

## Information Displays and Preference Reversals

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Preference reversals occur when a decision maker prefers one option to another in one response mode but reverses that ordering when preferences are elicited in another response mode. We report the results of two experiments which significantly impact the frequency of preference reversals. Specifically, when the probabilities are displayed in a format which appears harder to process, the frequency of reversals is increased. Process-tracing evidence suggests that decision-makers also shifted information processing strategies as a function of information format. We discuss the implications for theories of preference reversals and strategy selection, and for the design of information displays.

### INTRODUCTION

A trademark of modern behavioral decision research is the use of inconsistencies in preference to study the processes underlying choice and judgment. No other inconsistency has attracted as much empirical and theoretical attention, across a variety of disciplines, as demonstrations of preference reversals. A preference reversal involves eliciting preferences for two choice options, usually lotteries, using two ways of collecting responses, such as observing choices between the options and obtaining selling prices. A preference reversal occurs when subjects prefer different options in each response mode (Goldstein & Einhorn, 1987; Lichtenstein & Slovic, 1971; Lindman, 1971).

Because preference reversals question the basic principles of rational choice, such as transitivity, in a fairly convenient experimental paradigm,

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they have attracted considerable attention from both economists and psychologists. This research falls into two closely related streams: The first is a set of studies designed to establish the robustness of the preference reversal phenomenon (e.g., Berg, Dickhaut, & O'Brien, 1985; Grether & Plott, 1979; Hamm, 1979; Lichtenstein & Slovic, 1973; Mowen & Gentry, 1980; Pommerehne, Schneider, & Zweifel, 1982; Reilly, 1982). In general, the frequency of preference reversals has remained constant or significantly increased, despite efforts to reduce it. Of particular interest is the fact that sizable incentives do not reduce the frequency of reversals. As noted by Grether and Plott (1979), this rules out an explanation of preference reversals based upon misspecified incentives or the unwillingness of subjects to put effort into the decision.

The second stream of research attempts to describe the psychological mechanisms underlying preference reversal. This work focuses on the strategies underlying the evaluation of simple gambles, and how they lead to the observed inconsistencies in preference (Goldstein & Einhorn, 1987; Lichtenstein & Slovic, 1971; Loomes & Sudgen, 1983; Schkade & Johnson, 1988).

Our current work is related to both streams. We present the results of two studies which manipulate whether probabilities are presented as decimals (say .9) or equivalent, but more complex looking, fractions (e.g. 513/570). Our central hypothesis is that the more effortful the integration of information about probabilities with payoff information, the greater the likelihood of preference reversals. We propose that the cause of this effect is a shift from expectation types of strategies when probabilities are easier to process to more heuristic strategies when the probability information is more difficult to process. Such heuristics often involve processing by attribute rather than by alternative (Bettman, 1979). Consequently, we also hypothesize that the amount of processing by attribute will increase when the task is more difficult. These hypotheses are supported by previous research on format effects and the role of effort considerations in strategy selection.

There is a sizable literature in decision-making demonstrating display effects (Bettman, Payne, & Staelin, 1986; Payne, 1982). One explanation for the impact of display on decision behavior is that people are responsive to the amount of effort required by a choice (Beach & Mitchell, 1978; Johnson & Payne, 1985). Since different display formats affect the effort required by various strategies, decision-makers may react to changes in display format by adopting strategies which minimize their effort. Thus, organizing unit price information into a table makes such information easier to use, increasing its impact upon choices (Russo, 1977). Similarly, when options are described by words instead of numbers, decision-makers abandon strategies that use mental arithmetic (Huber, 1980), sav-

ing themselves the effort of generating numeric equivalents of the verbal representation. According to this perspective, format manipulations change the mental effort required to execute different decision procedures, resulting in these strategy shifts. Such strategy shifts can result in less accurate decisions (Russo, 1977).

Effort considerations played a central role in the earliest explanations of preference reversals. For instance, Slovic (1967) states that "it seems plausible that the cognitive effort involved in making this sort of compatibility transformation discouraged [subjects] . . . from relying on probabilities in a precise manner" (p. 34). That is, the more effort required, the greater the likelihood that subjects will ignore or misuse the information. Slovic and Lichtenstein (1968) also emphasize how cognitive strain may cause decision-makers to resort to simplified strategies, many of which lead to biased responses. Finally, Slovic (1972) makes the related observation that rather than transform presented data to make superior strategies easier to use, people shift to heuristics that use the information as given. Such heuristics may then cause systematic and significant errors, such as preference reversals and violations of transitivity.

While effort and the possibility of strategy shifts played an important role in early explanations of preference reversals, more recent theories do not easily accommodate the possibility that changes in information display might change the frequency of preference reversals. For example, Goldstein and Einhorn (1987) assume that a single, invariant strategy is used to evaluate gambles regardless of response mode. Expression theory (Goldstein & Einhorn, 1987) locates the principal source of bias in the expression of the underlying evaluation onto different response scales.

To summarize, the present paper explores the impact of information format on preference reversals. We hypothesize that presenting probability information in a more complex format will (1) increase the difficulty of the task, (2) cause a shift in processing strategies, and (3) increase the frequency of preference reversals.

The rest of the paper presents two experiments designed to test these hypotheses. Experiment 1 uses a standard pencil and paper procedure to determine if the frequency of reversals is affected by format variations. Experiment 2 uses a new computer-based process tracing methodology to explore how format impacts on effort, strategy changes, and preference reversals.

## EXPERIMENT 1

The purpose of this experiment was to determine if the frequency of preference reversals could be influenced by simple changes in the way in which probability information was displayed.

### Method

*Stimuli.* The stimuli were pairs of simple gambles of the form win amount  $\$X$  with probability  $p$ , otherwise receive nothing. One gamble in a pair offered a high probability of a modest amount to win (called the P-bet) and the other gamble offered a low probability of a large amount to win (called the  $\$$ -bet). Six pairs of gambles were constructed. Each pair of gambles had equal expected values. Table 1 provides a listing of all the pairs of gambles used in the experiment.

The way probability information was displayed was varied across subjects. For some subjects, the probabilities were given in the form of simple decimals, such as a .88 chance to win. For other subjects, the same gamble was described by a  $7/8$  chance of winning. A third group saw the same gamble described by a  $77/88$  chance of winning, and a fourth group saw the same probability described as a  $399/456$  chance of winning. Note that all these numbers represent the same probability, but that the ease of manipulating these numbers should differ. Specifically, the literature on mental arithmetic suggests that operations such as adding or multiplying two numbers would become more effortful as the number of digits is increased. These four conditions hence represent an ordering in processing difficulty, ranging from the easiest, the decimal condition, through the

TABLE 1  
STIMULI, EXPERIMENT 1

Payoffs	Probabilities			
	Easy	Moderate	Hard	Decimal
\$2	9/10	81/90	513/570	.9
\$9	2/10	18/90	114/570	.2
\$12	9/10	72/80	513/570	.9
\$36	3/10	24/80	171/570	.3
\$3	7/8	77/88	399/456	.88
\$21	1/8	11/88	57/456	.12
\$8	8/10	56/70	456/570	.8
\$32	2/10	14/70	114/570	.2
\$4	8/9 <sup>a</sup>	32/36	856/963	.89
\$40	1/9	4/36	107/963	.11
\$2	5/6 <sup>a</sup>	30/36	535/642	.83
\$9	1/6	6/36	107/642	.17

<sup>a</sup> These two gambles were mistyped as 8/19 and 5/16 on the stimulus forms. They were not included in the analysis for the easy fraction condition.

three fraction formats, which we will term the easy, moderate, and hard fraction conditions. As noted above, we hypothesize that increasing processing difficulty will lead to greater frequency of preference reversals.

*Subjects.* Eighteen subjects, 20 subjects, and 18 subjects responded to gambles described by the easy, moderate, and hard fractions, respectively. Twenty-five subjects were presented with gambles described using decimals. These subjects were randomly assigned to one of the four format conditions. All 81 subjects were MBA students at UCLA. They were paid a fixed fee for participation. In addition, there was an opportunity to be randomly selected to play a gamble, with potential winnings of up to \$40.

*Procedure.* Each subject was asked to rate each of the 12 gambles using a 20-point attractiveness scale like the one used by Goldstein and Einhorn (1987). This scale ranged from 1 (representing an extremely unattractive option) to 20 (representing an extremely attractive option (the *rating mode*)). Each subject also evaluated each of the 12 gambles in terms of the amount of money that was worth as much as playing the gamble (the *bid mode*). This comparison between preferences obtained by bids and ratings of attractiveness produces the highest frequency of reversals (Goldstein & Einhorn, 1987). The gambles were ordered randomly, with the same random order used for all subjects. The rating and bid tasks were separated by another unrelated decision task. The order of the rating and bid tasks was counterbalanced across subjects.

The subjects were told that there were no right and wrong answers, and that we were only interested in their preferences regarding the gambles. In order to increase motivation, the subjects were told that 10% of the subjects would be selected at random and given the opportunity to actually play one of the gambles. They were told that for each subject selected, a pair of gambles would be randomly selected and the gamble for which they had indicated a stronger preference (i.e., higher rating or larger bid depending upon the assessment mode characterizing the specific gamble pair selected) would be played. Those who won were allowed to keep their winnings. No losses were possible.

### *Results*

The ratings and bids provided by the subjects for each P-bet /\$-bet pair were examined for reversals. As in previous research, these are classified into two groups: *Predicted* reversals, in which a subject rates the P gamble higher than the associated \$ gamble, but bids more for the \$ gamble than for the P gamble; and *unpredicted* reversals, which show the opposite pattern and serve as a baseline, since they are generally thought of as resulting from careless errors. All ties were counted as consistent choices. The number of reversals was divided by the total number of pairs

of gambles rated by the subject to yield our main dependent variables, the proportions of predicted and unpredicted preference reversals.<sup>1</sup>

These data show that the hard fraction condition had a much higher frequency of predicted reversals when compared to the other displays: the mean proportion of reversals in the hard condition was .45, while it was .24, .22, and .25 in the decimal, the easy, and the moderate fraction conditions, respectively. Thus, while the information in all four presentation formats is identical, the hard fraction display appears to cause almost twice as many preference reversals as the other conditions.

This result was confirmed by an analysis of variance conducted on an arcsin transformation of the proportion data (Neter & Wassermann, 1974, p. 508) to produce a normal distribution. This shows that the overall effect of display approaches significance,  $F(3,77) = 2.42, p = .073$ . More importantly, the contrast comparing the hard fraction group to the three other formats is quite significant,  $F(1,77) = 6.88, p < .01$ , as are all paired comparisons of the decimal, easy fraction, and moderate fraction groups with the hard fraction group.

While predicted reversals differed across the display conditions, there are no systematic differences in unpredicted reversals. Overall, the frequency of such reversals is low, 0.4, and the means are similar: .03, .01, .05, and .06 for the decimal, easy, moderate, and hard fraction conditions, respectively. An ANOVA using the arcsin transformation failed to indicate any significant effect of display format,  $F(3,77) = .81, p > .50$ . Further, the frequencies of predicted to unpredicted reversals were significantly different by McNemar's Q, all  $X^2 > 14, p < .001$  (see Lichtenstein & Slovic, 1971, p. 53, for a discussion of this test). Thus, the differences in predicted reversals, since they are not accompanied by a similar increase in unpredicted reversals, do not appear to be solely the product of increased error in the responses.

A comparison of items within the decimal condition provides additional evidence that the format of the probability information affects the frequency of preference reversals. Notice in Table 1 that 3 items have probabilities expressed as single digit decimals, and 3 have probabilities expressed in two digits, (i.e., .9 vs .88). The frequency of reversals for the two digit decimals is significantly higher (.29) than for the single digit decimals (.17). A repeated measures ANOVA on the arcsin proportions within these items indicated that this effect is significant,  $F(1,24) = 4.50, p < .05$ .

While this study does not provide direct evidence that strategy changes mediate the increase in preference reversals, there is some evidence con-

<sup>1</sup> Proportions were used because unequal cell sizes resulted from typographical errors in the easy fraction condition.

sistent with that hypothesis. The stimuli for the study were constructed so that the P and \$ gambles in each pair had equal expected value. Thus someone who calculated expected value would produce a tie in the price or rating for the two items in a pair. Ties between the two gambles were much more common in the decimal and easy fraction conditions (mean proportions: .43 and .33, respectively) than in the moderate and hard fraction conditions (.22 in both). Thus there is indirect evidence that calculating expected value was more frequent with simpler displays of probability information.

### *Discussion*

In sum, changing the way probabilities were displayed produced a fairly large change in the frequency of preference reversals. While we attribute this to a strategy change, Experiment 1 is limited in two ways: First, it does not provide any direct evidence that the hard fractions are indeed perceived by decision-makers to be more difficult. Second, it does not provide any direct evidence that strategies do indeed change. Instead, Experiment 1 provides only outcome-based evidence that is consistent with these effects.

To provide evidence that would examine these issues directly, we conducted a second experiment using the two extreme display conditions from Experiment 1: the decimal and hard fraction conditions. In this study, we collect evidence on subjects' perceptions of the effort required in these two conditions. In addition, we use a process-tracing methodology to examine any possible change in strategy. The methodology is based on the Mouselab system (Johnson, Payne, Schkade, & Bettman, 1986). This system monitors the information acquisition behavior of subjects as they evaluate the gambles. Since different evaluation strategies imply different search orders (Payne, 1976), observing search enables us to test the hypothesis that changes in strategy are caused by the display formats.

## EXPERIMENT 2

The purpose of this experiment was to examine how information format was related to (1) perceived task difficulty, and (2) shifts in processing, as well as (3) frequency of reversals. The specific hypotheses will be described below after the process-tracing procedure.

*Overview.* Subjects provided ratings and bids for six pairs of gambles using a computerized process-tracing system. Response times, proportion of time spent examining probabilities and amounts, and the pattern of information acquisition were obtained by the system. The format of the probability information was manipulated as a between-subjects factor with two levels: decimals and hard fractions.

TABLE 2  
STIMULI, EXPERIMENT 2

Decimal	Greater <sup>a</sup> outcome		Payoff	Decimal	Lesser outcome		Payoff
	Probability	Fraction			Probability	Fraction	
.8		284/355	\$6	.2		71/355	-\$1
.2		79/395	\$27	.8		316/395	-\$1
.8		388/485	\$7	.2		97/485	\$0
.2		134/670	\$28	.8		536/670	\$0
.9		657/730	\$6	.1		73/730	-\$2
.2		83/415	\$34	.8		332/415	-\$2
.9		477/530	\$8	.1		53/530	\$0
.2		89/445	\$36	.8		356/445	\$0
.9		369/410	\$9	.1		41/410	-\$3
.3		177/590	\$33	.7		413/590	-\$3
.9		549/610	\$12	.1		61/610	\$0
.3		141/470	\$36	.7		329/470	\$0

<sup>a</sup> The \$-bet is shown first, followed by the P-bet. Immediately following each original pair is the pair formed by adding a constant amount to each outcome of the original pair.

### Method

*Stimuli.* Six pairs of gambles were used. The 12 gambles presented to subjects are shown in Table 2. They are similar to those used in Study 1, but some contain a nonzero amount to lose. Each pair consists of a P-Gamble and a \$-Gamble, each having exactly the same expected value. The 6 pairs of gambles consist of an original set of three pairs and a second set of three pairs which was formed by adding a constant to each of the outcomes of the original pair.<sup>2</sup>

*The Mouselab process-tracing system.* The Mouselab system presents gambles to subjects using the display of an IBM-PC or equivalent.<sup>3</sup> Subjects use a computer-based pointing device, called a *mouse*, to move a cursor in order to acquire information about alternatives. As shown in Fig. 1, each of the outcomes and its probability were presented in decision

<sup>2</sup> There was no difference in the frequency of preference reversals between the gambles with and without losses. Hence, this distinction is not discussed further.

<sup>3</sup> The Mouselab system can present many different types of choice problems to subjects (e.g., standard matrix choice problems or multiattribute risky choices), but gambles are the focus of the current study.

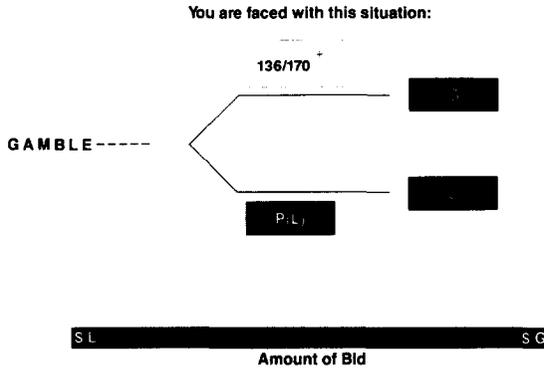


FIG. 1. Computer display, Experiment 2.

tree form, and each piece of information was available within a labeled cell. When a cursor entered the cell, the label disappeared and the relevant information was displayed. When the cursor left the cell, the label reappeared almost immediately. Subjects responded on the continuous scale that appeared below the gamble by using the mouse to move a pointer along the scale. The scale within each response mode corresponded to the requirements for that mode (i.e., the scale for ratings was the same 1 to 20 scale used in Study 1, and the scale for bids was a dollar scale). The bidding response scale was anchored at one end by the amount to lose and at the other by the amount to win (the labels for the scale endpoints were \$L and \$G—see Fig. 1).<sup>4</sup>

The Mouselab system records many of the details of subjects' search and responses: The time, order, and frequency of entry and exit for each cell of the display; the time, starting point and ending point of movements along the response scale; and the total latency for the trial. These served as the basis for the measures we will describe below. Because the mouse is a facile pointing device (Card, Moran, & Newell, 1983), the Mouselab system allows us a convenient method for studying acquisitions with detail approaching that of eye-movement recording. Both theoretical analyses and empirical observation suggest that acquisitions can be made in periods as brief as a few hundred milliseconds. Earlier work using Mouselab suggests that the system does not alter subjects' processing, as

<sup>4</sup> An anonymous reviewer suggested a possible problem with this response scale. Since the scale is anchored by \$L and \$G, a proportionality approach to responding may be encouraged for both the bidding and rating tasks. This scale differs from the normal bidding task of writing the amount bid on a sheet. If response compatibility holds, then the task used in Experiment 2 may thus show a reduced overall frequency of preference reversals. However, our interest in this study is the relationship between the frequency of reversals in the hard fraction and decimal conditions, although lower reversals overall may make such a difference more difficult to demonstrate.

standard results in choice processing (e.g., the effects of increasing numbers of alternatives) are replicated by subjects using Mouselab (e.g., Johnson, Meyer, & Ghose, 1988). For more details on Mouselab, see Johnson *et al.* (1986).

*Subjects.* Ninety-one subjects participated as part of a course requirement. Random assignment placed 45 in the decimal condition and 46 in the hard fraction condition. All were students in undergraduate business classes at Carnegie-Mellon University. All had the opportunity to be randomly selected to play one of the gambles.

*Procedure.* Subjects first familiarized themselves with searching for information and making responses with the mouse. Instructions for either the bidding or rating response mode were then presented on the monitor, with the order of the two response modes counterbalanced across subjects. Subjects then evaluated each gamble using that response mode, with the gambles randomly ordered for each subject. After completing an unrelated decision task, subjects again received instructions and judged each item in the alternate response mode. They then completed a post-experimental questionnaire concerning their strategy, course work, and their understanding of expected value. In addition, at the end of each response mode (i.e., after rating or bidding on all 12 gambles), subjects rated the difficulty of the task on an 11-point scale (1 = very easy, 11 = very difficult).

In order to increase motivation, 10% of the subjects were selected randomly to play one of the two last gambles that they had seen. The gamble selected was determined by their responses: the one that had received the higher bid or rating (whichever mode characterized the gamble selected) was played; if subjects won, they received the indicated payoff. Losses were not assessed.

*Measures and hypotheses.* We expect the display format manipulation to affect perceptions of task difficulty, frequency of reversals, and processing strategies. More specifically, the hard fraction condition, as compared to the decimal condition, should be viewed as more difficult, should be characterized by a higher frequency of reversals, and should lead to shifts in processing strategy. In addition, we will examine whether shifts in strategies mediate any observed effects on reversals. The specific measures used and hypotheses developed regarding processing strategies are presented next.

Three process measures assessed by the Mouselab system will be of primary interest. First, we will examine the total time required to make a response, either rating or bid (TotalT). Total time provides a trial by trial measure of the difficulty of the task. This measure thus provides another manipulation check. We expect that the total time to respond (TotalT) should be greater for the hard fraction display condition.

Second, we examine the proportion of time spent examining probability information (PTP). Proportion of time on probabilities provides a measure of the content of search and the degree of selectivity in search. There are several reasons why PTP is of interest. At one level, one might expect PTP to increase for the fraction condition simply because it is a more difficult part of the decision problem. More theoretically, there are two competing hypotheses regarding PTP. First, *if* subjects were to calculate expected value, they may simplify the fraction prior to multiplying probabilities times payoffs. Thus, PTP would be greater for the fraction condition. Furthermore, this suggests that the greater the proportion of time spent looking at probability information, the fewer reversals, because EV calculation should lead to *fewer* reversals. The competing hypothesis, suggested by prior research about the causes of preference reversals, makes the opposite prediction: According to the response mode compatibility hypothesis (Slovic, Fischhoff, & Lichtenstein, 1982; Slovic & Lichtenstein, 1968) and the anchoring and adjustment explanations originally proposed by Slovic and Lichtenstein (1968, 1971), the relative weight given to probability information will be different in the two response modes. According to both theories, relatively more emphasis may be put upon the dollar amounts in the bidding response mode, since the amount to win will likely serve as an anchor. Probability information is then used as part of the adjustment process. To the extent that the format change causes the misuse of probability information (i.e., insufficient adjustment), this effect is expected to be larger with probabilities displayed as fractions. This suggests the hypothesis that the greater PTP, the *more* frequent reversals. Our hypotheses are in line with the latter reasoning presented above: that PTP will be greater with fractions, and that PTP will be associated with more reversals. We believe that subjects will respond to format changes by changing processing, not by transforming the more difficult probability information in order to facilitate the use of an expectation process (Slovic, 1972).

The third process measure of particular importance is the pattern of acquisitions, using an index due to Payne and Braunstein (1978). Holistic decision strategies, particularly expected value, suggest that subjects combine payoffs with probabilities, producing *outcome* transitions, involving a movement between the two components of the outcome. Other heuristics, often associated with an increase in choice errors (Russo & Doshier, 1983), are associated with *dimensional transitions*, such as comparing two outcomes or probabilities. While we as yet have little understanding of the explicit processes underlying preference reversals, it seems reasonable to suggest that dimensional processing, to the extent it reflects lesser use of expectation strategies, might be associated with reversals. Our measure of search patterns was the index calculated by

$(\text{Percentage of Outcome Transitions} - \text{Percentage of Dimensional Transitions}) / (\text{Percentage of Outcome Transitions} + \text{Percentage of Dimensional Transitions})$ . This results in a value of 1 if all transitions are within an outcome, and  $-1$  if all the transitions are within a dimension. As noted above, heuristics should be used to a greater extent as the difficulty of the task increases. Hence, we expect the pattern index to be positive in the decimal condition, where we expect that holistic strategies, such as expected value, should dominate, and more negative in the fraction condition, where we expect increased use of heuristic strategies. Note that this processing index can help to differentiate the two competing hypotheses for PTP above. If subjects try to simplify fractions prior to taking expectations, we would expect the pattern index to be positive. Thus, examining the joint pattern of PTP and the pattern index can provide insights.

Finally, we examine whether strategy changes mediate the effect of display on preference reversals. To show such mediation, three relationships need to be established (Baron & Kenny, 1986):

(1) that the process measures differ in the two display conditions, and therefore that display differences cause differences in processing;

(2) that the process measures are associated with an increase in the dependent measure, reversals; and

(3) that when these process measures are entered as covariates, the effect of the display manipulation upon reversals is weakened or eliminated.

We examine mediation for proportion of time spent on probabilities and the pattern index.

In sum, there are five major predictions: (1) The hard fraction group will judge the task to be more difficult and will take more time (essentially a manipulation check); (2) the hard fraction group will have more preference reversals; (3) the hard fraction group will devote a greater proportion of time to probability information; (4) the hard fraction group will show a less positive pattern index; and (5) the effect of the format manipulation on reversals is mediated by changes in proportion of time on probabilities and the pattern index.

*Analysis.* The experiment was characterized by one between-subjects factor, display format (decimals vs hard fractions), and one within-subjects factor, mode of assessing the gambles (ratings of attractiveness vs bids). Since reversals are defined by comparing responses across modes, a simple one-way ANOVA using display format as the between-subjects factor was conducted. For the other dependent measures, one between-subjects factor (display), one within-subjects factor (mode) mixed analyses of variance were conducted. Although the mode effects are not of specific interest, as the hypotheses concern display effects, we report them below for completeness.

TABLE 3  
OUTCOME AND PROCESS MEASURES FOR EACH DISPLAY MODE, EXPERIMENT 2

	Decimal	Hard fraction
Number of predicted reversals <sup>a</sup>	.94	1.77*
Number of unpredicted reversals <sup>a</sup>	.13	.12
Total time	23.19	28.43**
Proportion of time spent on probabilities	43%	64%***
Pattern index	.37	.04***

<sup>a</sup> Mean after taking the mean values of the inverse transformed data on reversals and retransforming them to the associated frequency counts. The maximum number of reversals is 6.

\*  $p < .05$ .

\*\*  $p < .01$ .

\*\*\*  $p < .001$ .

### Results

*Manipulation check.* We expected the display conditions to affect ratings of task difficulty. This expectation was upheld. Subjects judged the fraction condition to be significantly more difficult than the decimal condition ( $M = 5.07$  vs  $M = 4.14$ ,  $F(1,89) = 5.85$ ,  $p < .001$ ). There was a marginal effect of mode on task difficulty ratings ( $M = 4.34$  for ratings vs  $M = 4.86$  for bids,  $F(1,89) = 2.76$ ,  $p = .10$ ). The interaction of display and mode was not significant ( $F(1,89) = .28$ ). The effects of display on time taken are discussed below with the other process measures.

*Reversals.* Table 3 displays the means for the number of reversals for the decimal and fraction display conditions. Since the data were skewed, we analyzed these data using a reciprocal transformation,  $x' = 1/(x + .5)$ , which restores normality to frequency data such as these (Neter and Wassermann, 1974, p. 508).<sup>5</sup> The means in the table were generated by taking the means of the inverse transformed data on reversals and retransforming them to the associated frequency counts. As the table shows, the fraction display increases the frequency of preference reversals. As in the previous experiment, the fraction condition produced almost twice as many reversals as the decimal display of probabilities.

To confirm these effects, we conducted a one-way ANOVA on the transformed data. This ANOVA confirmed that the effect of display was significant,  $F(1,89) = 4.22$ ,  $p < .05$ . An analysis of the frequency of unpredicted reversals, on the other hand, showed no differences due to the type of display:  $F(1,89) = .04$ ,  $p < .75$ . Thus, the basic result that preference reversals are more common with difficult fractional displays is

<sup>5</sup> As noted above, the inverse transformation could not be used for Study 1 because of a typographical error in the easy fraction condition.

replicated, despite changes in subject populations, items, and experimental methodology.

*Process measures: display effects.* The display manipulation produced several changes in the way subjects acquired information. As Table 3 shows, the three central process measures are affected by the manipulation. As hypothesized, there is a marked increase in total time to respond in the fraction condition ( $M = 23.29$  s for decimals vs  $M = 28.43$  s for fractions,  $F(1,87) = 8.27$ ,  $p < .005$ ). There also is an increase in the percentage of time spent looking at probabilities and a marked decrease in the amount of outcome processing in the fraction conditions. Although subjects spend 43% of the time looking at the probabilities in the decimal condition, that number increases to 64% in the fraction condition ( $F(1,87) = 109.79$ ,  $p < .001$ ). The change in the pattern index from .37 in the decimal condition to .04 in the fraction condition implies that subjects are moving from a strategy that is primarily examining information within outcomes to one which moves within and between outcomes with about equal frequencies ( $F(1,87) = 22.53$ ,  $p < .001$ ). This finding is consistent with the notion that subjects in the hard fraction condition abandon an expectation type of process. In other words, the joint pattern of the proportion of time spent on probabilities and the pattern index implies that subjects do not appear to be merely spending more time simplifying the probabilities while applying an expectation process. All of these results confirm the major main effect predictions presented above.

While they are not the central focus of our study, there are several significant process differences due to response mode (see Table 4 for means). On average, responses made in the bidding task took longer,  $F(1, 87) = 66.23$ ,  $p < .001$ . This difference in times again suggests that subjects found making bids more difficult than generating ratings of attractiveness. Subjects also spent a greater proportion of their time examining probabilities in the rating response mode ( $F(1,87) = 10.97$ ,  $p < .001$ ). This result is consistent with the compatibility hypotheses. There is no effect of response mode on the pattern index ( $F(1,87) = 1.22$ ). There were no

TABLE 4  
PROCESS MEASURES FOR EACH RESPONSE MODE, EXPERIMENT 2

Process measure	Mode	
	Ratings	Bids
Total time	19.99	31.58***
Proportion of time spent on probabilities	.55	.51***
Pattern index	.19	.22

\*\*\*  $p < .001$ .

significant condition by mode interactions on any of the process variables discussed above. Since our focus is on display effects and strategy change, we will not pursue these response mode differences further. A more extensive discussion of response mode differences and their relationship to reversals is found in Schkade and Johnson (1988).

In sum, the results for the two process measures, proportion of time spent on probabilities, and the pattern index, provide strong evidence that the display manipulation changes information processing.

*Process shifts and reversals.* As noted above, to show that changes in processing mediate the effects of display condition on reversals, three results must be shown: (1) display significantly affects processing; (2) processing is significantly related to reversals; and (3) the effect of display on reversals is weakened if processing measures are used as covariates.

The results reported above demonstrate that both proportion of time on probabilities and the pattern index are affected by display. Next, we need to examine the relationship between the process measures and the observed frequency of preference reversals. To do this, we examine the correlation between the transformed frequency of reversals and the process measures, averaged over all of a subject's trials.<sup>6</sup> The results, both over all subjects and within conditions, are presented in Table 5.

The proportion of time spent on probabilities showed a significant association with the inverse-transformed measure of the frequency of reversals across all subjects ( $r = -.28, p < .01$ ). Because of the nature of the transformation, the negative correlation implies that a greater proportion of time spent on probabilities led to more reversals. This relationship also holds within both the decimal and hard fraction conditions, although it does not reach significance. On the other hand, the pattern index does not show an overall relationship to reversals ( $r = -.04, ns$ ). Indeed, the relationship between processing and reversals appears to differ greatly across display conditions. We will return to this finding below. For the present, however, the implication is that proportion of time spent on probabilities meets the second test for mediation, while the pattern index does not.

Hence, we examined the third criterion for mediation, the effect of display condition on reversals (inverse transformed) with proportion of time spent on probabilities included as a covariate. The effect of display format is no longer significant ( $F(1,87) = .05$ ), while the effect of proportion of time on probabilities is marginally significant ( $F(1,87) = 3.31, p = .07$ ). The interaction of display condition and proportion of time spent on probabilities does not reach significance ( $F(1,87) = .15$ ). Thus, the pro-

<sup>6</sup> An analysis conducted at the level of the individual trial using point-biserial correlation coefficients showed similar results.

TABLE 5  
 PATTERNS OF CORRELATIONS BETWEEN PROCESS MEASURES AND REVERSALS

	All subjects ( $N = 91$ )		
	TotalT	PTP	Pattern
Transformed reversals	.06	-.28**	-.04
TotalT		.15	-.21**
PTP			-.41***
	Decimals ( $N = 45$ )		
	TotalT	PTP	Pattern
Transformed reversals	.10	-.19	.05
TotalT		-.22	.32*
PTP			-.41***
	Hard fractions ( $N = 46$ )		
	TotalT	PTP	Pattern
Transformed reversals	.19	-.20	-.33*
TotalT		-.03	-.39**
PTP			.17

\*  $p < .05$ .

\*\*  $p < .01$ .

\*\*\*  $p < .001$ .

portion of time spent on probabilities meets all three tests for mediation, and we conclude that the proportion of time spent on probabilities mediates the effect of display condition on reversals.

To gain further insights into the relationship between processing and reversals, the correlations among these measures *within* display conditions, shown in Table 5, can be examined in more detail. These correlations show different interrelationships within conditions. Within the decimal condition, the pattern index is unrelated to reversals. In addition, the greater the proportion of time that is spent on probabilities, the more processing within dimension is done (the correlation between PTP and the pattern index is  $-.41$ ,  $p < .001$ ). Also, the greater the time spent on the task, the more outcome processing is done ( $r = .32$ ,  $p < .05$ ). These results suggest that within the easy decimal condition, more time spent on probabilities is associated with greater use of heuristics and more reversals, although there is not a direct link between the relative degree of outcome and dimensional processing and reversals.

The intercorrelations within the hard fraction condition present a different picture. The pattern index is significantly related to reversals ( $r = -.33$ ,  $p < .05$ ). This correlation shows, contrary to our original expectations, that greater outcome processing is associated with *more* reversals in the hard fraction condition. Also, greater times taken to complete the

task are associated with more dimensional processing ( $r = -.39, p < .01$ ). The correlation between outcome processing and proportion of time spent on probabilities is positive ( $r = .17$ ), although not significant. The latter two relationships are opposite to those for the easy decimal condition. Thus, in the hard fraction condition, it appears that attempting to process within outcomes leads to more reversals and less time taken. Perhaps subjects find the task too difficult and make crude approximations which lead to error. Hence, contrary to our original hypothesis about the relationship between processing and preference reversals, heuristic processing may lead to fewer errors in the more demanding fraction condition than attempting to process by a normative strategy which may be too difficult to execute. However, the relationships are fairly complex, and our interpretation is speculative at this point.

The lack of a relationship between processing pattern and reversals in the decimal condition is somewhat surprising. There may be several reasons for this finding, however. First, the decimal condition may be easy enough that many strategies can succeed. Hence, the correlation between processing pattern and reversals may be weak. In some sense, the task may simply be too "forgiving." A related reason is that our subjects appear to adopt what might be termed a "buffering" strategy, i.e., reading four items of available information, and then processing it once it has been encoded into short-term memory. Evidence that this strategy was used is strong: The modal number of times each piece of information was acquired is one, and some subjects never looked at the probability of losing, realizing that it was simply 1 minus the probability of winning. Similarly, subjects tended to search the information in one prototypical pattern. Over 95% of the trials began with acquisition of the probability of winning followed by the amount to win. When subjects execute such a buffering strategy, the connection between information search and subsequent processing is attenuated. While this makes the interpretation of the process measures in the current study incomplete, it does not necessarily dim hopes for the Mouselab paradigm. In more complex displays, the amount of information may overwhelm the capacity of short-term memory, making a buffering strategy impractical. We have found strong connections between observed search patterns and performance in risky choice research using more complex displays (Payne, Bettman, & Johnson, 1988).<sup>7</sup>

<sup>7</sup> Further support for the existence of such a buffering strategy comes from examination of the proportion of the total time on the task spent examining information in the cells (as opposed to time spent determining a response without looking at any cell). For the current study, this proportion is .35; in Payne, Bettman, and Johnson (1988), with a  $5 \times 4$  matrix display and no time pressure, the proportion is .64. A greater proportion of time is spent searching the display when the display is more complex.

An important methodological lesson to be learned from this result is that search patterns alone may not always reveal process differences, particularly when the display is relatively barren, lending itself to a buffering strategy. Russo (1978) develops a similar analysis of eye fixations, suggesting that what he terms "memorization strategies" might be used when information acquisition becomes more expensive than memorization.

In sum, strong statements about the relationship between processing patterns and the frequency of preference reversals await further research. However, the proportion of time spent examining probability information appears to mediate the effects of display format on preference reversals, although not in the manner we originally hypothesized (i.e., in the hard fraction condition, greater PTP is not associated with more dimensional processing, and more dimensional processing is associated with fewer reversals).

To summarize, the results of Experiment 2 support the notions that (1) the fractional display leads to an increase in the perceived effort associated with the task and the time taken to complete the task; (2) the fractional display leads to more reversals; (3) the fractional display is characterized by a greater proportion of time spent on probabilities and lower levels of outcome processing; (4) the proportion of time spent on probabilities mediates the effect of display on preference reversals; and (5) the relationship between processing pattern and reversals appears fairly complex.

## DISCUSSION

The history of interest in preference reversals is full of attempts to minimize the effect. As we have noted, such attempts have included sizable incentives, which, somewhat surprisingly, have often failed to produce sizable decreases in the occurrence of reversals. In contrast, the effort-related manipulation employed here demonstrates differences in the frequency of reversals for different display formats. For some reason, subjects seem unable to better their performance when faced with incentives as great as \$40. Similar groups of subjects, however, show markedly better performance when we simply change the way that probability information is displayed from hard fractions to decimals.

The form of an information display can encourage or discourage certain forms of processing. As Slovic (1972) notes, rather than transform data to fit strategies, subjects may take the information as presented and change strategies to suit the display. Hence, the use of simplified representations may be able to cut preference reversals dramatically. This suggests the possibility of *passive decision support*. In contrast to more active approaches which replace human cognitive processes to aid decisions, the

current research is consistent with the notion that better decisions can be encouraged by designing displays in ways which passively encourage better strategies by making them easier to execute (Russo, 1977, and Russo *et al.*, 1986, report field studies consistent with this notion). Thus, while one might be tempted, in designing a display for a decision-maker, to report decimal numbers to the fourth decimal place to increase "accuracy," our work suggests that overall accuracy might in fact decrease.

The selection among decision strategies is often seen as a tradeoff between (1) the amount of cognitive resources (effort) required to use each strategy, and (2) the ability of each strategy to produce an "accurate" response (Beach & Mitchell, 1978; Johnson & Payne, 1985; Russo & Doshier, 1983). The observation that a change from hard fractions to decimals can improve performance when sizable monetary incentives fail raises some questions for the notion that decision-makers adopt heuristics after a rational and complete tradeoff between the accuracy of various strategies and their effort, i.e., calculated rationality. Either these decision-makers are relatively insensitive to reasonably large sums of money and very sensitive to cognitive effort, or are unaware of the consequences of their strategy selection.

The current results also have implications for explaining preference reversals. Some current existing explanations of the preference reversal phenomenon posit the use of a single heuristic strategy that leads to bias at one of three stages: encoding, integration, or expression (e.g., Goldstein & Einhorn, 1987). We share their view that an ultimate explanation of preference reversals will involve integrated understanding of processes at these three stages. As Goldstein and Einhorn note, it is likely that there are several processes that are sufficient to generate preference reversals. The current work provides additional data for models to explain. We show that a simple display manipulation impacts on the frequency of reversals. We also show that process *changes* do occur, even for the rather simple evaluation tasks used in preference reversal studies. However, the exact relationships between process changes and the frequency of reversals remain unclear. Collection of further process-tracing data, perhaps involving more complex information displays, would be a fruitful area for research to clarify the specific processes involved in preference reversals.

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