, H. J. Performances on simple vigilance tasks in noise and quiet. *Journal of the Acoustical Society of America*, 1957, 29, 1163-1165.

Task: Mackworth Clock Test
Noise: 112.5 dB broadband
Results: No difference in efficiency attributable to noise level was found.

Jerison, H. J. Effects of noise on human performance. *Journal of Applied Psychology*, 1959, 43, 96-101.

Task: Mackworth Clock Test
Mental Counting
Mental Counting and Time Judgement combined
Noise: 114 and 111.5 dB broadband noise
Results: Changes in alertness as determined by the Mackworth Clock Test were found after 1 1/2 hours in noise; none were found in quiet. Time judgments were distorted by noise. A significant but complex effect of noise on the mental counting task was also found.

Kirk, R. E. & Hecht, E. Maintenance of vigilance by programmed noise. *Perceptual and Motor Skills*, 1963, 16, 553-560.

Task: CRT-display monitoring
Noise: a. Constant 64.5 dB noise
b. Variable noise having average intensity of 64.5 dB
c. Quiet condition--61 dB
Results: The probability of signal detection is higher for the variable noise condition than for the constant noise and quiet conditions. No differences in variability of detection were found between the later two conditions.

McBain, W. N. Noise, the "arousal hypothesis", and monotonous work. *Journal of Applied Psychology*, 1961, 45, 309-317.

Task: Handprinting paired letters continuously in sequence
Noise: a. quiet--clicks of apparatus and sound of fan
b. noise--on magnetic tape, words, music of varying loudness
Results: Improvement in performance in terms of errors made in task is associated with exposure to noise. Awareness of errors was unchanged. Noise reduced the number of errors relative to the number made while performing monotonous task in quiet.

McCann, P. H. The effects of ambient noise on vigilance performance. *Human Factors*, 1969, 11, 251-256.

Task: Audio-visual checking
Noise: 50 dB of 520 Hz presented continuously and intermittently
Results: Although there was no difference between the effects of the two kinds of noise produced a larger number of omission errors than did continuous noise.

Mech, E. V. Factors influencing routine performance under noise: I. The influence of set. *Journal of Psychology*, 1953, 35, 283.

Task: Adding 6, 7, 8, and 9 successively to a given two-place number and then repeating this operation for 60 seconds.
Noise: a. Volume 1: "I can hear it now", side No. 1 (News events of 1933-1945 era) 70 dB
b. quiet
c. intermittent--ABBA order
Results: "Verbal noise, per se, of a given intensity, does not appear to have any necessary effect on the execution of routine work tasks."

Miller, H. Effects of high intensity noise on retention. *Journal of Applied Psychology*, 1957, 41, 370-372.

Task: Visual learning and recall tasks
Noise: 111± dB, 100-6,000 flat-cycles per second
Results: "Noise of the intensity and frequencies employed in this experiment does not significantly affect recall of verbal material learned under controlled conditions."

O'Malley, J. J. & Poplawsky, Alex. Noise induced arousal and breadth of attention. *Perceptual and Motor Skills*, 1971, 33, 887-890

Experiment 1:
Task: Serial anticipation task
Noise: White noise--intermittent; 3 levels: 75, 85, & 100 dB ± 2 dB spl
Results: "...general reduction in utilization of spatially peripheral, or irrelevant, information due to increases in noise-induced arousal."

Experiment 2:
Task: Stroop Color-Word Test
Noise: a. No noise
b. Noise--85 dB
Results: S's operating under noise performed significantly better than those under no-noise.
General findings: Increasing emotional arousal causes a narrowing of attention.

Park, J. F. & Payne, M. C. Effects of noise level and difficulty of task in performing division. *Journal of Applied Psychology*, 1963, 47, 367-368.

Task: Hard and easy division problems
Noise: Air Horn, 98-108 dB, at combined frequencies of 277, 329, and 440 Hz.
Results: There was no decrement in performance attributable to noise level. Under intense noise variability, performance was significantly greater than in the quiet condition with easy problems; there was no such difference with hard problems.

Plutchick, R. Effect of high intensity intermittent sound on compensatory tracking and mirror tracing. *Perceptual and Motor Skills*, 1961, 12, 187-194.

Task: a. Mirror tracing
b. Compensatory tracking
Noise: 105-122 dB with average 115 dB, 2,500 cps or 100 cps, intermittent
Results: High intensity intermittent sound at levels 105-122 dB with frequencies of 1,000-2,500 cps and with repetition rates of 3 pps has no effect on compensatory tracking performance or on error time in mirror tracing.

Poulton, E. C. & Edwards, R. S. Interactions and range effects in experiments on pairs of stresses: mild heat and low frequency noise. *Journal of Experimental Psychology*, 1974, 102, 621-628.

Task: a. Tracking with peripheral lights
b. Five-choice task
c. Visual vigilance
Noise: 102 dB low frequency noise, at 38 degrees-33 degrees C (100-102 degrees F), with the two stresses combined.
Results: The low frequency noise had a beneficial effect upon all three tasks. It interacted with the mild heat on the tracking, and on false detections in the vigilance task. The results are related to behavioral arousal. When compared with a previous experiment on mild heat and loss of nightly sleep, performance in the control condition was found to be influenced by the stresses included in the within-subjects experimental design. This raises doubts about the validity of the interaction.

Reiter, H. H. Effects of noise on discrimination reaction time. *Perceptual and Motor Skills*, 1963, 17, 418.

Task: Press appropriate button at signal
Noise: Ranges from no noise to +3 uV
Results: Beginning at the optimal range of noise, level may increase efficiency in performance of certain discrimination tasks in industrial settings.

Saunders, A. G. The influence of noise on two discrimination tasks. *Ergonomics*, 1961, 4, 253-258.

Task: Variations of:
  a. Bourdon-Wiersma cancelling test
  b. Kraepelin addition test
Noise: White noise--2 conditions
  a. steady--75 dB
  b. varying--65-90 dB, 85-1360 Hz continuous
Results: No overall differences in achievement between varying and steady noise conditions--variances higher for varying than steady noise in second half of each day's session--varying noise showed an effect on performance at average level of 75 dB compared with steady noise at 70 dB (supports Broadbent--changing noise more harmful to performance than continuous).

Smith, K. R. Intermittent loud noise and mental performance. *Science*, 1951, 114, 132-133.

Task: a. Minnesota Clerical Test
  b. Revised Minnesota Paper Form Board Test (Series AA)
Noise: 100± 2 dB broadband noise. Noise was presented in bursts of sound ranging between 10 and 50 sec. Total silent time was equal to total noise time for each successive minute.
Results: Effect upon short-term mental performance of bursts of intense noise is to increase quantity and decrease the quality of response, but these effects are of such magnitude as to suggest that they are practically negligible.

Stevens, S. S., Egan, J. P., Waterman, T. H., Miller, J., Knapp, R. H. & Rome, S. C. The effects of noise on psychomotor efficiency. *National Research Council*, OSRD Report 274, December 1941.

Task: a. Serial disjunctive reaction time task
  b. Coordinate serial reaction time task
  c. Coordinate serial pursuit task
  d. Fast speed pursuit rotor
  e. Card sorting
Noise: 90 and 115 dB aircraft noise
Results: No effects on serial disjunctive RT, coordinated serial pursuit, fast speed pursuit rotor and card sorting. Coordinate serial RT test showed 5.4% reduction in speed.

Teichner, W. H., Arees, E. & Reilly, R. Noise and human performance, a psychophysiological approach. *Ergonomics*, 1963, 6, 83-97.

Experiment 1:
Task: Letter series identification task paced by subject
Noise: White noise through ear phones with levels of 57, 69, 81, 93, and 105 dB.
Results: Errors were negligible. No significant differences among groups due to noise levels. But change in noise level is a variable with a systematic distracting effect.

Experiment 2:
Task: Search task, paced by experimenter
Noise: White noise at 100 dB presented binaurally through earphones 4 on/off ratios
Results: Performance is directly related to the on/off ratio early in exposure and inversely related to the ratio later in exposure. At all sound ratios performance in noise is better than in quiet.

Thackray, R. I. Correlates of reaction time to startle. *Human Factors*, 1965, 7, 75-80.

Task: Flip button at onset of tone
Noise: One tone, 120 dB followed by signal 75 dB
Results: Autonomic reactivity to first intense stimulus was positively correlated with response latency. Negative relationship of response time to final stimulus.

Theologus, G. C., Wheaton, G. R. & Fleishman, E. A. Effects of intermittent moderate intensity noise stress on human performance. *Journal of Applied Psychology*, 1974, 59, 539-547.

Task: Reaction time, tracking, and timesharing (reaction time and tracking combined).
Noise: 85 dB broadband. Randomly intermittent or patterned intermittent.
Results: Patterned noise had insignificant effects. Random noise affected reaction time task. Tracking was not affected, and time-sharing the tasks was affected only after continued exposure to noise.

Tinker, M. A. Intelligence in an intelligence test with an auditory distractor. *American Journal of Psychology*, 1925, 36, 467-468.

Task: Otis Intelligence Test
Noise: a. Two electric bells--intermittent
b. Quiet
Results: Men of all quartiles lost in accuracy when the distractor sounded, but men of the upper quartile lost most (2.7% as against .08% for the lower quartile).

Viteles, M. S. & Smith, K. R. An experimental investigation of the effect of change in atmospheric conditions and noise upon performance. Transactions by the *American Society of Heating and Ventilation*, 1946, 52, 167-182.

Task: a. Mental Multiplication
b. Number comparison
c. Grid location
d. Visual maze
Noise: 70, 80, 90 dB
Results: Increased speed on mental multiplication and number comparison, increased errors on mental multiplication, and fewer errors on grid location as function of increase in intensity.

Warner, H. D. Effects of intermittent noise on human target detection *Human Factors*, 1969, 11, 245-250.

Task: Visual detection (slides) of whether a field of homogeneous letters contained an odd letter or not.
Noise: Intensity levels: 80, 90, 100 dB
Results: Detection time was not significantly affected by the noise level. The total number of errors recorded for each noise condition showed that, in general, as intensity level increased, the total number of errors decreased.

Warner, H. D. & Heimstra, N. W. Effects of intermittent noise on visual search tasks of varying complexity. *Perceptual and Motor Skills* 1971, 32, 219-226.

Task: Visual search task, 2 levels of difficulty
Noise: White noise, 100 dB, 4 ratios of noise on/off in successive 9-sec intervals (0,30%, 70%, 100%)
Results: Detection speeds for the more difficult task condition were faster for any ratio of noise than in the control condition but for the less difficult condition only the 30% noise ratio was faster than the control. The speeds for the 70% and 100% ratios were slower for the less difficult condition. The order of the 30, 70, and 100% ratios, however, without the central comparison indicated that the relative difference between noise effects was the same for both levels of task complexity. The order of condition beginning with fastest was: 30%, 100%, and 70%.

Warner, H. D. & Heimstra, N. W. Effects of noise intensity on visual target-detection performance. *Human Factors*, 1972, 14, 181-185.

Task: Visual search task, 3 levels of difficulty
Noise: Intensity levels: 0, 80, 90, 100 dB
Results: Noise-intensity and display-difficulty levels were significantly interrelated with respect to detection speed but not to detection error.

Weinstein, N. D. Effect of noise on intellectual performance. *Journal of Applied Psychology*, 1974, 54, 548-554.

Task: Proofreading
Noise: Produced by teletype (66-70 dB). Random bursts of noise from 2 1/2 to 15 seconds duration.
Results: Noise subjects did not differ significantly from quiet subjects in detection, spelling errors, but were poorer at identifying grammatical errors. Recall of content of proofreading passages was unaffected. Subjects initially worked more slowly and less steadily during noise bursts than during intervening quiet periods, but more accurately.

Wilkinson, R. T. Interaction of noise with knowledge of results and sleep deprivation. *Journal of Experimental Psychology*, 1963, 66, 332-337.

Task: Leonard's 5-choice Test of Serial Reaction
Noise: Continuous broadband noise at 100 dB
Results: The effect of noise was increased by knowledge of results, reduced by sleep deprivation, and greater among subjects with previous practice on the test. Conclusions are: (a) noise impairs performance as incentive is high and as the task loses novelty through practice; (b) noise and sleep deprivation produce different types of "fatigue" which may oppose each other's action; with sleep deprivation arousal may be too low (especially with no knowledge of results); with noise it may be too high (especially with knowledge of results).

Wolf, R. H. & Weiner, F. F. Effects of four noise conditions on arithmetic performance. *Perceptual and Motor Skills*, 1972, 35, 928-930.

Task: Simple arithmetic problems
Noise: Quiet, speech (87 dB), music (95 dB), industrial noise (105 dB)
Results: S's answered significantly higher proportion correctly for the music condition than for the industrial noise condition.

Woodhead, Muriel. The effects of bursts of noise on an arithmetic task *American Journal of Psychology*, 1964, 77, 627-633.

Task: Mental arithmetic
Noise: Recorded rocket firing, consisting mainly of low frequencies. Peak intensity level was 100 dB
Results: In comparison with quiet condition, the occurrence of a brief noise while the numbers were being learned produced a tendency to get the subsequent calculation wrong. When the noise occurred during the calculation period, the rate of work increased throughout the session from a rather slow start.

Woodhead, Muriel. Effect of brief loud noise on decision making. *Journal of the Acoustical Society of America*, 1959, 31, 1329-1331.

Task: Decision making (Mackworth multichannel test)
Noise: 110 dB, and 85, 95, 115 dB recorded rocket noise
Results: A significant decrement in performance due to noise distraction was found. Effects of noise were related to intensity.

Woodhead, Muriel. Searching a visual display in intermittent noise. *Journal of Sound and Vibration*, 1964, 1, 157-161.

Task: Visual search
Noise: 110 and 70 dB recorded rocket noise, 1-sec duration, presented 5 times during 15-min task.
Results: The number of errors in the whole of a 15-minute search did not differ between the three conditions, but searching was less efficient in the half-minute following the bursts at 110 dB compared with the same periods in either control.

Woodhead, Muriel M. An effect of noise on the distribution of attention. *Journal of Applied Psychology*, 1966, 50, 296-299.

Task: Group 1: Memorizing numbers of letters
Group 2: searching for letters
Noise: a. quiet--68 dB
b. noise--105 dB
band 80-6,000 cycles
Results: When directions emphasized searching, there is little difference between noise and quiet groups--when instructions emphasize memorizing noise affected performance by reducing errors.

Woodhead, Muriel. Performing a visual task in the vicinity of reproduced sonic bands. *Journal of Sound and Vibration*, 1969, 9, 121-125.

Task: Decision making
Noise: Recorded sonic bangs
Pressure level was 2.53, 1.42, and .80 lb/sq ft
Results: Performance was temporarily impaired at the highest noise level.