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A COMPARISON OF THE VISUAL AND AUDITORY SENSES AS CHANNELS FOR DATA PRESENTATION

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FOREWORD

This report constitutes an effort to compare the auditory and visual senses as channels for the presentation of information to the human operator. It concludes with a number of tentative suggestions for the communications engineer as to a choice between the visual or auditory presentation of data. The survey of the experimental literature and analysis of the operational demands were made by Dr. R. H. Henneman and Dr. E. R. Long at the request of the Aero Medical Laboratory. Several Psychologists in the field of human engineering have contributed criticisms and suggestions for revision of a preliminary draft of this report. Special acknowledgement is made to Dr. Alphonse Chapanis, Dr. J. W. Gebhard, and Dr. G. H. Mowbray for their contributions. This report was prepared at the University of Virginia under Contract No. W33(038)-ac-21269. This contract was initiated under a project identified by Research and Development Order 694-37 (now Project 7192, Task 71603), Visual Message Presentation. The contract was administered by the Psychology Branch of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, with James E. Smithson acting as Project Engineer.

ABSTRACT

It is the contention of the present report that the choice between the eyes and the ears as sense channels for the presentation of information to the human operator rests upon the specific demands of various operational situations. Three sets of variables impose demands for the presentation of data, some of which have implications for visual or auditory presentation. These three sets of demands are: (1) Demands imposed by response variables (e.g., orientation in space, fine quantitative comparison, rapid referability). (2) Demands imposed by operator variables (e.g., previous habits, fatigue, motivation). (3) Demands imposed by special environmental conditions favoring one or the other sense channel (e.g., ambient noise, sudden changes of illumination, excessive vibration).

The stimulus properties of light and sound differ; the receptor characteristics of vision and audition also differ. It is possible, by matching these distinguishing sense characteristics with specific demands of particular situations, to suggest some "division of labor" between the two sense channels for purposes of data presentation. Four principal categories of demands for informational input have been proposed as follows: (1) typical demands for visual presentation; (2) typical demands for auditory presentation; (3) typical demands served by either sense alone; (4) typical demands for dual audio-visual presentation.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
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INTRODUCTION

The Problem of Auditory Versus Visual Presentation

The post-war evolution of the field of human engineering has focused attention on the limitations and capabilities of the human operator as factors determining the efficient design of equipment used in man-machine systems. A striking illustration of the human operator variable is to be found in recent discussion of an old question, namely, do the eyes or the ears afford the more efficient sensory channel through which to present information? The answer to this question is not simple, and neither psychologists, design engineers, nor operator personnel are agreed on the answer. Engineers have been quite successful in building complex visual presenters and consequently tend to favor visual displays. For purposes of communication at least, operating personnel have argued strongly in favor of retaining the human voice, thus the auditory channel. Psychologists, working in the area of human engineering, are sharply divided on the issue. The lack of agreement is strikingly illustrated in debate over the relative information-handling capacities of the eyes and ears. Jacobson (47, 48), for example, estimates the channel capacity of the visual sense to be many times greater than that of audition, while Fano (23), Licklider, and Newman, working at the Massachusetts Institute of Technology and Harvard, are doubtful if there is any marked difference in channel capacity between the eye and the ear.[1] From a review of the research literature and from discussion of this subject with psychologists interested in human engineering, the impression is gained that there are currently three positions relative to this controversial question: (1) the eye is far better adapted than the ear for most types of data presentation; (2) the auditory sense is superior to vision for certain purposes, especially for communicating warning, commands, and status information to the operator; (3) the two sense modalities are potentially equal for utilization as channels for the input of information. Supporters of this last viewpoint contend that the auditory sense channel simply has not yet been sufficiently exploited to make use of its inherent capacity for data presentation.

A comparison of the auditory and visual senses, as related to the presentation of information in operational situations has become an emphatic need of the communications engineer. In spite of the recognition of human operator factors, such considerations as weight, space, range, and radio frequency spectrum, continue to be the most frequently considered criteria in equipment design research. The engineer is not wholly to blame for this

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1. The basis for this statement is contained in a personal communication to the writers from Dr. E. B. Newman, Department of Psychology, Harvard University.

situation. Psychologists have not been able to provide, in easily understood terminology, the basic facts of human perception necessary for practical recommendations. In discussing this need for information by the engineers, it is well to point out the difficulties involved in securing and integrating psychological background data, as well as the reasons for the existence of these difficulties.

Difficulties Involved in Comparing Audition and Vision

Extensive surveys of the experimental literature of audition and vision have revealed few studies directly comparing the two senses for purposes of communication. These few investigations have been conducted principally in the fields of education and advertising to discover the relative advantages of visual and auditory presentation for the learning and retention of various types of material. The experimental results have been far from conclusive, the relative superiority of the one sense modality or the other appearing to be a function of the specific experimental conditions. Even when one searches the experimental literature to ascertain differences between audition and vision which might be applied to the presentation of information, the results are disappointing. The majority of the studies have been concerned with receptor processes and sensory thresholds rather than with perceptual phenomena. The communications engineer, however, confronted with the problem of devising equipment to present meaningful signals (to be interpreted as control data or commands) is more interested in auditory and visual perception, than in the more basic sensory phenomena of the two senses.

The dearth of experimentally verified comparisons between auditory and visual perception is not entirely attributable to arbitrary neglect by sensory psychologists. Further consideration of this problem leads to the realization of the many practical difficulties that have stood in the way of directly comparing these two sense modalities in the experimental laboratory. It has not thus far been possible to establish common dimensions along which to locate comparable visual and auditory stimuli. Furthermore, different psychophysical procedures must frequently be employed in comparing the two modalities (largely because of the temporal-sequential character of auditory stimuli). As a consequence, it is not possible to compare directly auditory and visual judgments with broad generality and a high degree of practicability. How practicable, for example, is it to compare pitch discrimination with color discrimination for conveying information to a human observer? Which of the two senses possesses the larger number of usable stimulus dimensions for purposes of coding information? Certainly, psychologists are not in agreement on the answer. Again, if the engineer wished to know whether the intelligibility of speech or of visual print were more resistant to physical degradation of the signals, how experimentally could this question be answered? Are very brief visual stimuli equivalent, as signals, to very brief auditory stimuli? Is loudness equivalent to brightness? Is auditory volume equivalent to visual extent? It might be argued that partial answers to the above questions are possible from laboratory experimentation. However, it is to be stressed that such experiments can be set up to cover only limited ranges of stimulus dimensions, with consequent failure to yield the broad and useful generalizations desired by the communications engineer.

Conditions Determining the Choice Between Auditory and Visual Input

It is the contention of the present report that the question of the relative superiority of vision and audition, when asked broadly, and without specification of the relevant conditions, is largely meaningless and unanswerable. A more profitable form of the question would be: Under what conditions, or for what purposes, is auditory or visual data presentation more efficient? There are basic differences between the auditory and visual senses which provide peculiar advantages and deficiencies depending upon their intended use. It should be emphasized that the human operator may be called upon to make many different types of responses in reacting to data displays. Thus, the operational situation may require any one or several of the following: (1) signal detection; (2) target location or selection; (3) target identification; (4) complex computation; (5) "decision-making"; (6) the selection of appropriate words in replying to messages; (7) the selection of appropriate controls in machine operation; (8) the proper adjustment of these controls (e.g., in direction or extent). These different kinds of human activities have different needs with respect to informational input. In other words, various types of operator responses may be said to have their own peculiar "demands" for data displays and information-presenters.

In addition to these response demands, both environmental factors and conditions affecting the organism, play a part in the choice of the sensory channel through which data would best be presented. Thus aside from the question, "What does the operator have to do with the information?", one needs to ask further questions, such as "What are the environmental conditions under which the information is presented?" "What is the physiological and motivational state of the operator?" "What are his previous habits of receiving such kinds of information?" Environmental variables such as illumination level, ambient noise, air pressure, or excessive vibration, obviously exercise a differential influence upon the seeing and hearing efficiency of the human operator. The practical implications of some of these environmental conditions will be noted in a subsequent section of this paper. The physiological state of the organism, as illustrated by fatigue or anoxia, is also of importance in determining the human's sensitivity to auditory or visual stimuli. Finally, habit plays an important, sometimes a dominant role in human perception. The heavy reliance upon the voice as the primary medium of communication in everyday life is probably the principal reason for the insistence of pilots and control tower operators upon retention of the conventional radio-telephone and "intercom" systems.

Final Behavior as the Ultimate Criterion

To sum up the thesis of the present report, the ultimate criterion by which the sensory input channel should be selected is the efficiency of the operator's final behavior in practical situations. This final behavior is a joint product of the several factors noted above, i.e., the nature of the responses being made, environmental conditions, and conditions within the organism, including fatigue, motivation, expectancies, and previous habits of perceiving. With these factors in mind, it should be possible to relate the known characteristics of vision and audition (as learned from physics, physiology and psychology) to the established demands of various operational situations. Stevens has defined communication in a broad, operational manner which is quite congruent with the final behavior criterion (75). For him, "communication is the discriminatory response of an organism to a stimulus". Note that the crucial distinguishing feature is that a differential reaction of some sort is made; "the message that gets no response is not a communication". The remainder of this report will be concerned with an attempt to illustrate this matching or relating of sensory input characteristics to behavioral demands with some consequent suggestions as to the choice between vision and audition for specific purposes.

Purpose and Plan of the Present Report

The primary purpose of the present report is to suggest a number of practical choices between auditory and visual data presentation for consideration by communications engineers and psychologists interested in the field of human engineering. Many such practical differences between the auditory and visual sense channels can as yet be only hypothetical, that is, only partly supported by experimental evidence. Thus a considerable amount of speculative comparison is necessitated both by the lack of precise knowledge at the present time (as noted above), and by current disagreement over the basic characteristics of vision and audition (also referred to above). Therefore the formulation of the suggestions in the concluding section of this report has necessarily entailed heavy reliance on professional judgment in the absence of clearcut empirical evidence. This professional judgment has been based partly on a knowledge of the experimental psychology of vision and audition, and partly on a knowledge of the operational situations to which application is sought.

The general plan of the report calls for three principal sections following the Introduction. The first of these will summarize a comparison of the visual and auditory senses with respect to stimulus-receptor characteristics. The salient points of this section, drawn largely from experimental psychology, will provide the bases for some of the inferences to be made in the final section. The second section will seek to present and amplify the concept of demands for sensory input and to illustrate this concept with three categories of such demands: (1) those based on the nature of the responses made by the operator to the data presented; (2) those derived from a consideration of variable conditions within the operator receiving the data; and (3) those associated with special environmental conditions favorable to data reception through one sense channel or the other. The concluding section contains the gist of the report, i.e., a presentation of various classes of demands for visual or auditory data presentation. Four such classes of demands will be proposed: (1) demands for visual presentation; (2) demands for auditory presentation; (3) demands for dual audio-visual presentation; and (4) demands served equally well by data presentation through either sense channel alone. Empirical evidence, where available, will be cited in connection with the generalizations proposed in this final section.

A BRIEF COMPARISON OF AUDITION AND VISION AS INFORMATIONAL INPUT CHANNELS

Scope of the Attempted Comparison

An exhaustive comparison of the auditory and visual senses as channels for the input of information is not possible in the present report. Several such detailed comparisons have been attempted by other writers. The literature comparing the relative intelligibility of materials presented through the eyes and the ears has been surveyed by Day and Beach (19), and by Cheatham (11). The psychophysical aspects of the two senses have been compared in a stimulating monograph by Harris (41). There are other excellent sources of comparative information about the two senses, such as Stevens (74), Geldard (34), Chapanis, Garner and Morgan (10), and the Tufts College Handbook of Human Engineering Data (78). It would be extremely lengthy and of doubtful value to present in this report sensitivity functions and threshold values for the two senses derived from various of the above sources. As was pointed out in the introductory section, much of the experimental data available on the visual and auditory senses has very questionable relevance to practical problems of identifying information from data presenters, or responding efficiently to messages in operational situations.

Nevertheless, in order to afford some firm bases for the generalizations to be proposed in the concluding section, a summary comparison of the two sense channels should be included in the present report. In the ensuing comparison two points are to be kept in mind: (1) the items selected for mention have been chosen from among a large number of possible points of comparison, and (2) some of the generalizations can be stated only tentatively at the present time. This latter restriction results from either a limited number of relevant experimental studies, or from lack of agreement among the various studies, or from both. The points included in the summary comparison to follow have been selected as applying to the intake of meaningful data and/or messages in operational situations, and as supporting the suggestions to be advanced in the final section of the report.

Finally, it should be noted that the writers had a choice of two approaches in making the comparison between audition and vision: (1) from a rather practical viewpoint with evidence based on actual use of the two sense channels up to this time, and (2) from a more theoretical and long-range viewpoint, derived from speculation as to ultimate potentialities of the visual and auditory senses. The writers have chosen the former approach, partly because of considerations imposed by the limitations of time available for the preparation of this report, and partly because of current lack of agreement in this area of experimental psychology.

Stimulus Characteristics of Audition and Vision

The physical properties of light and sound stimuli are primarily the concern of the engineer who must provide for the transmission of the energy from the transmission source to the human operator who is to receive and act upon the presented data. While energy transmission may be safely consigned to the engineer, data presenters must themselves transmit light or sound stimuli to the eye or ear of the operator before he can perceive them as signals. There are some characteristics of light and sound that bear directly upon a choice of presentation devices or type of display. Some of the more important of these are the following:

1. Wave length. The very short light waves contribute to the greater visual efficiency in detecting such object properties as position, size, shape, etc. They also cause the linear propagation of light with resultant sharp shadows. The longer sound waves suffer much less obstruction from objects located in their paths.

2. Velocity. The fact that light travels roughly a million times faster than sound can affect the relative capabilities of seeing and hearing where distance from the presentation source is considerable. Thus, at a distance of 100 yards, a sound stimulus would lag behind a light stimulus to the extend of about .30 sec., a fact which forces timers of track meets to start their watches at the smoke of the starter's gun and not at its sound.

3. Sidebands or modulation effects. The sidebands caused by the intermittent stopping and starting of a tone or noise extend over a substantial part of the audible range, whereas the same frequency spread in the case of the visual spectrum is imperceptible. These sideband differences between light and sound may have some implication for the relative capacity of the eye and the ear to distinguish closely spaced pulses of sound or light. Thus observers might be discriminating very short pulses of sound on the basis of differences in spectral distribution. The matter of the relative temporal discrimination of the ears and the eyes will be discussed more fully below.

4. The relative distribution of light and sound stimuli in space and time. Although both sound and light sources (and reflecting surfaces) are distributed along both spatial and temporal dimensions, for practical

purposes sound waves seem to be more subject to mutual cancellation and reinforcement than do light waves. Thus the listener who at one point in the auditorium can hear perfectly but at another point can hear nothing, is very much aware of standing wave patterns and their influence on hearing. This sort of problem is seldom encountered in vision, an example being where a person wishing to detect a target under water must peer through an oil slick. Ordinarily, the interference of light waves can be produced and observed only under special laboratory conditions. This differential characteristic of the two wave forms suggests a superiority of vision over audition unless the standing wave patterns of sound are eliminated by some special provision of acoustical engineering.

5. Perceptible range. Many forms of visual stimuli, such as flashes of light, smoke, flares, or signal flags, are detectible at greater distances than are most auditory stimuli (without mechanical aid). Such time-honored means of visual signalling would appear to "carry" farther than the bugle and drum, traditional devices for transmitting auditory information at a distance.

6. Stability of illumination. Ordinarily, illumination conditions are fairly stable and relatively homogeneous in time, while auditory stimuli are characteristically periodic and heterogeneous. It is probably these stimulus properties that lead to the striking distinction between vision and audition in adaptation effects, which have frequently been attributed to differences in the auditory and visual receptor processes. The radical change of illumination level between day and night, and between indoors and outdoors, provide important exceptions to illumination stability and consequently create problems of adaptation. The fact of these much greater practical adaptation effects in vision than in audition often influences the choice between the two senses as input channels.

7. Generation of light and sound signals by humans. The point has sometimes been made that humans carry with them built-in sound generators (the speech mechanism), but no light transmitters. While this is strictly speaking true, it ignores the extensive use of gestures, facial expressions, and posture for the communication of ideas. It may well be that speech provides us with the most flexible, rapid and "natural" means of communicating with others. For most individuals, habitual reliance upon voice communication probably makes this true. It is to be noted, however, that gesturing can be quite as rapid or as spontaneous as speech; indeed, the deaf mute, highly skilled in "talking with his hands", achieves amazing speed and flexibility of expression.

Selectivity and Directivity of Reception

A difference between the visual and auditory reception of information which has important implications for data presentation is what may be termed selectivity or directivity. Because the eyes can be closed, and because the visual field is spatially restricted, and further because of the mobility of the eyes, they provide much better directive and selective sense organs than do the ears which are largely at the mercy of environmental stimulation from any point in space. The fact that the ears can receive signals from any direction means that they are at the same time more easily disturbed by noise or irrelevant signals coming from many directions at once. It is much easier to detect and "read" a changing light pattern located in a field of competing light stimuli than it is to pick out and "read" exclusively the signals from one of many simultaneous scattered sound sources (4).

Available Dimensions for Coding (Relative Sensitivity of the Eyes and the Ears).

At the present time there are considerably more practical ways of displaying information to the eyes than to the ears. The great variety of visual displays such as meters, gauges, oscilloscopes, maps, charts, scale models, bulletin boards, light panels, pictures, tables, graphs, letters and other symbols, is more impressive than the methods of auditory presentation (e.g., speech, music, warning signals, Morse Code, whistles, drums, etc.) Whether this preponderant reliance upon the visual channel reflects basic differences in potential informational transmission capacity between vision and audition is an interesting question and one not easily answered. Two opposed viewpoints are prevalent. The first holds that the present large scale employment of visual presentation devices is primarily a result of tradition and chance development of communications equipment. It is argued that if sufficient time and effort were to be concentrated upon a fuller exploitation of the sense of hearing, many more practical uses of sound could be discovered for the transmission and presentation of information. Those adhering to the second viewpoint maintain that the visual sense provides us with more basic stimulus dimensions than does audition. Thus, there are six quite accurate dimensions in vision which are useful for coding: the two spatial co-ordinates, intensity, wave length, time, and depth. Correspondingly, the principal auditory dimensions are intensity, frequency, and time, with spatial location added as a rather inefficient fourth type of discrimination.

One may turn to the comparative research literature of vision and audition in seeking evidence to support one or the other of the above positions. This literature deals primarily with the sensitivity or discriminability of the two senses. Discriminability refers to the number of just noticeable differences along a particular dimension (e.g., sones for loudness, or mels for pitch). Discriminability also refers more broadly to the total number of discriminable sense steps within a single modality, that is, all of the various sense dimensions, e.g., hue, brightness and saturation in vision, or pitch and loudness in audition. Pertinent references in this area include Geldard (34), Harris (41), Stevens (74), Davis (18), The Tufts College Handbook (78), and Chapanis, Garner and Morgan (10), which have been referred to above.

The very considerable amount of psychophysical research which has been done on these two senses has yielded a great deal of information about their relative discriminabilities, but is of only limited value for the problem at hand. For the interpretation of data in practical situations the human operator is called upon to make absolute judgments rather than to make comparative judgments. That is, he must recognize accurately a certain shape, color, pitch, or loudness when the signal occurs alone, rather than merely to state which of two lines is longer, or which of two tones has the higher pitch. It is obvious that absolute judgments or recognitions are far more difficult for the human observer than the comparative judgment stimulus dimensions. The fact that human capacity to judge small stimulus differences so greatly exceeds ability to make absolute judgments has influenced some psychologists in the field of human engineering to consider the possibility of developing data presenters that would make greater use of sensory discrimination.[1]

It is difficult to compare directly the relative sensitivity of the visual and auditory senses. The conflicting conclusions of Jacobson (47, 48) on the one hand, and those of Fano (23), Licklider, and Newman have already been referred to in the Introduction. Differential thresholds for wave length, or intensity, or frequency, for example, depend upon numerous factors in the case of both senses. What seems obvious is, that either sense possesses very acute sensitivity, there being far more j.n.d.'s along the more common dimensions than are actually used in any existent displays. The basic problem here appears to be one of exploiting the potentials of the two sense channels maximally to meet the demands of various practical situations. What new types of displays may be developed in the course of such exploitation in the future can only be a matter of speculation.

Recent psychophysical studies have uncovered evidence of a very interesting, possibly a fundamental, characteristic of human perception of information through the senses. The results of several investigators suggest that there is a maximum amount of information that can be obtained from absolute judgments along a single stimulus dimension, and that this amount is about the same for all senses. The range of this maximum is from 2 to 3.32 bits, i.e., is equivalent to the use of 4 to 10 stimulus categories. In audition, Garner (31) has found that the greatest amount of information is transmitted in the absolute judgments of loudness when 5 categories are used (2.2 bits being transmitted). Increases or decreases in the number of categories result in decreases in transmitted information. Pollack (68) reports similar findings for the absolute judgments of pitch (5 categories or 2.3 bits transmitting maximum information).

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1. This idea has been expressed to the writers by Dr. J. W. Gebhard of the Applied Physics Laboratory, Johns Hopkins University. Dr. Gebhard has research along these lines in progress at the present time.

In the case of vision, Hake and Garner (39) report that the most useful number of categories is 10 when a single dot is being located along a straight line. Klemmer and Frick (51) point out that the 3.32 bits of transmitted information of the Hake and Garner unidimensional experiment may be increased by increasing the number of dimensions---a maximum of 7.8 bits being transmitted when eight coordinates were employed. Gebhard and Slivinske (both by personal communication to the writers) report results similar to, although slightly lower than, those previously mentioned by Hake and Garner. Gebhard reports that a maximum amount of information is transmitted in the absolute judgment of depth when approximately five categories are employed. Slivinske reports essentially the same number of categories to be best in the absolute judgment of circularity along a continuum ranging from a straight line through elipses of varying axis ratios to a completely symmetrical circle.

Spector (73) reports similar findings for the absolute judgments of vibration, maximum information being transmitted when five categories were used for intensity, seven for temporal duration, and six for spatial locus. The data reported here are the maxima, means for all subjects being slightly less than those values.

The major conclusion from the above research is that there seems to be some maximum amount of information that can be obtained from the absolute judgments of a single stimulus dimension, this being 2 to 3.32 bits and equivalent to the use of 4 to 10 categories. This indication of a general information-handling capacity for all senses suggests the operation of a brain mechanism at work, rather than sense organ processes as the principal determiner of rate of information assimilation.

The Spatial and Temporal Attributes of Vision and Audition

For purposes of data presentation, perhaps the most important difference between the auditory and visual senses is their respective discriminability in the spatial domain. Vision is a highly developed spatial sense, while audition is primarily a temporal sense. Thus, because of its spatial acuity or resolving power, vision is particularly well adapted to the reception of locational and relational data presented simultaneously, but distributed in space. Many forms of displays, such as maps, diagrams, charts, tables, and pictures, afford examples of our common reliance upon vision for this purpose. Audition, on the other hand, because of the structure of the receptor mechanism, has much greater temporal than spatial acuity, and is better adapted to the discrimination of signals distributed in time. Speech, Morse Code, and music afford everyday examples of temporal patterns of sound stimuli. It is important to note that data presented to the perceiver through the ears must be presented sequentially, whereas visually presented data may be displayed either simultaneously or sequentially. This is not to deny that the eye "takes in" spatially distributed stimuli in successive "scans", nor that the ear is totally unable to scan and analyze a complex pattern of auditory stimuli. In listening to a full orchestra, for example, the auditory process may afford analytic listening much as the eye might look over a map for certain landmarks. The trained musician is able to make many fine discriminations in such a situation, taking advantage of simultaneous complex sound patterns as his cues. For many practical purposes, however, most investigators agree to the generalization that vision is a far more accurate sense for spatial discrimination. The auditory sense admittedly allows for a limited degree of spatial discrimination (such as the approximate location of sound sources) and to that extent is able to supplement visual spatial discrimination, but it seems unlikely that audition could ever replace vision as a spatial sense to the same degree that vision could be substituted for audition as a temporal sense.

The problem of the relative temporal discriminability of audition and vision is more complex than was formerly thought. It is easy to make the general assertion that audition is "the time sense", just as vision is "the space sense". But vision, except at low stimulus intensity levels and extremely short temporal durations, also possesses excellent temporal acuity. Recent research comparing the temporal discrimination of the two senses has not provided altogether clearcut evidence. Thus Bice and Taubman have obtained evidence for auditory superiority in the identification of discrete stimuli. Taubman (76, 77) has reported that as many as ten discrete auditory stimuli can be clearly reported when separated by a time interval of 0.125 seconds. Ten discrete visual stimuli cannot be reported until they are separated by intervals of 0.500 seconds. Bice (3) reports that auditory Morse Code can be received much more rapidly than visual code, even when the slow operation of the shutters in the visual blinker system has been removed. Cheatham and White (12), on the other hand, find (under different experimental conditions from Taubman) that vision and audition are about equal for the detection of discrete stimuli, both approaching a maximum perceptual (numerosity) rate of ten per second. Gebhard and Mowbray (in a personal communication to the writers of this report) also maintain that the temporal discrimination of vision and audition are approximately the same.

In this connection another comparison between the senses is of interest, namely, visual simultaneous(spatial) versus auditory temporal discrimination. Kaufman et al. (50) have found that with an exposure of 0.20 seconds four visual dots could be counted without error. Taubman (76, 77) found that four auditory stimuli (or any larger number up to ten) could be counted if the interval between stimuli was as long as 0.125 seconds. This means that when a 40-milli-sec. stimulus presentation time is used, 0.535 seconds are required. Thus four simultaneously presented visual stimuli can be identified with a much shorter presentation time than four temporally distributed auditory stimuli. Apparently, according to these data, 1.125 seconds are required for the correct recognition of ten auditory stimuli occurring successively. It would be interesting to see if the visual superiority would persist if the number of visual stimuli were increased beyond the apprehension span (i.e., six) to say, ten.

Three tentative conclusions are suggested by the comparative research in this area: (1) the efficiency of the visual sense for temporal discrimination is much greater than was formerly thought; (2) whether there is any actual difference between the two senses in this regard seems to depend upon specific experimental conditions; (3) with adequate training it would seem possible that either sense might be employed for the intake of information requiring fine discrimination of temporal intervals; (4) the visual sense probably affords more redundancy (which may be useful, irrelevant, or even obstructive) than audition because of its greater overall sensitivity to spatially and temporally distributed stimuli combined.

Referability

An informational display may be said to have good referability when it presents data for relatively long durations, or repeatedly, thus affording the operator opportunity to refer back to it as needed to direct his behavior. Thus, maps and bulletin boards are displays primarily designed to afford good referability. Instructions or information presented by voice, on the other hand, are not referable except in the form of "repeats".

As a result of sequential presentation, aurally presented stimuli have poor referability (i. e., they cannot be kept continuously before the observer for reference as can visual stimuli). The message may be repeated, but only periodically. In contrast, most forms of visual presentation afford good referability because of "storage" characteristics inherent in the display. "Hard copies" of printed messages may be provided, or other types of displays can be presented for varying periods of time as may be needed by the perceiver. The importance of referability in minimizing errors of memory is obvious. Auditory referability achieved by periodic repetition is also effective in the case of brief signals or messages. Radio station identifications are common instances of such auditory referability. The A and N signals of the radio beam provide another example of this type.

The Factor of Attention as Related to Auditory and Visual Input.

One of the most important considerations in any practical comparison of audition and vision is the factor of attention. There are two aspects to the operation of this factor: (a) a warning or "setting" process to facilitate the perception of new or unexpected stimuli, and (b) a shifting back and forth between two or more competing sequences of stimuli in multiple simultaneous task performance.

Auditory stimuli appear to be inherently more "attention-demanding" than visual stimuli of moderate intensities. They "break-in" upon the receiver though he may be pre-occupied with distracting tasks, or relaxed and not expecting a signal. On the other hand, visual stimuli are perceptible (as a rule) only when and if the operator is looking at the display and expecting a signal. Visual stimuli have no "captive audience" as a rule. Mackworth (59, 60) points out that lack of activity can produce marked impairment of visual efficiency. Evidence from 73 two-hour tests with synthetic radar showed that blank periods of 5 to 10 minutes resulted in the missing of 2% to 10% (25% immediately after inactivity) of the visual signals. Raising the brightness of the signal echo compensated in part for this loss. This seems to suggest that audition might have been better in this case because of its "break in" characteristics.

The "divided attention" factor is becoming of increasing importance because the human operator is being called upon to perform ever more complex tasks in decreasing time allotments. Examples of simultaneous multiple task performance are both numerous and important in air operations. The fighter pilot, the GCI and GCA controllers, and the control tower operator all perform basic perceptual-motor tasks during which they are frequently interrupted to respond to additional signals or to exchange messages. A series of investigations at the University of Virginia (42, 43, 46, 70) have shown that under conditions of a distracting task voice messages are more intelligible than visual (printed) messages. This auditory superiority held for both visual and non-visual distracting tasks, and for a wide variety of messages.

Other investigators have studied the effects of the simultaneous input of information through the eyes and the ears when the two inputs were in competition. The evidence seems to indicate that when a person is required to divide his attention or to shift back and forth between two tasks, one visually controlled, the other aurally controlled, either task can be made a "priority" task at the expense of the other. Sense channel as such does not determine this priority. Thus Mowbray (64, 65) found that when visually presented data were especially attention-demanding the aurally presented data suffered markedly.

CONDITIONS DETERMINING DEMANDS FOR THE SENSORY INPUT OF DATA

Varying Demands for Informational Input

As has been pointed out above, a persistent difficulty in comparing audition and vision is that their relative superiority appears to depend upon the specific conditions making up a particular situation. This frequently verified finding compels a consideration of the probable reasons behind it. Apparently the respective characteristics of the two senses are adapted differentially to meeting the needs of various response situations and operator variables. This principle was advanced in the introductory section and will be amplified and illustrated in the present section.

Traditionally the interest of psychologists in the field of communication has been largely centered on message legibility and audibility, as tying together techniques of presentation with the sensory limitations of the human operator (11). The principal question under investigation might be phrased as "What is the most intelligible manner of presenting messages?" Answers to this question have been sought by investigating such problems as the legibility of letters and digits, the readability of dials, and the most efficient signal-to-noise ratio for the interpretation of speech.

It has been characteristic of such research to hold all variables, other than those associated with the stimulus, constant. Furthermore, in holding them constant the experimenter has usually chosen those values of the variables which would contribute the smallest possible variance to the results. As an illustration, in determining the most efficient signal-to-noise ratio in speech detectability, the simplest possible (e.g., repetition of the word as heard) response on the part of the operator would be typically required. From the standpoint of good experimental methodology this is undoubtedly wise, for the results are thus left unconfounded by extraneous variable conditions. On the other hand, from the standpoint of practical communications this procedure may impose a severe limitation upon the generality of the conclusions. It is a principal thesis of the present report that effective psychological research must include not only the operator's perception of messages, but the manner in which the special characteristics of either audition or vision interact with other operator variables. Suppose, for example, that the operator is required to make a response involving a continuous movement of the hand in space through a path which is quite narrow. Suppose further that this path must be communicated to him. It seems quite reasonable that this might more easily be accomplished by way of vision because of certain characteristics of the visual sense referred to in the previous section. To the extent, then, that either audition or vision has certain unique characteristics that contribute to response efficiency, the sense channel in question better meets the demands of that response. Stated in a slightly different fashion, it would be said that different responses have different demands which are better fulfilled by one rather than the other sense channel.

This idea has been developed and expounded in several papers prepared by psychologists at the University of Virginia.[1] Stevens (75) was also

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1. This position was basic in an analysis of the communication process appearing in Progress Report No. 20, Visual Message Presentation Contract, University of Virginia, June--August, 1951. This same thesis was developed more fully in a paper presented at the National Conference on Airborne Electronics in Dayton, May 1952, "An Analysis of Ground-Air Communication from the Viewpoint of Human Engineering". An abstract of this paper appeared in Airborne Electronics, 1952, pp. 129-130. A similar argument was advanced in a memorandum comparing the

cited in the introductory section as having voiced this same viewpoint. The effectiveness of a given communication system can be evaluated only in terms of the speed and accuracy of responses made by the key human operators involved.

Viewed psychologically, messages are to be regarded as stimuli selected so as to bring about appropriate responses. An efficient communication system is one in which the form of stimulation is best adapted to inducing the desired behavior on the part of those receiving the messages. This idea will be recognized as essentially related to the concept of "stimulus-response compatability" which has recently been advanced by human engineering psychologists (26, 33).

Whereas the engineer is apt to limit his attention to the presentation equipment, and factors determining the legibility or audibility of signals, the psychologist remembers that it takes more than a stimulus to produce behavior---there must also be an organism (in this case the human operator). And this organism introduces an important, if unwelcome, variable into the communication system. For example, the aircraft pilot or control tower operator may fail to react appropriately even when the radio message reaching him is loud and clear. The following paragraphs of the present section will be devoted to an amplification of the position that response factors and organismic conditions play significant roles in determining the sense channel through which information can be most efficiently presented.

Response Variables Imposing Demands for Sensory Input

It is obvious that the operator (for example an aircraft pilot or traffic controller) may be called upon to perform a variety of activities at one time or another. Thus, he may have to respond immediately to a message (as in answering a question), or may need to remember its content for a long period of time. Flight plans, weather information or target information are examples of messages calling for delayed response. The operator may sometimes be required to make decisions or computations, based on information contained in the message. Again, the operator's activities may consist largely of a number of precise manual adjustments of controls made in response to vectoring instructions. Air intercept controlling and ground controlled approaches are examples. In any of the above classes of behavior speed of response may or may not be important.

It is probable that a systematic psychological analysis of the responses called for in a variety of operational situations would be highly

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auditory and visual senses for purposes of communication, which was prepared for the Aero Medical Laboratory by the University of Virginia, September 1953. The present technical report is a revision of this last memorandum.

fruitful. Such analysis might be derived from a systems research approach, or possibly from the psychological literature on the analysis of human abilities. Whatever the approach, the goal of such analysis would be the identification of a set of dimensions in terms of which responses to messages could be described and measured. One may guess what some of these dimensions would be: (1) number of response alternatives to choose among; (2) dependence of the response upon sensory input data (as opposed to control by operator memory); (3) time limits within which the response must be made; (4) interval of delay between stimulus (message) and response; (5) total response duration, i.e., time required to complete the response; (6) discreteness or sequential character of the responses to be made. It is reasonable to believe that there are optimal forms of message presentation geared to such response variables as those noted above (26, 33).

Operator Variables Imposing Demands for Informational Input

One of the outstanding achievements of modern psychology has been the establishment of the variability of human behavior. This variability exists from one person to another in the same situation, and in the same individual from one situation to another, and from one time to another in the same situation. Increasingly in recent years research on perception has demonstrated that factors within the observer play important, sometimes dominant, roles in determining responses to stimuli. Therefore in comparing sense channels for data presentation it is necessary to consider variable conditions within the human operator. Level of training, previous habits of listening and looking, expectation or "set", fatigue, and motivation are instances of variable factors which might be expected to play a part in determining the relative efficiency of visual or auditory presentation. Some of the more obvious of these factors will be treated briefly below.

1. The role of past experience in comparing vision and audition. It seems reasonable to assume that the habits, attitudes, and values which have been acquired through past experience and training in the human links of a communication system are important variables to be considered in a practical audio-visual comparison. Thus, in the past, an operator who has received simple direct instructions and orders, as spoken by others, may well respond more efficiently to such messages when presented by voice than when presented visually, in spite of many other considerations. To illustrate the above viewpoint, one may note a number of communication situations where habit has determined the type of message presentation used. In Western culture generally, it has become more natural to respond to questions orally. It is also particularly typical of American culture to express familiar, highly meaningful material by speech rather than by writing. The general experimental finding that familiar, meaningful material is most efficiently presented aurally (19, 21, 36, 54, 55, 56, 81, 83, 84) may indeed be due to the higher serial dependency (acquired by learning) between successive auditory elements than between corresponding visual elements, and thus the greater redundancy of material received through the ears.

In line with the above, it is to be noted that veteran pilots generally prefer voice rather than visual communication. Moreover, the accuracy of their communication behavior probably closely parallels their preferences. Since part or most of this attitude is based on their greater amount of past training and experience with auditory communication systems, rather than on any intrinsic properties of the two senses, different training procedures might well have to be instituted before valid operational comparisons (i.e., those not penalizing vision) can be made between the two senses. In this connection, it is highly probable that operators can be taught new habits of looking or listening which would greatly improve initial intelligibility measures for a given type of presentation. There is abundant evidence from laboratory studies that accuracy of response to difficult perceptual discriminations can be greatly improved through training (35, 79). However, it is highly probable also that there are definite limits to these training effects. Evidence of this sort is provided by a recent investigation of Fitts (26).

2. Motor ability of the operator. Another of the organismic variables which limits the channel capacity of the communication system and thus probably enters into the comparison of vision and audition is the motor ability of the human operator. With respect to this, Fitts [1] points out that there are some fundamental differences between a typical physical communication system and a human being, particularly with respect to the problem of stimulus-response coding. He contends that whereas "a physical transmission channel, usually has fixed input and output characteristics, man can respond to a large variety of 'inputs', can transform or re-encode information in many ways, and can produce a great variety of 'outputs'. The question of coding information for maximum human information-handling capacity, therefore, involves not only the matching of the statistical characteristics of messages and the fixed constraints of a communication channel, but also requires the selection of an optimum response code, an optimum stimulus code, and the 'matching' of these stimulus and response codes."

3. Operator fatigue. Airborne operators are frequently subject to the effects of fatigue. Long flights and combat strain are capable of tiring the best conditioned of men. It should be recognized that as the effects of fatigue mount, the importance of messages in controlling the operator's reactions greatly increases. Simultaneously, of course, the operator's visual and auditory acuity decrease with growing fatigue, rendering message reception more difficult.

Audition, largely because of its attention-demanding quality, is probably the superior sense for transmitting information to fatigued operators.

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1. Fitts, P. M. The Influence of Response Coding on Performance in Motor Tasks. In Patton, R. A. (ed.) Current Trends in Information Theory. Pittsburgh: University of Pittsburgh Press, 1954.

The numerous studies concerning radar scope monitoring and fatigue have indicated the large amount of error attending such a visual presentation under fatigue conditions. The close relationship between fatigue and anoxia ---which causes the eyes to become ineffective before the ears--is another consideration favoring the auditory sense channel in fatigue states.

4. Operator motivation and morale. Another and closely associated factor with fatigue is morale. The importance of motivation in determining efficient responding is one of the best demonstrated principles in experimental psychology, hence the morale of the human operator in a communication system is an important variable. Numerous pilots and controllers assert that when low morale conditions prevail, the reassuring and comforting qualities of a familiar human voice outweigh other considerations. The scientific validity of this contention is, of course, difficult to determine. None-the-less, it is entirely possible that this factor constitutes a basic difference between voice and other types of communication, both visual and auditory. Certainly the long distance telephone companies do a tremendous volume of business derived from this aspect of human motivation!

Special Environmental Conditions Imposing Demands for Sensory Input

Because of the differing characteristics of light and sound stimuli, and because of differences in sensory functioning between the eyes and the ears, special environmental conditions may favor one or the other sense channel for the input of information. The periodic transition from daylight to night and back, for example, leads to important changes in visual reception, especially involving sensory adaptation. A problem of changing illumination levels is frequently encountered in control centers when the operator has to shift from scope watching to the scanning of more highly illuminated status boards. The auditory reception of information is frequently hindered by the presence of high ambient noise levels. The earphone is able to combat much of this kind of disturbance for the reception of speech and code messages, provided the channel is not simultaneously conducting messages from several different sources.

Carson, Miles and Stevens (8) suggest that the ears more than the eyes are subjected to environmental stress. After eight hours in airplane noise of 115 decibels, the normal ear shows a hearing loss of 40 decibels in the region of 4000 cycles. Although recovery from this loss usually occurs in about 24 hours, repeated exposure may result in some permanent loss.

The eyes, too, are subjected to environmental changes which lower their efficiency. For example, in night flying, efficiency of visual functioning is largely dependent upon the maintenance of dark adaptation. This has been difficult and sometimes impossible because of the necessary periodic reference to such illuminated areas as the instrument panel or the radar scope. In the case of the instrument panel the intensities and spectral composition of the lights have frequently been poorly chosen. Byrnes (5) points out that dark adaptation may be lost by short exposure to dials, map-reading lights, shell fire, searchlights, etc. Furthermore, oxygen deprivation produces decreased retinal sensitivity to low illumination. Blacking out under "G" usually occurs when force is greater than 4 G's; loss of consciousness, between 5 and 8 G's. Negative G may cause retinal hemorrhage. Carson (7) indicates that prolonged flight at 8 to 10 thousand feet causes measurable impairment of the retinal response---(1) diminished perception of low contrast; (2) increased absolute threshold; (3) sensitivity of red impaired much less than to blue or green (which frequently appear gray under anoxic conditions); and (4) the area of the blind spot increases markedly.

Sense Channel Oversaturation.

As noted in a previous technical report from the University of Virginia (42), aircraft pilots frequently argue for the continuance of voice message exchange on the ground that the pilot's visual sense channel is already occupied to its maximum limit with the various visually controlled tasks involved in flying the aircraft, scanning the sky for other airplanes, etc. According to this viewpoint, a major role is assigned to the sense channel in the process of perceiving. Moreover, there is the additional assumption that simultaneous multiple tasks are performed more efficiently under multi-sensory control than when the directing information is received through a single sense channel. In other words, it would follow that the information-handling capacity of the human operator is partly determined by the number of sense channels through which he is receiving information. If this position is correct, and if the operator's visual sense is really oversaturated at present, research efforts should be directed to lessen the work-load of the eyes in air operations by seeking a greater utilization of the other senses (auditory, tactual, kinesthetic, and vibratory). Exploratory research on the vibratory sense as a possible communication channel is now in progress. [1]

However, the assumptive nature of this viewpoint must be pointed out. At the present time there seems to be no clearcut evidence from laboratory research as to what are the precise capacities of any one sense channel to receive information in complex behavioral situations, nor any findings which would clearly indicate superior multiple task performance under conditions of multi-channel data presentation. An investigation of the efficiency of complex task performance at the University of Virginia (70)

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1. The Aero Medical Laboratory, Wright Air Development Center, has a contract for research in this area with the Commonwealth Engineering Company of Ohio. Under a contract with the Office of Naval Research, the Psychological Laboratory of the University of Virginia has a related investigation in progress.

would seem to indicate that other factors, such as the number of competing stimulus-response units, time limits imposed, and level of operator practice, are more important than the diversity of sense channels through which the controlling task data are presented. Other research at the same university has shown, however, that auditory messages are more accurately received, and interfere less with other activities, under conditions of simultaneous motor task performance and reception of verbal messages (42, 43, 46). Obviously, more research on the conditions determining the overall efficiency of performance in multiple task situations is required in order to establish firmly the role of the sense channel of informational input in this regard.

DEMANDS FOR THE AUDITORY AND VISUAL PRESENTATION OF INFORMATION

I. Typical Demands for Visual Presentation

A. Demands Derived From Response Variables

1. Demand for spatial orientation. This class of demands refers to responses requiring control or guidance in space, such as search and positioning. Common examples are visual scanning in air operations, target location and tracking on a radar scope, and selection and adjustment of controls in machine operation. For such purposes the principal auditory medium of control would be speech, as exemplified in GCA (Ground Controlled Approach), but voice directions entail the use of visual indicators as auxilliary means of controlling the desired behavior. The failure of the "Flybar" experiments some years ago exemplify the limits of the ear as a sense channel for the input of spatial control information by signals other than speech (27).

2. Demand for relational comparison. Because vision is both a spatial and a temporal sense, visual stimuli afford more and often better reference data than do sounds. Because of the temporal-sequential nature of auditory stimuli, only successive comparison is possible through the ears, with attendant loss of time and susceptibility to memory error. Therefore, most types of rapid relational comparisons are more efficiently accomplished visually regardless of whether the comparison involves static or changing stimulus configurations.

   a. Static relational comparison refers to the bulletin board type of situation where the items to be compared are unchanging. Functional graphs, pictures, and mock-ups are common examples of visual displays employed for this purpose. It is far easier, for example, to compare the sizes, colors, or titles, of several books by sight, than by listening to their properties described one at a time. The time-saving superiority of vision in static comparisons springs from visual receptor characteristics which allow the perception of multiple simultaneous displays.

b. Relational comparison of changing stimulus configurations is exemplified in the use of such common presenters as instrument dials and CRT displays. The reason for the visual superiority in dynamic comparisons is similar to the one advanced above, i.e., simultaneous visual signals simply do not mask each other as do simultaneous auditory signals. The mutual interference of speech messages received simultaneously from several sources has been demonstrated by Broadbent (4).

3. Demand for fine, quantitative discrimination. Thus far it has proven easier to build equipment for coding information for visual presentation in a far greater variety of forms than for auditory presentation. Various types of meters and household gauges afford common examples. Auditory information of the same degree of accuracy is largely limited to speech, which is certainly more time-consuming to present, even if equally accurate. The auditory limitations shown by the "Flybar" experiments are again relevant here (27). It would seem that precise estimates of quantity demand scales extended in space and affording simultaneous comparison, a demand obviously difficult to fulfill through the sense of hearing.

4. For quick selection from large stocks of information. Certain situations common in control centers, require the presentation of large amounts of information simultaneously or within very short periods of time (24, 25, 28, 38). The visual sense should be employed under these conditions for a variety of reasons: (1) multiple simultaneous visual displays do not mask each other; (2) reading comprehension is faster than listening comprehension under many conditions (13, 36, 56); (3) because of noise, differences in voice accent and enunciation, and other sources of uncertainty in speech, voice messages frequently require repetition to avoid error (38); (4) voice messages currently in use are highly redundant--a fact contributing to comprehension, but adding to transmission-presentation time.

5. Demand for rapid referability. The limitations of human memory and the stable duration characteristics of visual stimuli combine to give the visual sense a great advantage where "referable" data are essential. Auditory signals or

messages can be made referable only by time-consuming "repeats". Terrain data, weather information, and flight plans are examples of information for which "hard copies" might contribute to the efficiency of airborne operators. For purposes of mathematical computation, as in navigation, visual referability is demanded. The visual displays in the control rooms of railroad dispatchers afford another example. Several types of visual displays have been proposed in recent years for control towers and aircraft.

6. Where pictorial representation is desirable. For many purposes the high association value, the spatial inter-relationships, and completeness of detail of the visual picture contribute essentially to efficient responding. The value of pictures for education, advertising, and reconnaissance has been firmly established. Research reported by the Radio Corporation of America (69) and by Carpenter and others (6, 67) tends to substantiate the superiority of vision in meeting this type of situational demand. Two specific advantages of pictures might be pointed out: they often obviate the use of symbolic coding or provide a substitute for language difficulties; furthermore, it is obvious that language can never quite accurately or completely describe the entire situation portrayed in a picture. Granting the existance of irrelevant details in pictures, they nevertheless provide information not readily obtained aurally. No lover of art would substitute a verbal description of the Mona Lisa for a visual examination of this renowned masterpiece!

7. To facilitate the comprehension of unfamiliar or otherwise difficult material. Visual presentation has been found superior for efficient responding to, and retention of, strange and difficult material by numerous investigators (13, 52). "Difficult" here refers to such material as highly technical prose. Previously mentioned factors, such as referability, quantitative discriminability, and opportunity for relational comparisons probably account for most of this visual superiority for difficult stimulus materials.

B. Demands Derived From Operator Variables

1. Where previous habits demand visual presentation. The importance of habit in perception has already been stressed in the preceding section. Most persons have become accustomed to perceiving certain kinds of information either through the eyes (e.g., traffic lights) or through the ears (e.g., police sirens). Thus persons accustomed to relying on highway maps have undue difficulty in comprehending detailed road information by voice. Most persons have become accustomed to rely upon a variety of visual presenters for common reference information, such as time tables, maps, traffic signs, and a variety of meters.

C. Demands Derived From Special Environmental Conditions

1. Where environmental conditions handicap auditory presentation. The most common disruption to auditory intake is ambient noise or the mutual masking of simultaneous sound stimuli. Again, where the operator is at a considerable distance from the sound source, auditory signals may become non-detectable. The use of gestures, signal flags, blinkers, and smoke signals as substitutes for the voice at great distances furnish instances of this type of visual advantage. Sudden changes in air pressure may also temporarily reduce the efficiency of hearing.

II. Typical Demands for Auditory Presentation

A. Demands Derived From Response Variables

1. For warning or alerting the operator. The extensive employment of sound signals for warning attest to the superiority of audition with respect to "attention demandingness". Several reasons for this auditory superiority have already been advanced (in the second section), chief among which are the facts that the auditory field embraces all 360 degrees about the perceiver, and sound signals of sufficiently high intensity may be heard around or through visually opaque obstacles in the environment. An especially common application of this generalization is the use of sound to alert a number of persons in different locations simultaneously; the air raid warning siren is an example.

2. For communication during multiple task performance. By reason of the superior "break-in" qualities of auditory stimuli, the ear is better than the eye as a communication channel when the human operator is occupied with multiple simultaneous tasks and thus not expecting an incoming message. A call on the radio-telephone can alert the pilot who is "buried in his instruments". Laboratory research at the University of Virginia has clearly demonstrated that when persons are engaged in highly attention-demanding tasks, voice messages are more intelligible than printed ones, which have to be read (42, 43, 46, 70). These results support the preference of aircraft pilots for retaining the radio telephone as a medium of communication.

3. For rapid two-way communication. The human voice apparently has no close rival for the rapid and accurate exchange of information. Speech is the ordinary person's most natural and most flexible mode of generating information. Long practice at conversation has rendered him quite adept at receiving information from the speech of other persons. Use of the visual channel for transmitting information imposes the need for encoding the message---unless it is written in clear text. Writing or other

forms of encoding takes time at the transmission end and requires knowledge of the code at the receiving end. Furthermore, the use of visual symbols in coded messages often necessitates some kind of simplified or standardized message system, thus sacrificing flexibility. It should be noted, in this regard, that the flexibility of visual communication could probably be very greatly increased if adequate research were to be devoted to this objective.

4. For the retention of familiar, highly meaningful material. Numerous investigators have reported that for easy, meaningful material, auditory presentation is superior for retention of the subject-matter (9, 21, 81, 83, 84). Radio commercials afford common examples. The explanation of this general finding is probably to be found in everyday listening habits. Furthermore, familiar, meaningful material does not demand rapid referability, one of the visual sense channel's greatest assets.

B. Demands Derived From Operator Variables

1. Where previous habits demand auditory presentation. With respect to previous habits of listening, the example of conversation has already been mentioned. Most of us are accustomed to receiving questions and greetings by ear and answering them by voice rather than by visual signalling. Signals indicating the beginning and end of time intervals are usually auditory rather than visual. The morale factor involved in recognition of the human voice in times of stress or emergency has sometimes been emphasized by operating personnel (see preceding section).

2. Under conditions of reduced operator alertness. Both common observation and reports of operating personnel attest to the generalization that auditory stimuli are more effective than visual stimuli at the usual range of intensities, for arousing the human operator when under the influence of fatigue, drug conditions, or anoxia. This point was discussed in the last section, though direct experimental evidence seems to be lacking.

C. Demands Derived From Special Environmental Conditions

1. Sudden illumination changes involving rapid shifts in adaptation level. When sudden shifts in adaptation level (e.g., from dark to light) would interfere with operating efficiency, auditory presentation should be superior for data presentation purposes (14, 16).

2. Under conditions of excessive vibration. When vibration of both the instrument panel and the operator occur, especially the latter, the effectiveness of visual presentation is considerably lowered. Although such a condition might also lower the

effectiveness of auditory reception, it would not do so to the same degree (17).

3. Under lighting conditions giving rise to visual after-effects. When light conditions exist which maximize such "subjective" phenomena as figural after-effects (53), after images, and size illusions, the accuracy of the visual intake of information is severely limited. The necessity of avoiding such effects would strongly demand the use of auditory presentation.

4. When opaque obstacles intervene between signal source and perceiver. Because the longer sound waves do not cast such sharp "shadows" as light, sound signals of sufficient intensity are able to carry around many kinds of barriers which light cannot.

5. Oversaturation of the visual sense channel. In the preceding section this subject received some discussion. While basically unsupported by experimental evidence, there is a widely held view that the visual sense channel of the pilot has now been called upon to exceed its capacity for informational input. The remedy for such a situation is to utilize other sense channels to a greater extent.

III. Typical Demands Served by Either Sense Alone

It seems probable that for a wide variety of purposes either auditory or visual presentation would afford equally adequate information to direct the operator's responses. With the aid of special training or forewarned expectation, it is likely that either sense channel may be successfully utilized for many operational purposes. Habit and expectancy are powerful factors in equalizing what may once have been intelligibility differences in data displays. It is also apparent that both sense channels have potentialities as information transmission channels which have not yet been fully exploited. Currently, this statement probably applies more accurately to the auditory sense than to vision. Four categories of demands which may be served with approximately equal efficiency by either sense channel are suggested below.

A. Where Responses are Discrete, Short, and Follow Quickly After Presentation

Responses to brief instructions or to simple data displays, made soon after presentation of the information, impose no special demands as to sense channel of presentation. It is assumed that for such responses the displays require neither referability to combat memory loss nor reference data for relational comparison. Air traffic control instructions afford an instance of this type of information. For example, landing instructions may be presented to the pilot aurally (GCA), or visually (ILAS). Stop lights or the traffic policeman's whistle may be used to direct the behavior of automobile drivers.

B. Where Simple Reference Information is Needed Continuously Over Long Periods of Time

An everyday example of this category is afforded by common methods of ascertaining the correct time: a person may consult his watch, ask a friend, or make a telephone call. The A or N signals of the radio range might be equally effective as either visual or auditory reference signals.

C. Demand for Temporal Discrimination

The relative capacities of the eye and the ear for judging temporal intervals was discussed in the second section of the present report. It was pointed out that at middle ranges of stimulus intensity, and for all except very short durations, there was no reason to regard one sense as superior to the other. The experimental literature is not entirely clear about the relative efficiency of audition and vision for low intensities and very short time intervals. Thus Bice (3) and Taubman (76, 77) have obtained results indicating auditory superiority for the identification of discrete stimuli (e.g., "numerosity" and Morse Code). This evidence is challenged by such investigators as Cheatham and White (12), Gebhard [1], and Mowbray [1]. It appears that any actual difference between the two senses in capacity to discriminate time intervals seems to depend upon the specific conditions of a particular situation. With adequate operator training it would seem possible to utilize either the eyes or the ears with equal efficiency as sense channels for this purpose.

D. For Simple Signals Already Anticipated By the Operator

Where the operator is "set" to respond to simple, familiar signals, the sense channel through which they are received is of secondary importance. More of the GCA instructions are now being presented visually and less by voice. Indeed the ILAS represents an all-visual system for controlling the same kind of behavior (i.e., low approaches for landing without visual contact with the ground). The examples of GCA and ILAS underline the importance of training and personal habits of the operator in determining the relative efficiency of data presentation by voice or by visual indicators.

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1. Dr. J. W. Gebhard and Dr. G. H. Mowbray of the Applied Physics Laboratory, Johns Hopkins University, have argued this point in defense of vision with the writers of the present report.

IV. Typical Demands for Dual Audio-Visual Presentation

For certain kinds of responding, for especially urgent or critical situations, or for unusual environmental conditions, it might well be that simultaneous presentation of information through both the eyes and the ears would provide better control of the desired operator behavior than would input through either sense channel alone. Four such categories of demands are suggested below.

A. Where Great Redundancy Is Desirable

Extra redundancy is sometimes essential to combat excessive noise in a communication system. The greater the degree of uncertainty, or the more complex the information, the greater the redundancy necessary to maintain an optimal efficiency of operator response. The success of movies and television for entertainment and for the portrayal of sports events is evidence of the value of high redundancy in presenting complex information. Controlled experimentation supports these observations (69). The effectiveness of visual aids with auxiliary voice explanation in education affords further evidence along these lines. There is evidence in the research literature that responses required under "noisy" conditions can be rendered more accurate by simultaneous auditory and visual signalling. Thus, Schafer and Shewmaker (71) have shown that when a combination of auditory and visual stimulation is used in judging underwater distances with sonar, greater accuracy is achieved than with either sense alone. In a different situation, Broadbent (4) found that visual call signs were significantly more effective than auditory call signs in aiding operators to select the correct auditory message from two simultaneous messages presented from the same spatial direction by different voices.

B. For Remembering Large Amounts of Information

Where referable presentation is not provided, experimental evidence indicates that a combined audio-visual presentation is superior for the retention of information. Day and Beach (19) have reported a large number of retention studies supporting the superiority of combined visual and auditory presentation of material (20, 52). Educational research in the audio-visual aid areas has also furnished evidence to support these findings (55).

C. For Emergency Warning

Where it is urgent to attract attention to a new situation or incoming message, simultaneous stimulation through both sense channels may be expected to provide a greater overall effect upon the operator's behavior. The common use of simultaneous flashing lights and sirens on firetrucks and ambulances exemplifies this point.

D. Where Environmental Conditions Handicap Data Presentation Through Either Sense Channel Alone

Evidence for this last category is more logical than empirical. There appears to be no experimental evidence directly bearing on this point.

It is to be noted that dual auditory-visual input is not always an aid to efficiency of operator response. Under certain conditions simultaneous input of information through the eyes and ears leads to reduced efficiency of behavior. Discussion of intersensory competition is beyond the scope of the present paper, but it would be expected that mutual interference would be most serious where the information received simultaneously through the two channels is not integrated, that is, leads to competing responses by the operator. Mowbray has demonstrated that when observers had to look at and listen to different material simultaneously, the data presented through one channel (in this case vision) could markedly interfere with the reception of data through the other channel (64, 65).

SUMMARY

It is the contention of the present report that the choice between the eyes and the ears as sense channels for the presentation of information to the human operator rests upon the specific demands of various operational situations. Three sets of variables impose demands for the presentation of data, some of which have implications for visual or auditory presentation. These three sets of demands are: (1) Demands imposed by response variables (e.g., orientation in space, fine quantitative comparison, rapid referability). (2) Demands imposed by operator variables (e.g., previous habits, fatigue, motivation). (3) Demands imposed by special environmental conditions favoring one or the other sense channel (e.g., ambient noise, sudden changes of illumination, excessive vibration).

The stimulus properties of light and sound differ. The receptor characteristics of vision and audition also differ. It is possible, by matching these distinguishing sense characteristics with specific demands of particular situations, to suggest some "division of labor" between the two sense channels for purposes of data presentation.

Four principal categories of demands for informational input have been proposed as follows: (1) typical demands for visual presentation; (2) typical demands for auditory presentation; (3) typical demands served by either sense alone; (4) typical demands for dual audio-visual presentation. These four sets of demands are summarized in the following table.

SUMMARY OF DEMANDS WITH ESTIMATED DEGREES OF VERIFICATION

Demand for Informational Input	Estimated Degree of Verification		
	Direct, specific experimental evidence	Indirect, general experimental evidence, or justified by general usage	Little or no experimental evidence; based on professional judgment
A. Typical Demands for Visual Presentation			
1. Demand for spatial orientation	X		
2. Demand for relational comparison		X	
3. Demand for fine quantitative discrimination	X		
4. For quick selection from large stocks of information		X	
5. Demand for rapid referability		X	
6. Where pictorial representation is desirable		X	
7. To facilitate the comprehension of unfamiliar or otherwise difficult material	X		
8. Where previous habits demand visual presentation		X	
9. Where environmental conditions handicap auditory presentation		X	

Demand for Informational Input	Estimated Degree of Verification: Direct, specific experimental evidence	Indirect, general experimental evidence, or justified by general usage	Little or no experimental evidence; based on professional judgment
B. Typical Demands for Auditory Presentation			
1. For warning or alerting the operator		X	
2. For communication during multiple task performance	X		
3. For rapid two-way communication		X	
4. For the retention of familiar, highly meaningful material	X		
5. Where previous habits demand auditory presentation		X	
6. Under conditions of reduced operator alertness		X	
7. Where environmental conditions handicap visual presentation	X		

Demand for Informational Input	Estimated Degree of Verification: Direct, specific experimental evidence	Indirect, general experimental evidence, or justified by general usage	Little or no experimental evidence; based on professional judgment
C. Typical Demands Served by Either Sense Alone			
1. Where responses are discrete, short, and follow quickly after presentation		X	
2. Where simple reference information is needed continuously over long periods of time		X	
3. Demand for temporal discrimination	X		
4. For simple signals already anticipated by the operator			X
D. Typical Demands for Dual Audio-Visual Presentation			
1. Where great redundancy is desirable		X	
2. For remembering large amounts of information	X		
3. For emergency warning		X	
4. Where environmental conditions handicap data presentation through either sense channel alone			X

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