The Role of Integral Displays in Decision Making

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INTRODUCTION

A common approach to designing human-computer decision systems is to divide decision tasks between the person and the computer. The success of this approach depends on knowledge of the specific task components and their interactions, information important for allocating tasks to man and machine. Such knowledge is often unavailable for complex, realistic decision situations. Also, people are reluctant to relinquish part of their decision-making responsibilities. One way to circumvent these problems is to provide general assistance to the decision maker that is independent of any particular decision situation. We propose to use the computer to reduce the decision maker's cognitive load rather than his task load. Specifically, we hope to show that human decision processes can be aided by displaying decision-relevant information in ways that capitalize on certain characteristics of the human perceputal system.

A large body of research exists on the perceptual processing of multidimensional stimuli. Garner [3], for example, investigated the effects of the inherent structural properties of stimuli on perceptual tasks. An important finding is that certain combinations of stimulus dimensions are perceived as an integrated whole (integral dimensions) while other combinations allow the perception of individual stimulus dimensions (separable dimensions). In tasks that require the use of both stimulus dimensions, performance is better with integral than separable dimensions. Although these findings are based primarily on simple discrimination tasks such as classification and sorting, the structure of multidimensional stimuli may also affect more complex cognitive processes.

A related area of research is concerned with the representation of multidimensional data. Traditionally, statistical data have been represented numerically or in other standard forms such as bar graphs. Recently, attention has turned to discovering more effective, graphical representations of data. Jacob and Egeth [4] compared several such representations and showed that forms which allow data to be viewed as an integrated whole result in better performance than those that impose a more sequential analysis. For example, mapping each dimension of a multidimensional data point onto a different characteristic of a schematic face produced superior performance in classification and paired-associate learning tasks. Apparently, well-integrated displays, such as the face, enhance recognition of relationships inherent in the data dimensions.

Integral information displays may also benefit performance in more realistic decision tasks. Many everyday decisions require people to combine multiple pieces of information to form an inference about some uncertain event. A complex functional relation often exists between the multiple information cues and the event being predicted. Decision makers may increase their understanding of this relation and improve their judgments by successively estimating an event and observing its outcome. A stock broker, for example, combines various sources of financial information to evaluate the future of stocks. After receiving feedback from previous judgments, the stock broker may be better able to recognize a certain pattern of data as diagnostic of a particular outcome. Similar judgments are required to diagnose illnesses, predict successful oil drilling sites, evaluate job applicants, and solve a variety of other everyday problems.

Psychologists have systematically investigated the ability to integrate and act upon multiple sources of information using a laboratory task assumed to have relevance for many realistic decision situations. Under the multiple cue probability learning (MCPL) paradigm, a subject receives a combination of information cues, estimates the criterion value associated with those cues, and then receives the true criterion value as feedback. The results of MCPL studies show people to be poor diagnosticians. A significant variable influencing the quality of these judgments is the complexity of the function relating information cues to the criterion variable. People learn to predict criterion variables that are related to information cues by a simple linear relation quite well, but nonlinear relations are learned slower and less effectively [1, 6].

In a series of experiments, we have investigated the role of integral information displays on subjects' ability to combine and use multiple sources of information in a MCPL task. We hypothesize that the perceptual integration that occurs during the processing of information in an integral display will enhance subjects' use of the information. Thus, integral displays should lead to faster and more effective learning of the cue-criterion relation as indicated by subjects' improved prediction of the criterion.

GENERAL PROCEDURE

The following experiments varied both the integrality of the information displays and the amount of configurality relating information cues to the criterion. This section describes those procedures common to all of the experiments.

Subjects and Design

Display type and the cue-criterion relation were factorially related in a between-subjects design. In all experiments, 15 subjects were randomly assigned to each condition. Subjects were introductory psychology students at New Mexico State University who participated in partial fulfillment of a course requirement.

Task Characteristics

Previous studies have investigated the complexity of cue-criterion relations by varying the linear-curvilinear or the additive-configural components of the relation [1, 6]. A curvilinear relation is often produced by including exponential or trigonometric terms in the function relating cues to criterion. A configural relation exists when the weighting of one cue varies with the value of other cues. Configural relations require using the interdependency among the cues to correctly predict the criterion. The multiple correlation between the information cues and the criterion has previously been used as a measure of both the linear-curvilinear and the additive-configural characteristics of the task. A problem with this approach is that linear and configural components cannot be separated on the basis of this measure alone. Instead, we define linearity and configurality by means of an analysis-of-variance model with orthogonal polynomials used to analyze the linear components. An analysis-of-variance, with cues as the only factors in the design, is performed on the set of criterion values. Linearity is defined by the proportion of total variance that occurs in the linear components of the cue variables and their interactions. Configurality is defined by the proportion of total variance that occurs in the interactions between the cue variables. This technique allows configurality to be varied independently.

The analysis-of-variance approach was used to generate cue-criterion relations with constant linearity and varying amounts of configurality. In one case, 2 cues (X and Y), with 10 values each, were factorially combined resulting in an uncorrelated set of 100 cue value combinations. The cue values for X and Y were: 1, 3, 5, 7, 9, 11, 13, 15, 17, and 19. Three functions were used to produce additive, mixed, and configural relations. The functions are actually based on the original cue values minus ten which yields the set of linear weights from an orthogonal polynomial analysis. The results of an analysis-of-variance are not affected by subtracting a constant from each cue value. The three functions are:

Additive: $C = \frac{X+Y+18}{2}$

Mixed: $C = \frac{2XY+9X+9Y+162}{27}$

Configural: $C = \frac{XY+81}{9}$

The constant terms were used to produce an identical range of criterion values for all three relations. When necessary, the results of the functions were rounded to the nearest integer. An analysis-of-variance on the resulting values yielded configurality measures of 0, .46 and 1.00 for the additive, mixed and configural relations, respectively. Linearity was approximately 1.00 for each relation.

In a second case, 3 cues (X, Y and Z) with 5 levels each were completely paired resulting in 125 cue value combinations. The cue values were 1, 2, 3, 4, and 5. Three was subtracted from each cue value before applying the functions. Criterion vaules were derived by the following functions:

Additive: $C = X+Y+Z+36$

Configural: $C = \frac{3XYZ+144}{4}$

These functions resulted in configurality values of 0 and 1.00 for the additive and configural relations, respectively. Linearity was again approximately 1.00 for both relations.

Apparatus

A Terak 8510 microcomputer controlled the experiment and collected the data. The information displays were graphically presented on the Terak CRT.

Information Displays

The integral information displays are described separately for each experiment. The separable display always consisted of either two or three bar graphs, depending on the number of information cues used. Variation in cue values was mapped onto the heights of the bar graphs. The bar graphs were 4 mm wide and ranged in height from 5 mm to 95 mm.

Instructions

Subjects were informed of the relevant cue dimensions for each display type (e.g., height of bar graphs), and were told that a constant relation existed between the cue value combinations and the criterion values. Their task was to learn this relation in order to improve their predictions of the criterion values. The instructions encouraged subjects to respond quickly and to reduce their error scores throughout the experiment.

Procedure

A block of trials consisted of all of the cue value combinations for a particular cue-criterion relation. Blocks of trials were independently randomized for each subject.

On each trial subjects saw the information display, entered a response on the keyboard, and then observed the true criterion value which appeared immediately below. All information remained on the screen for 2 seconds at which time the screen was cleared and the next display appeared. A warning tone reminded the subjects to respond 11 seconds after the display appeared. Performance feedback consisting of a standardized mean square error measure was presented after every 10 trials.

Data Analysis

Performance was measured by the correlation between estimates of the criterion values and the true values. Subjects' judgments were individually correlated with the criterion values for each block and then transformed to Fisher's Z coefficients. The data analysis was then performed on these transformed values.

EXPERIMENT 1

Experiment 1 consisted of two blocks of trials from the two cue case. Ninety subjects participated in a two types of information displays by three cue-criterion relations factorial design.

Integral Displays

Variation in cue values was represented in an integral information display by the width and height of rectangles. The rectangles varied in height and width from 5 mm to 95 mm. Felfody [2] previously demonstrated that rectangles satisfy the criteria of stimulus integrality.

Results and Discussion

The data from Experiment 1 was analyzed in a 2 displays X 3 relations X 2 blocks analysis-of-variance. The analysis revealed significant main effects for displays, $F(1,84)=8.00$, $p<.01$, relations, $F(2,84)=176.96$, $p<.001$, and blocks of trials, $F(1,84)=119.55$, $p<.001$. The rectangle display resulted in better performance under all conditions. Performance decreased with configurality and increased between blocks. Table 1 presents the mean achievement correlation in Fisher's Z scores for each condition.

Table 1

Mean Achievement Correlations in Fisher's Z Scores

Experiment	Relation	Display	Blocks 1	2	3	4	5	6
	ADD	BAR	.96	1.54	-	-	-	-
	ADD	REC	1.32	1.53	-	-	-	-
1	MIX	BAR	.82	1.15	-	-	-	-
	MIX	REC	.95	1.22	-	-	-	-
	CON	BAR	.11	.23	-	-	-	-
	CON	REC	.19	.44	-	-	-	-
2	CON	BAR	.39	.61	.75	.94	.99	1.14
	CON	REC	.23	.47	.60	.77	.96	.98
	ADD	BAR	.93	1.26	-	-	-	-
	ADD	TR1	1.09	1.51	-	-	-	-
3	ADD	TR2	1.36	1.70	-	-	-	-
	CON	BAR	.07	.10	-	-	-	-
	CON	TR1	.06	.22	-	-	-	-
	CON	TR2	.07	.24	-	-	-	-
4	CON	BAR	.06	.10	.18	.26	.27	.36
	CON	TR1	.13	.40	.50	.65	.71	.84

ADD - additive relation
MIX - mixed relation
CON - configural relation
BAR - bar graph display
REC - rectangle display
TR1 - triangle display with radii
TR2 - triangle display without radii

Significant interactions occurred for blocks x relations, $F(2,84)=5.33$, $p<.05$, and blocks x relations x displays, $F(2,84)=7.22$, $p<.05$. The superiority of the rectangle display varied with configurality and with amount of prior practice. The advantage of the rectangle display was greatest in Block 1 for the additive relation, $t(84)=5.49$, $p<.01$, and Block 2 for the configural relation, $t(84)=3.20$, $p<.05$. No other display effects reached standard significance levels. These results indicate that the facilitation provided by an integral display is affected by both the functional relation between the information cues and the criterion as well as the level of understanding a judge has of this relation.

Subjects had little difficulty learning to combine information in an environment that was purely linear and nonconfigural. Performance was high in the additive relation by the end of Block 1 and increased minimally between blocks. A ceiling effect may have produced the insignificant display effects observed in the the second block with the additive relation. In contrast, little learning had occurred with the configural relation even after 100 trials. Not until the second block did performance begin to improve, and it is here where the integral display was significantly better. A floor effect may have resulted in the insignificant display effects in the first block. Taken together these findings suggest that integral displays may be most beneficial during a period of significant learning of the cue-criterion relation. When subjects are either in a state of complete ignorance about the cue-criterion relation or are at an asymptotic level of performance, the benefits of the integral information display are minimal. Experiment 2 was designed to further investigate the effects of an integral display with more opportunity for learning.

EXPERIMENT 2

Experiment 2 used the same information displays as the preceding experiment but restricted the set of cue-criterion relations to the configural case. The learning period was extended by giving subjects two blocks of trials over three separate days for a total of 600 trials. Since the subjects in the first experiment were still performing poorly in the configural condition after the second block, the configural relation should allow the examination of display effects over an extended learning period. A total of 30 subjects participated.

Results and Discussion

The data were analyzed in a 2 displays X 3 days X 2 blocks analysis-of-variance. Significant main effects for days, $F(2,56)=129.77$, $p<.001$ and blocks, $F(1,28)=58.49$, $p<.001$, were found. A blocks x days interaction was also significant, $F(2,56)=4.63$, $p<.01$. Subjects improved their predictions of the criterion values across both days and blocks with most of the improvement occurring on the first and second days.

As shown in Table 1, the bar graphs were slightly superior to the rectangles, although this difference was not significant, $F(1,28)=1.93$, $p>.10$. This was surprising in view of the robust display effects found in Experiment 1. The first two blocks from Experiments 1 and 2 shows that the bar graphs led to markedly better performance in Experiment 2.

The null results from Experiment 2 suggested a third experiment to help clarify the role of integral displays. Most realistic decision tasks involve more than two sources of information. A judge's cognitive load should increase as the number of separate pieces of information increases. If integral displays do in fact assist judgmental processes by reducing cognitive load, then the advantage of integral displays should increase as the number of information cues increases. Experiment 3 tested integral and separable displays with three information cues.

EXPERIMENT 3

Experiment 3 used the additive and configural case for three cues to test two new integral displays. The warning tone occurred at 7 seconds instead of 11 seconds after display onset in order to reduce subjects' response times. Two blocks of trials were given to ninety subjects.

Integral Displays

The integral displays were produced using a technique described by Jacob and Egeth [4]. With this technique variation in cue values is represented by the lengths of equally spaced radii emanating from a common center. A multidimensional polygon is created by connecting the end points of adjacent radii. The resulting figure for three cues is a triangle. The radii were left in the figure in one display and removed from a second display. Both displays varied in width from 25 mm to 125 mm and in height from 17 mm to 85 mm. In contrast to the previous experiments, subjects were not informed of the relevant cue dimensions of the integral displays. Instead, the instructions encouraged subjects to use the overall shape or form of the figure to learn to predict the criterion values.

Results and Discussion

The results of a 3 displays x 2 relations x 2 blocks analysis-of-variance showed significant main effects for displays, $F(2,84)=5.56$, $p<.01$, relations, $F(1,84)=349.01$, $p<.001$, and blocks, $F(1,84)=56.71$, $p<.001$. Both triangle displays resulted in better performance than the bar graphs for both relations. The benefit due to the triangle displays was greater for the additive than the configural relation, although the diplays x relations interaction failed to reach significance, $F(2,84)=2.79$, $p<.10$. A significant relations x blocks interaction $F(1,84)=14.36$, $p<.001$ again reflected the greater increase in performance across blocks for the additive than configural relation.

Performance was not hindered by having subjects view the overall form of the integral displays. Instead, attending to the gestalt of the integral display was more beneficial than observing the actual cue dimensions in the separable display. Comparing the two triangle displays in Table 1, shows that the greatest increase in performance between blocks occurred for the triangle display with inside radii. This display was used in a final experiment to explore how display effects vary over an extended period of learning. In this respect, Experiment 4 was similar to Experiment 2.

EXPERIMENT 4

Experiment 4 used the triangle display with inside radii from Experiment 3 and the configural relation of the three cue case. Two blocks of trials were presented to thirty subjects on three separate days for a total of 750 trials.

Results and Discussion

A 2 displays x 3 days x 2 blocks analysis of variance showed significant main effects for displays, $F(1,28)=30.59$, $p<.001$, days, $F(2,56)=58.83$, $p<.001$ and blocks, $F(1,28)=25.39$, $p<.001$. The triangle display was significantly superior to the bar graphs for representing configural information. Significant displays x days, F(2,56)=7.81, p<.01, and displays x blocks, F(1,28)=4.22, p<.05 interactions resulted from an increasing difference in performance between the integral and separable displays across both blocks and days. The advantage of the triangle display steadily increased from a difference in achievement scores of .07 in Block 1 to .48 by Block 6. Subjects with the integral display learned to predict the criterion values considerably better than those with the separable display by the end of the experiment.

The results from Experiment 4 indicate that integral diplays provide the most facilitation during significant periods of learning. Subjects significantly improved their ability to predict the criterion values during the experiment, although there was no indication that performance had reached an asymptote. This advantage of the integral display during knowledge acquisition of the cue-criterion relation supports the similar finding in Experiment 1.

GENERAL DISCUSSION

The combined findings of these experiments indicate that the integration and use of multiple sources of information can be facilitated by displaying the information in a holistic fashion. The role of integral displays still needs further clarification, though, as exemplified by the null results of Experiment 2. While our findings are in general agreement with those of Jacob and Egeth [4], we found inferior performance with a schematic face in some pilot testing. Perhaps it is important to have integral displays that also preserve the comparative values on different dimensions when decision making is involved.

Additional information is needed on the relationship between task complexity and display type. This study indicates that integral displays can be beneficial in both additive and configural task environments. This is a useful property for applications to realistic decision situations where the task characteristics are often unknown. The results of Experiments 3 and 4 indicate that more robust benefits of integral displays can occur by increasing the number of information cues. Again, this is desirable since real world decision tasks usually involve many sources of information.

An ever increasing number of people receive decision-relevant information via computer terminals, many of which have graphics capabilities. This information is most often presented in a numeric, piecemeal fashion requiring sequential processing. Substantial improvements in decision performance should be possible by displaying information in a more holistic fashion.

The preceding experiments were an initial effort to investigate the role of integral displays on higher level decision processes. Future research in this area could take a number of directions. At what level in the information processing system do integral displays reduce cognitive load? Do integral displays help subjects to learn a rule for predicting criterion values from combinations of information cues, or do they simply allow subjects to better recall the criterion value for a particular visual pattern? Are integral displays beneficial for both learning judgmental strategies and applying already acquired rules? How does the integrality of information displays affect other decision processes such as probability estimation? Is it possible to correct such judgmental biases as representativeness and availability [5, 7] by representing information in an integral display?

Theoretically, this research begins to explore the interaction between perceptual and decision processes. Similar approaches could investigate how other aspects of the human cognitive system, such as attention and knowledge representation, are involved in decision processes. The general approach to the study of decision making advocated here is to examine human decision processes as part of the general human information processing system. This promises to be a fruitful approach for improving human-computer decision systems.

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