Multidimensional stimulus identification¹

HOWARD EGETH² AND ROBERT PACHELLA
THE JOHNS HOPKINS UNIVERSITY

In an absolute judgment task, total information transmitted about a set of stimuli increases as the dimensionality of the stimuli is increased. However, as the number of dimensions is increased, information transmitted about each component dimension decreases. Four factors were proposed that might, singly or in combination, account for this decrement: stimulus duration, interdimensional interference, distraction, and response complexity. The results of four experiments established that each of these factors may be operative under appropriate circumstances. It was also concluded that component dimensions were processed simultaneously rather than sequentially. However, the processing was not truly parallel because the input channels were not independent of one another.

The ability of humans to make accurate categorical judgments about stimuli that vary along a single continuum such as wavelength or sound pressure level has been shown to be quite limited. Using the method of absolute judgment, in which S must identify each stimulus as it is presented, investigators have shown that the channel capacities for a variety of dimensions fall in the range from 2 to 3.2 bits, values which correspond to perfect discrimination among four to nine categories. [See Garner (1962) and Miller (1956) for reviews of this literature.]³

This finding seems to be strikingly at variance with the observation that in their everyday experience humans can easily and accurately identify thousands of words, faces, and objects. Miller (1956) pointed to the probable explanation of this discrepancy when he noted that stimuli such as words, faces, and objects differ from one another in many ways whereas the studies mentioned above were concerned with stimuli that differed from one another in only one respect. In support of this argument Miller drew together the data of several different experiments and compared results obtained with unidimensional and multidimensional stimuli. These comparisons clearly indicated that as the dimensionality of a stimulus set was increased, total information transmission also increased, just as expected. However, these data also made it abundantly clear that the increase in overall capacity to render absolute judgments was accompanied by a concomitant decrease in the ability to identify values on each of the component dimensions of the complex displays. In other words, there was a trade-off between what might be called depth and breadth in information processing; it was possible to render fairly accurate judgments about a single dimension, but only relatively crude judgments could be made about that dimension when several other dimensions also had to be judged. It is this still unexplained trade-off that forms the focus of the present series of experiments, which have been designed to explore some factors that may underlie the decrement in accuracy of identification that occurs when a stimulus dimension is judged as part of a multidimensional display rather than alone.

An examination of the research on absolute judgment revealed four factors that might, singly or in combination, account for the observed decrement. A description of these four factors follows.

(1) *Stimulus duration.* Garner (1962) and Miller (1956) compared data obtained by Hake and Garner (1951) on channel capacity for judgments of position on a line with data

obtained by Klemmer and Frick (1953) and Osborne, Quastler, and Tweedell (1955) on channel capacity for judgments of position within a two-dimensional area. Information transmission in the unidimensional study was 3.2 bits and in the bidimensional studies about 4.4 bits—or only about 2.2 bits per component dimension. However, in the unidimensional study no limit was put on stimulus duration whereas in the bidimensional studies the stimuli were presented tachistoscopically. It seems likely that more time would be needed to extract information about several dimensions than about a single dimension. Therefore, in comparing information transmission of unidimensional and multidimensional judgments one must be careful to take stimulus duration into account. In any event, it does not seem appropriate to compare long exposures of unidimensional stimuli and short exposures of multidimensional ones and then observe a “decrement” in the multidimensional conditions.

(2) *Interdimensional interference.* This factor is best described with a hypothetical example. Imagine a set of stimuli defined by the joint values of two dimensions, X and Y. Typically, information transmission for X is determined by requiring judgments on X as X is varied at some fixed value of Y. Similarly, Y is judged with a set of stimuli in which X is held constant. However, when bidimensional judgments are required both X and Y are varied and both must be judged on every trial. In this case, X judgments are made at many different values of Y, and Y judgments are made at many different values of X. The interference argument is simply that: (1) X values may not be equally discriminable at all values of Y, and vice versa, and (2) unidimensional judgments are usually obtained at that value of the other dimension that leads to optimal performance. Thus an optimal unidimensional condition (say for X) is compared with a bidimensional condition in which Y varies, sometimes being at a level that makes X maximally discriminable, but at other times being at a level that leads to some degree of interference.

(3) *Distraction.* In the hypothetical example above, we may conceive of an S's report in the bidimensional condition as the result of the following kind of process: When the S is examining X he must temporarily ignore or filter the Y-value, and conversely, when he is examining Y he must ignore the X-value of the stimulus. With respect to the identification of X, Y is an irrelevant variable, and similarly Y is irrelevant to the identification of X. Not only do X and Y serve as irrelevant dimensions for one another, but they vary in value from trial-to-trial, and previous research has shown that Ss may have great difficulty in ignoring such variation along irrelevant dimensions and selectively attending to the appropriate information (Egeth, 1967).

It is interesting to speculate about the possibility of an interaction between the factors of distraction and duration. It may be possible for Ss to filter irrelevant information, but only at a cost in time. Thus distraction may be important at short durations but not long ones.

(4) *Response complexity.* In most studies requiring multidimensional judgments, Ss are requested to specify the value of each relevant dimension on every trial. Almost inevitably this means that they must respond serially, one dimension at a time, and thus order-of-report effects must be expected to assert themselves. Lawrence and LaBerge (1956) established that when three attributes of a tachistoscopically

presented display had to be judged in a specified order, the first was identified significantly more accurately than the second or third. The relevance of this finding to the present investigation is clear. In a multidimensional absolute judgment task, average information transmission per dimension reflects a combination of relatively accurate and inaccurate performances (i.e., 'first dimension vs later dimensions), and thus ought to be lower than transmission in a unidimensional task where only a "first" dimension is ever reported.

There are several reasonable explanations for the finding that accuracy is greater for the first dimension reported than for later ones. For example, it seems likely that, in the absence of instructions to the contrary, Ss will tend to encode the values of stimulus dimensions in the same order as the order in which the dimensions must be reported. Harris and Haber (1963) have shown that with tachistoscopically presented stimuli, order-of-encoding was a powerful determinant of accuracy of report. Since visual afterimages fade rapidly, adequacy of recall for a particular dimension may depend upon the state of the image at the time when information concerning the dimension is encoded. Thus, it would seem reasonable to expect that the effect of response complexity would be mitigated at durations long enough to permit adequate encoding of all stimulus dimensions. This particular explanation is, obviously, predicated on the assumption of a serial mode of examination of dimensions.

EXPERIMENT 1

The first study in the series was an investigation of the factor of interdimensional interference using the dimensions of saltiness and sweetness. Beebe-Center, Rogers, and O'Connell (1955) have shown that multidimensional information transmission with these dimensions fits the standard pattern: improvement over the best single dimension but at the cost of a decrement on both component dimensions. Specifically, when Ss were tested with various concentrations of saline solution 1.70 bits of information were transmitted, and when they were tested with sucrose solutions 1.69 bits were transmitted. However, when a set of compound solutions containing both salt and sucrose was used, total information transmission was 2.25 bits. Analysis of the data obtained with the compound solutions showed that in this multidimensional task Ss were only transmitting 1.14 bits about salt concentration and 1.00 bits about sucrose concentration. This is perhaps the single clearest example of the multidimensional information transmission decrement that exists in the literature.

For interference to be an important factor in the foregoing experiment it is necessary only that information transmission on each of the involved dimensions be related to the level of the other dimension. For example, the decrement for salt judgments ($1.70 - 1.14 = .56$ bits) may be due to the fact that the unidimensional judgments (1.70 bits) were obtained with a set of salt solutions that contained no sucrose at all, whereas the bidimensional judgments (1.14 bits) were obtained with a set of solutions that contained sucrose in addition to salt, the concentration of sucrose varying from very low to very high. Of course, a parallel argument holds for judgments of sucrose concentration.

As a test of the interference hypothesis, absolute judgments of saltiness were obtained using each of two extreme concentrations of sucrose, zero and 115 g per 100 ml of water (115 was the highest concentration used in the Beebe-Center et al study). It should be emphasized that judging saline concentration is a unidimensional task whether it is carried out against a background of zero sucrose concentration or of some high but constant level.

Method

Stimuli. Ten solutions were prepared daily. These ten

represented the factorial combination of five amounts of NaCl (0, .3, 1.0, 4.8, and 34.7 g) and two amounts of sucrose (0 and 115 g) dissolved completely in 100 ml of tap water.

Procedure. The two experimental conditions were defined by the two levels of sucrose concentration. Each S was run in four sessions on separate days. On the first three days they served in both experimental conditions and on the fourth day just the 115 g condition. Each condition was presented as a single block of 50 trials and the order of presentation of conditions was counterbalanced over days. Within a block of trials each salt concentration was presented equally often in a random order.

The solutions were presented to the blindfolded Ss on plastic spoons. There was no time pressure and S was allowed to taste the solution in any manner he chose. After rendering a judgment as to which of the five saline concentrations had been presented, the S rinsed his mouth with distilled water. Feedback was provided after every trial, and before beginning a test series of 50 trials 10 practice trials with feedback were given to minimize transfer effects.

Subjects. The two authors served alternately as S and E during each experimental session. The possibility that a theoretical bias might have led to "expected" rather than "unexpected" results under these circumstances is unlikely since the experimental sessions quickly became an intensely competitive situation. Indeed, the two Ss of the present experiment demonstrated consistently better performance than the more highly practiced Ss of the Beebe-Center et al (1955) experiment.

Results and Discussion

The results, in terms of bits of information transmitted, are presented in Fig. 1. It is clear that discrimination among salt concentrations is hindered when the solutions contain a large amount of sucrose, and it is also clear that the effect is not a transitory one.⁴

These data provide clear support for the hypothesis that interdimensional interference accounts for at least part of the multidimensional information transmission decrement found with the dimensions of sweetness and saltiness. Interdimensional interference has also been found with auditory stimuli. Pollack (1953) observed that when judgments of sound level or frequency were made in unidimensional tests, identification was superior in the middle range of the *other* stimulus dimension.

Fig. 1. Information transmitted about saline concentration on each day of Experiment 1. Upper two functions represent performance when no sucrose is present, lower two represent performance when 115 g sucrose is present in addition to NaCl in each 100 ml of test solution.

EXPERIMENT 2

In this experiment the effects of distraction, duration, and response complexity were investigated in one- and two-dimensional judgmental tasks. The stimulus materials were selected to minimize the effects of interdimensional interference studied in Experiment 1.

Method

Apparatus and materials. The S's task on each trial was to identify the position of a dot. Depending upon the experimental condition, the position of the stimulus dot varied from trial-to-trial along either one or two dimensions and the Ss had to report on one or both of the dimensions of variation.

The stimuli were prepared on cards and displayed in a two-field mirror tachistoscope. On each trial S saw a square white area (3 in. on a side at a viewing distance of 23 in.) surrounded by a larger black area. Within the white square there was a single black dot 1/16 in. in diam. There were 225 permissible locations for the dots, obtained by the imaginary division of the square into 15 rows and 15 columns, with the dots being placed at the centers of the resulting cells.

Design. There were three kinds of judgmental task used: unidimensional, pseudo-unidimensional, and bidimensional. In the unidimensional task the dots varied randomly in position along only one dimension and S had to identify which one of the 15 permissible positions the dot was in on each trial. For half of the Ss the dots varied in vertical position, for the other half in horizontal position. When horizontal position was being judged the dots were always at the middle value on the vertical dimension, and vice versa. In the pseudo-unidimensional task the dots could appear in any of the 225 permissible locations within the square, however, Ss were instructed to attend to and report the position of the dots with respect to only one of the dimensions of variation. Again, for half of the Ss vertical position was relevant and for the other half, horizontal. In the bidimensional task the dots varied randomly along both dimensions and Ss were asked to report the position of the dot with respect to both dimensions on each trial. Order of report was specified for these Ss, i.e., half reported the positions in the order horizontal-vertical and the other half in the order vertical-horizontal. The three judgmental tasks were combined factorially with two exposure durations, .1 sec and 2.0 sec.

The task names, unidimensional, pseudo-unidimensional, and bidimensional, are somewhat ambiguous and thus it seems preferable to introduce a more descriptive notation. Accordingly, a binary nomenclature is used in which the first digit indicates the number of dimensions of stimulus variation and the second digit indicates the number of dimensions that are reported in the response. For example, 2 → 1 refers to the pseudo-unidimensional condition in which the stimuli vary on two dimensions but the S reports only one of them.

Subjects. Forty-eight volunteer students at The Johns Hopkins University were each paid \$1.50 for participating. Each S was assigned at random to one of the experimental conditions and was tested individually in a session that lasted about an hour.

Results and Discussion

Information transmission was essentially identical for the horizontal and vertical dimensions and so that distinction has been ignored in the following analyses.

Table 1 presents mean performance, in bits, for the eight Ss that served in each of the experimental conditions. The figures for the 2 → 2 task are averaged over the first and second dimensions reported. An analysis of variance performed on these data indicated that the main effect of judgmental tasks was significant [$F(2,42) = 33.3$, $p < .001$]. Considering the near identity of the data from the 1 → 1 and 2 → 1 tasks, it is

Table 1
Information Transmitted: Experiments 2 and 3

Task	Stimulus Duration (seconds)		
	Experiment 2		Experiment 3
	.1	2.0	10.0
1 → 1	2.74	3.39	3.49
2 → 1	2.73	3.38	—
2 → 2	2.47	2.92	3.40

clear that the main effect of tasks attests to the significance of the difference between the 1 → 1 and 2 → 2 conditions, which is to say that the standard decrement obtains under the present conditions.

It was hypothesized that stimulus duration might be a critical factor, with a performance decrement occurring at short durations but not at long durations. Although duration had a significant main effect [$F(1,42) = 189.6$, $p < .001$], the interaction of duration and tasks was insignificant.

The importance of the factor of distraction may be assessed by comparing the 1 → 1 and 2 → 1 tasks. It has already been noted that performance was nearly identical in these two conditions, and this was the case at both exposure durations. It seems that Ss were able to filter perfectly even with a .1-sec exposure and thus we may conclude that distraction is of little importance with these stimuli.

The factor of response complexity was analyzed by comparing performance on the first and second dimensions reported in the 2 → 2 task. These data appear in Table 2. For the first dimension mean information transmission was 2.76 bits and for the second 2.63 bits, a small but highly reliable difference [$F(1,14) = 22.7$, $p < .01$]. This difference was about the same magnitude at .1 sec and 2.0 sec. It is important to note also that the first dimension reported in the 2 → 2 task is inferior to the single dimension reported in the 1 → 1 task at both stimulus durations.

EXPERIMENT 3

The effects of duration mentioned above presented a rather puzzling package. As a main effect it was a highly significant source of variance, however, the expected interactions of duration with judgmental tasks and with response complexity failed to obtain. To explore further the effects of stimulus duration, additional Ss were run in the 1 → 1 and 2 → 2 conditions of Experiment 2 with a 10.0-sec exposure duration. Sixteen volunteers were divided equally between these two conditions.

The results appear in Tables 1 and 2. In Table 1 it is evident that the multidimensional information transmission decrement is much reduced in magnitude with a 10.0-sec exposure. In fact, the .09-bit difference between the 1 → 1 and 2 → 2 conditions was not statistically significant ($p > .05$). However, in Table 2 it may be seen that the effect of response complexity, as indexed by the .17-bit difference between the first and second dimensions reported in the 2 → 2 condition, is undiminished in magnitude at 10.0 sec [$t(7) = 4.26$, $p < .01$]. Finally, it is worth noting that performance on the first

Table 2
Information Transmitted about First and Second Dimensions in
2 → 2 Tasks: Experiments 2 and 3

Dimension	Stimulus Duration (seconds)		
	Experiment 2		Experiment 3
	.1	2.0	10.0
First	2.54	2.99	3.48
Second	2.40	2.86	3.31

dimension reported in the 2 → 2 condition is essentially equal to the performance obtained in the 1 → 1 condition. What this means is that with a 10.0-sec exposure in this task of dot location, only response complexity remained as a source of decrement.

A word of caution is in order concerning the interpretation of these results. Since performance in the 1 → 1 task was virtually identical to performance on the first dimension of the 2 → 2 task and since the second dimension was judged significantly less accurately than the first in the 2 → 2 condition, one might reasonably expect to find a significant decrement, i.e., a reliable overall difference between the 1 → 1 and 2 → 2 conditions. The fact that this comparison failed of significance attests more to the lack of statistical power inherent in this comparison than to the state of nature.

EXPERIMENT 4

This study was an effort to extend the generality of the results of the preceding experiments with respect to the effects of duration, distraction, and response complexity on the multidimensional information transmission decrement. For this purpose a set of three dimensions was selected: color, ellipse size, and ellipse eccentricity.

Method

Apparatus and materials. Sequences of stimuli and instructions were prepared on film and presented by means of a filmstrip projector capable of displaying single frames for specified durations. Thus, each stimulus appeared on a single frame and this frame was displayed for either 1/8 sec or 1 sec depending upon the experimental condition. (The durations of 1/8 and 1 sec are approximately accurate nominal times, and thus have not been presented in decimal form.) A projected stimulus consisted of a colored square, 12 in. on a side, centered in which there was a black outline ellipse, its major axis horizontal. Instruction frames contained a single highly legible word, either "Ready" or "Respond."

Stimulus films were prepared by photographing sheets of colored paper over which were placed clear plastic sheets on which were drawn black outline ellipses. The particular values used on each dimension were selected to insure a substantial number of errors without having to use too many different stimuli. The colored papers consisted of a set of six "oranges" selected from the Color-Aid Company series of papers. (Specifically, each was a Tint 2 of the following hues: YO, OYO, O, ORO, RO, ROR.) Five ellipse sizes were used; these may conveniently be indexed by the lengths of their major axes (described as "widths" to the Ss): 3, 3¼, 3½, 3¾, and 4 in. These widths represent the actual sizes of the ellipses as projected on the screen and seen by Ss at the viewing distance of 7 ft. Five eccentricities (described as "shapes" to the Ss) were also used: 40, 45, 50, 55, and 60 deg. With six colors, five sizes, and five eccentricities there were 150 different stimuli possible.⁵

Design. Two exposure durations (1/8 and 1 sec) were combined factorially with four judgmental tasks resulting in eight experimental conditions. One of the judgmental tasks required unidimensional judgments with the values of the other two dimensions held constant from trial-to-trial, a 1 → 1 condition. In the three other tasks the values of all three dimensions varied randomly from trial-to-trial, and depending upon the specific task, S had to report on one, two, or three of these dimensions. Thus, these were 3 → 1, 3 → 2, and 3 → 3 tasks, respectively.

The design was completely balanced with respect to the use of specific dimensions. In the 1 → 1 and 3 → 1 conditions equal numbers of Ss judged color, eccentricity, and size, and in the 3 → 2 conditions all pairs of dimensions were used equally often. The factor of order-of-report was relevant only in the

3 → 2 and 3 → 3 conditions. In both of these conditions all possible orders were used equally often. Each S served in only one condition and used only one order of report.

Four filmstrips were prepared. One of them was used in conditions 3 → 1, 3 → 2, and 3 → 3. The other three were used in the 1 → 1 condition where a separate sequence of stimuli was required for each dimension that was judged. In each of these three films two dimensions were held constant. The values that were used for each dimension when it was held constant were: color (O), eccentricity (50 deg) and size (3½ in.).

Procedure. At the beginning of the experimental session S was told what the nature of his task would be and he was shown the values of the dimensions that he would be judging along with their designations. Eccentricity and size were described directly in degrees and inches as described above, but pilot work led to a nomenclature for the colors that was more easily grasped by Ss than the technical names provided by the Color-Aid Company.

On each trial there was a sequence of three film frames. The first said "Ready" and was shown for about 1 sec, the next was a stimulus and was presented for 1/8 sec or 1 sec depending on the condition in which the S was serving, and the third frame, which said "Respond," remained on until the S had finished responding, at which time the sequence repeated.

On each trial S indicated his judgment(s) on an IBM card prepared and coded to be appropriate to the judgmental task and order-of-report of that S. Responses were entered on cards from left-to-right, and Ss were monitored to insure that they were using the assigned order-of-report. After S finished his response E provided the correct answer. An experimental session of 150 trials lasted about an hour.

Subjects. Ninety-six male students at The Johns Hopkins University served as paid volunteers. They were all screened for normal color vision with the AO H-R-R Pseudo-isochromatic Plates. Twelve Ss were assigned at random to each of the eight experimental conditions.

Results and Discussion

In the present context the multidimensional information transmission decrement refers to the difference in performance between the 1 → 1 and 3 → 3 conditions. This difference may be seen in Table 3. To evaluate the significance of the difference between the two relevant judgmental tasks an analysis of variance was performed on the data of the 48 Ss involved. To simplify the analysis each S in the 3 → 3 conditions was assigned a single score representing his mean performance over all three dimensions reported. Information transmission in the unidimensional task was significantly superior to the average of the three dimensions reported in the multidimensional task [$F(1,44) = 27.4$, $p < .001$]. The effects of duration on the magnitude of the decrement were similar to the effects observed in Experiment 2, i.e., generally better performance at longer durations, but with no reduction in the magnitude of the decrement at the longer duration, although in the present case the main effect of duration was not significant for the four cells of Table 3 under consideration.

The factor of distraction was examined by comparing

Table 3
Information Transmitted: Experiment 4

Task	Duration (seconds)	
	1/8	1
1→1	1.16	1.41
3→1	1.00	1.26
3→2	.86	.99
3→3	.80	.83

Table 4
Information Transmitted by Dimensions, for 1→1 and 3→1 Judgmental Tasks: Experiment 4

Dimension	Duration (seconds)			
	1/8		1	
	1→1	3→1	1→1	3→1
Color	1.48	1.66	1.78	1.89
Eccentricity	1.30	.74	1.34	1.09
Size	.70	.60	1.11	.79

performance in the 1 → 1 and 3 → 1 tasks. Table 4 presents mean information transmission for the two judgmental tasks, broken down by stimulus duration and particular dimension reported. Analysis of variance indicated that all three effects were significant: for duration $F(1,36) = 14.2$, $p < .001$; for dimensions $F(2,36) = 63.6$, $p < .001$, and, most to the point, for tasks $F(1,36) = 5.35$, $p < .05$. Since tasks was a significant source of variance, performance in the 1 → 1 tasks being generally superior to performance in the 3 → 1 tasks, distraction thus seems to be a relevant factor. There was also one significant interaction, that of tasks and dimensions [$F(2,36) = 6.01$, $p < .01$]. The meaning of this interaction may be seen clearly in Table 4. Judgments of eccentricity and size both suffer when they must be made in a context of constantly varying irrelevant information whereas color judgments are not at all impaired under those same circumstances. One might wonder whether eccentricity and size judgments were actually impaired by "distraction" or whether those two dimensions themselves are subject to some kind of interdimensional interaction. For example, perhaps a particular size appears subjectively different to S depending upon the eccentricity of the ellipse. Such an illusory effect could reduce information transmission about size. To test for interaction effects the cross-contingencies (Garner, 1962, p. 117) between size and eccentricity were computed and found to be negligible. Thus, for these stimuli, distraction rather than interaction seems to result when irrelevant dimensions are varied from trial-to-trial.

Response complexity was evaluated for both the 3 → 2 and 3 → 3 tasks; Table 5 presents the relevant data. The statistical analyses of order-of-report took advantage of the fact that all possible orders were used equally often by including these orders as a source of variance. In the 3 → 3 task, order-of-report was a significant source of variance [$F(2,24) = 15.11$, $p < .001$], however, in the 3 → 2 task it was not significant ($p > .10$). In neither condition was there a reliable interaction of order-of-report with exposure duration.

GENERAL DISCUSSION

The experiments reported in this paper have explored four factors that were proposed to account for the finding that accuracy of identification on a particular stimulus dimension is lower when that dimension is judged in the context of a multidimensional absolute judgment task than when it is judged in a unidimensional task.

Interdimensional interference was demonstrated in Experiment 1. It can hardly be considered surprising that salt concentrations were not equally identifiable at the two levels of sucrose concentration that were used, just as it is not surprising that Pollack (1953) observed a similar effect with auditory stimuli. Indeed, logical considerations would lead us to expect that such interference effects would occur with many combinations of dimensions. For example, pitch identification must approach zero as loudness level approaches zero; it must also be very poor as loudness level approaches the upper threshold of hearing. Thus pitch identification ought to be best at intermediate loudness levels, just as Pollack found.

Yet there are other circumstances, such as the dot location task of Experiments 2 and 3 where interdimensional interference would not be expected to occur, and, in fact, does not occur. Unfortunately, the present research was not designed to explore the causes of interdimensional interference but merely took the phenomenon for granted. It would be a fruitful topic for further investigation.

The factor that has been called here distraction seemed to be limited in its effects to situations in which Ss had to ignore variation in color, and in this case filtering was equally difficult at the 1/8-sec and 1-sec stimulus durations. It is not yet clear how to integrate this finding into the literature on filtering. On the one hand, there have been previous studies in which variation in color from trial-to-trial has degraded identification performance on some other dimension (e.g., Morgan & Alluisi, 1967). On the other hand, it has not been a difficult matter to show that dimensions other than color can degrade performance when they are irrelevant and are varied in value from trial-to-trial (e.g., Hodge, 1959; Montague, 1965), although such variation does not inevitably lead to impaired performance (Tulving & Lindsay, 1967). One possible explanation of the pattern of results obtained in the present experiments that is consistent with the research cited and with current theorizing is that Ss can normally filter perfectly unless they have had extensive prior practice in responding to values along a currently irrelevant dimension. Thus, although no explicit practice in responding to colors was provided in the present experiment it has been provided by Ss' everyday experience. Ellipse size and ellipse eccentricity, however, are relatively novel in that Ss probably have not had experience in responding differentially on the basis of either dimension. The adequacy of this explanation may be assessed in a series of training and transfer studies, and such research is now under way.

Response complexity, which was regarded simply as an order-of-report phenomenon in these experiments, was a highly significant factor in Experiment 2 and also in the 3 → 3 condition of Experiment 4. Moreover, there was no indication of any interaction between duration and complexity; the decline in accuracy of report as a function of serial position within the report was about equal at long and short stimulus durations. It is difficult to believe that with an exposure as long as 10.0 sec Ss were forgetting the identification of the second dimension that they were to report while they were making their report on the first dimension. More likely is the possibility that Ss regarded the order instruction partly as an emphasis instruction and attended more closely to the first dimensions to be reported than to the later dimensions.

Simultaneous or Sequential Information Processing?

An issue that has been of considerable interest for the past few years concerns the mode of processing of the information provided by complex stimuli. The chief concern of that research has been to determine whether information about several dimensions is processed simultaneously or one dimension at a time (Egeth, 1966; Lindsay & Lindsay, 1966; Neisser, 1967; Nickerson & Fechner, 1964). It seemed worthwhile to attempt to extend this analysis to the absolute

Table 5
Information Transmitted about First, Second and Third Dimensions Reported in Multiple Response Conditions: Experiment 4

Task	Duration (seconds)					
	1/8			1		
	First	Second	Third	First	Second	Third
3→2	.92	.80	—	.99	.99	—
3→3	.97	.72	.71	.94	.84	.71

judgment task used in the present series of experiments. A precedent for this effort is provided by the work of Tulving and Lindsay (1967) on a closely related topic. These investigators explored the hypothesis, derived from Broadbent's (1958) model of attention, that simultaneously presented stimuli are examined sequentially. On the basis of this model, they predicted that if visual and auditory stimuli were presented simultaneously and briefly then Ss might be able to render accurate absolute judgments about one of these stimuli but would not have time to switch attention from one to the other and thus should not be able to make accurate judgments about both stimuli. However, at durations long enough to permit the switching of attention from one stimulus to the other Ss ought to be able to process information about both stimuli without difficulty. In other words, the sequential processing hypothesis leads to the prediction that a multidimensional information transmission decrement ought to obtain at short but not at long durations. They used durations of .02, .05, and 2.0 sec and found that the observed decrement was roughly equal across these three durations. Their conclusion was that the sequential processing hypothesis was untenable, a conclusion that is consistent with the data of Experiments 2 and 4 of the present report.

It is possible to provide a further test of the sequential processing hypothesis by examining the effects of exposure duration on the factor of response complexity. As pointed out in the Introduction, if information about the dimensions of a complex display is encoded one dimension at a time, as in the study by Harris and Haber (1963), then with long durations there ought to be relatively little decline in accuracy as a function of serial position within a report. However, the decline in accuracy with serial position that was observed in the present experiments was not dependent on stimulus duration, which provides further evidence that the serial processing hypothesis is inadequate for the multidimensional absolute judgment task. (It should be emphasized that the main effect of order-of-report does not, in itself, indicate that information *input* was organized serially. For example, if Ss had interpreted the order-of-report instructions as emphasis instructions then they might have attended more closely to the dimensions that were to be reported early than to the later ones. Such differential attending could occur in conjunction with either a simultaneous or a sequential mode of information processing. It is necessary to examine the interaction of order-of-report and duration to distinguish between these modes.)

The effects of duration on the magnitude of the multidimensional information transmission decrement and the lack of interaction between duration and response complexity are findings that are more consistent with a model that assumes simultaneous rather than sequential processing of information. However, it becomes important at this point to distinguish between two hypothetical kinds of simultaneous processing. On the one hand, information about individual dimensions may be carried by completely independent channels which do not interact with one another. This is parallel processing, as the term seems to be now used by psychologists (e.g., Neisser, 1967). On the other hand, information about individual dimensions may be carried on channels among which there is some degree of interdependence. In the absence of any well-established name of this kind of system, we will simply refer to it as multiplex processing. It is precisely this notion of multiplex processing that seems to be called for by the repeated observation that performance in unidimensional ($1 \rightarrow 1$) tasks is superior to performance in multidimensional ($2 \rightarrow 2$, $3 \rightarrow 2$, $3 \rightarrow 3$) tasks. In other words, when two or more dimensions must be judged there is every evidence that they are examined simultaneously, but each one is identified less accurately than if it were the only one being judged. This conclusion is consistent with the

results of a recent study that was explicitly concerned with the nature of the processes underlying multidimensional discrimination (Lindsay, Taylor, & Forbes, 1968). Thus, even in situations in which the effects of interdimensional interference, distraction, and response complexity are eliminated, we can expect to observe a trade-off between depth and breadth in information processing.

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NOTES

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2. Address: Department of Psychology, The Johns Hopkins University, Baltimore, Maryland 21218.
3. The use of informational terminology and methodology throughout this paper is consistent with that of Garner (1962).
4. The reader may be reassured to learn that when these data were plotted in terms of percentage of correct response instead of bits of information transmission, the same conclusion was reached. In fact, we have consistently found that all of the conclusions drawn in this paper on the basis of informational analyses were supported by analyses of percentage of correct response.
5. In the terms of the Munsell system, the colors correspond to: 7.5YR 8/10, 5.0YR 7/10, 10R 6/10, 7.5R 5.5/10, 5.0R 5/10, and 2.5R 5/10. For the ellipses, the ratios of the minor to the major axes were: .64, .71, .77, .82, and .87.

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