

## **Process Traces of Binary Choices: Evidence for Selective and Adaptive Decision Heuristics**

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While previous research has shown that human decision processes adjust to the characteristics of choice situations and task demands, the present study examined whether information processing would even adapt to the characteristics of an individual choice pair. By a process tracing method it was found that the amount of inspected information systematically depended upon the particular choice pair. In order to specify the selective and adaptive information processing, criterion-dependent choice models were introduced. These models postulate that information processing continues until the accumulated amount by which one alternative is better than the other reaches or exceeds a certain criterion. These models are strongly supported by the empirical data of the present study. Deviations between model predictions and observed data are explained in terms of fluctuating feature values of the choice alternatives.

### **GENERAL INTRODUCTION**

Over twenty years of research have shown that instead of normative rules, humans employ heuristic strategies for decision making (Slovic, Fischhoff and Lichtenstein, 1977). For the human information processor, heuristic strategies have several advantages over rigid rules. Above all, a heuristic strategy reduces the cognitive effort of choosing.

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One possibility for reducing choice effort is to process only selected parts of the information about the choice alternatives. In such a situation, the importance of an information unit may in part determine which information is processed by a decision heuristic. Since decision heuristics can be applied to varied situations, they also enable the cognitive processing to be more flexible with respect to the givens of a choice situation.

When alternatives are presented by multidimensional descriptions, a person may differentiate between relevant and irrelevant dimensions. By processing only those features of the choice alternatives that lie on the relevant dimensions, the amount of information processing may be substantially reduced.

Basically, two possibilities exist for determining which dimensions and features are processed in a given choice situation. Firstly, a person may specify the relevant dimensions prior to considering any particular alternatives. When confronted with choice alternatives, this person would then process the features on the dimensions that had previously been determined to be relevant. For example, when choosing a news magazine, a person who is interested in science and politics may determine that articles on science, articles on politics, and the price of the magazine would be the only relevant dimensions. Therefore, when choosing between two magazines, this person would only process the features of these three dimensions. For instance, if the choice between two German magazines, *Capital* and *Der Spiegel*, were presented to this person, the only relevant information would be:

- |                                   |                |
|-----------------------------------|----------------|
| 1. number of articles on science  | 4 vs. 1,       |
| 2. number of articles on politics | 70 vs. 25,     |
| 3. price of the magazine          | 6 DM vs. 4 DM. |

Thus, this decisionmaker would always process the same number of feature pairs or dimensions regardless of the characteristics of the particular choice pair.

Choice processes, however, have also been found to be extremely flexible (Payne, 1982). It may therefore be suspected that decision-makers can adapt their information processing to the characteristics of the choice alternatives themselves. For example, random walk models that have been successfully applied to the analysis of performance in psychophysical tasks, such as discriminating between two alternative events (Vickers, Caudrey and Willson, 1971), would predict that the amount of information being processed would systematically depend upon the characteristics (e.g. similarity or discriminability) of the stimuli. Cognitive information processing may similarly adjust to the characteristics of a choice pair when one of two real alternatives is to be

selected. A decisionmaker may therefore only process as many features as are required to choose between the particular two alternatives given. The number of features processed for a choice would thus systematically depend upon some characteristic of the choice alternatives. For example, more information processing may be desired for alternatives whose features are about equally attractive than for alternatives whose features strongly differ in their attractiveness. Schmalhofer and Saffrich<sup>1</sup> have shown that for real alternatives such adaptive choice heuristics may produce a quite favourable relationship between the cognitive effort of choosing and the quality of the resulting choice.

In order to investigate whether people process multidimensional descriptions of alternatives selectively, a process-tracing experiment was performed with binary choice alternatives. If such selective information processing does, indeed, occur, this experiment should also determine whether subjects process the same number of features for every choice pair or whether the number of processed features varies systematically with characteristics of a choice pair, such as the similarity between the choice alternatives.

## EXPERIMENT 1

Subjects were individually presented with multidimensionally described choice pairs shown on a display board. While this display board always revealed the names of the dimensions by which the alternatives were described, the features of a choice pair had to be separately uncovered for each dimension. Thus, subjects had to request the alternatives' features on one of the dimensions successively until they wanted to make a choice. The inspected feature pairs, as well as the subjects' choices, were recorded for every choice pair. In order to allow for some additional analyses, the subjects also had to rate the attractiveness of every feature of the choice alternatives.

## Method

### *Subjects*

Twenty-eight students from the University of Heidelberg, who were paid ten Marks per hour, participated in the experiment. Because of possible knowledge of decision research, students of business, economics, mathematics, and psychology were not permitted to participate in the experiment.

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<sup>1</sup>Schmalhofer, F., & Saffrich, W. (1984). Effort-quality trade-off characteristics of selective information processing. Working paper, University of Heidelberg.

### *Materials*

The choice tasks consisted of choosing a one-year subscription to a news magazine. Six real magazines, each of which was described by its features on 11 dimensions, were used as choice alternatives. All possible pairs of alternatives were constructed, thus yielding a complete paired comparison with 15 choice pairs. A choice pair could show the same feature for both alternatives on up to four dimensions. An English translation of a sample choice pair is shown in Table I.

### *Apparatus*

An Apple II microcomputer with a game paddle was used for collecting the attractiveness estimates for all 11 features of every choice alternative. The information display consisted of a cardboard frame with a rectangular window big enough to show the 11 dimensions and the 22 features of a choice pair, which were printed on a sheet of paper. This sheet of paper was lying underneath the cardboard frame, so that the 11 dimensions were always exposed by the window frame, and the 11 little doors attached to the frame could individually cover or uncover given feature pairs.

### *Procedure*

Subjects first evaluated the attractiveness of the alternatives' features with respect to the subscription situation. Each of the 66 features was individually presented on the videoscreen of an Apple II microcomputer: The order of presentation was newly randomized for every subject. Together with each individual feature, the name of the respective dimension and a rating scale with seven categories (1-7) appeared on the screen. The extreme categories of this rating scale were labelled "unattractive" and "very attractive". By turning a

Table I

*A Sample Choice Pair as it Would be Seen by a Subject Who Uncovered All 11 Dimensions*

Dimensions	Features of alternative	
	A	B
Frequency of publication	monthly	weekly
No. of articles on science	4	1
No. of advertisements	120	180
Price of magazine	6.-DM	4.-DM
No. of articles on politics	70	25
No. of articles on ecology	1	5
No. of articles on entertainment	5	3
No. of articles on cultural events	3	5
No. of pictures	15	15
No. of colour pictures	10	3
No. of pages in magazine	350	300

dial, a pointer could be moved to any of the seven attractiveness categories on the screen, so that the subject could classify the presented feature into one of the seven categories.

The subjects were then given 15 trials in which they had to choose between two news magazines. At the beginning of every choice, subjects only saw the names of the 11 dimensions used to describe the alternatives. They could then request and inspect a feature pair of any dimension, which remained visible thereafter. After inspecting these features, subjects could request the features of another dimension. This procedure was repeated until a subject wanted to make a choice. Subjects were instructed to inspect as many feature pairs or dimensions (up to 11) as they liked before making a choice. In addition to the choices, the selected dimensions were recorded by the experimenter and the number of processed dimensions was calculated for every choice pair.

Choice pairs were presented in a previously specified order, so that for every presented alternative it was guaranteed that at least one pair of other alternatives would intervene before the same alternative recurred in the sequence of choice pairs. Subjects were run in individual sessions, which were completely subject-paced and lasted about one hour. Both rating and choice tasks were preceded by some practice trials with unrelated materials.

## Results

The number of inspected feature pairs clearly indicated that subjects employed selective information processing, rather than processing every feature of a choice pair: From the 11 possible features of an alternative, subjects inspected only 5.97 features ( $SD = 2.31$ ) on average. In order to determine whether for a given subject the number of inspected dimensions was constant for all choice pairs, a cumulative frequency distribution of the number of inspected dimensions was plotted. This distribution specified the relative frequencies with which a subject processed  $j$  or less dimensions of a choice pair for all possible  $j$ 's = 1, 2, . . . , 11.

Three types of distributions may be distinguished: A distribution that is always equal to zero, except for  $j = 11$  where it is equal to one, characterizes the processing of all features. A second distribution type describes selective information processing with an equal number of dimensions being inspected for every choice pair. This type is specified by a single step from zero to one for some  $j < 11$ . Finally, a third type of distribution with several step increments from zero to one would indicate that for the different choice pairs, different numbers of dimensions had been inspected.

Figure 1 shows the cumulative frequency distributions of the three subjects who most closely matched the three types. By a visual inspection of the individual cumulative distribution functions every subject could easily and uniquely be assigned to exactly one of the three categories. The precise criteria for this classification were: frequency

distributions with an average number of inspected dimensions  $> 10$  and  $SD < 1$  were classified as Type 1; frequency distributions with an average number of inspected dimensions  $< 10$  and  $SD < 1$  were classified as Type 2; and frequency distributions with an average number of inspected dimensions  $< 10$  and  $SD > 1$  were classified as Type 3. This classification showed that only two subjects, or 7%, processed nearly all features. For both of these subjects, the average number of inspected dimensions was 10.5; the respective standard deviations were 0.52 and 0.64. Five subjects, or 18%, processed a smaller but mostly constant number of dimensions. For these subjects, the average number of requested dimensions ranged from 3.7 to 6.4, with a median of 3.9; the respective standard deviations ranged from 0.46 to 0.88, with a median value of 0.74. However, the majority of subjects, namely 21, or 75%, showed the third distribution type. For these subjects, the average number of requested features pairs ranged from 4.1 to 7.7 with a median

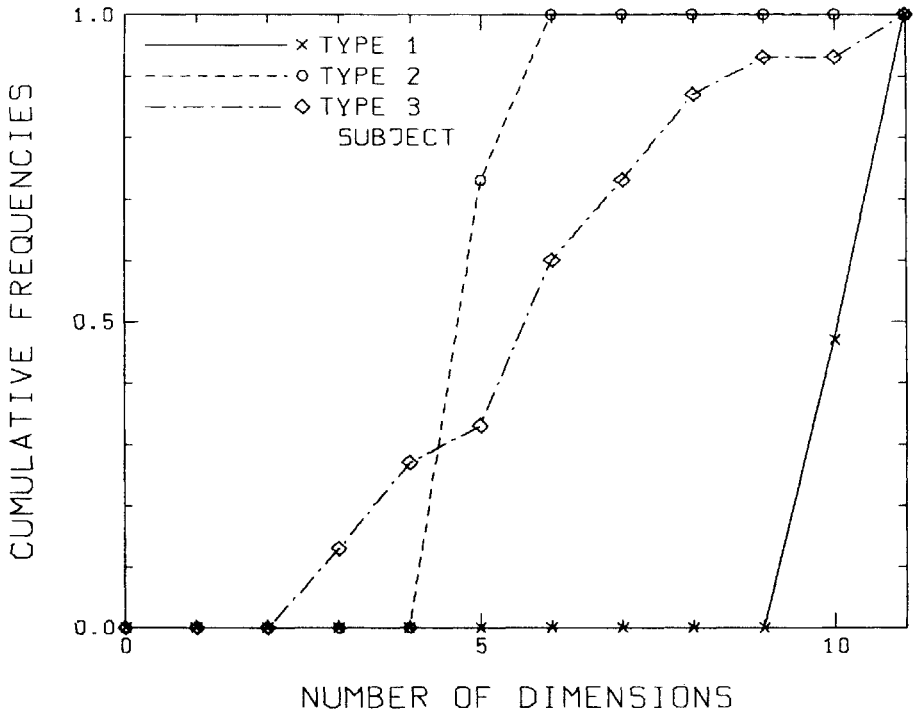


Figure 1. Cumulative frequency distributions of the number of inspected dimensions for three selected subjects.

*Note.* The three subjects who most closely matched the three different types of frequency distributions are shown.

of 6.0; the respective standard deviations ranged from 1.0 to 2.4, with the median standard deviation being 1.6.

These results show that most subjects inspected a variable number of dimensions. In order to demonstrate that the subjects' information processing adapted to the choice alternatives themselves, however, it must also be shown that the number of processed feature pairs systematically depended upon the characteristics of the choice pairs.

As mentioned earlier, for similar choice pairs more dimensions should be processed than for dissimilar pairs. In order to examine this hypothesis, the similarity of a choice pair was operationally defined. The number of dimensions with identical features was used as an indicator for the similarity of a choice pair. Rather than only the processed dimensions, all 11 dimensions of a choice pair were included for calculating the similarity index. Thus, the operational definition of similarity could be performed prior to, and completely independent of, the experimental data. Each choice pair was classified into a low-, medium- or high-similarity category. Thus, the 15 choice pairs were divided into three classes of five pairs each. For the classes with low, medium and high similarity the average numbers of identical features were 0, 1, and 2.6, respectively.

The cumulative frequency distributions of Figure 2, which were calculated from all 28 subjects' data, show that the number of processed dimensions increased systematically with the similarity of the choice pairs. A one-way ANOVA with similarity and number of inspected dimensions as the independent and dependent variable, respectively, substantiated this observation [ $F(2, 54) = 7.12, p < 0.005, MSE = 0.58$ ]. When two different operational definitions of similarity, which were derived from the subjects' individual attractiveness ratings and the subjects' preferential choices, were used for defining the three similarity classes, the respective analyses of variance yielded identical results.

## Discussion

The experimental results clearly demonstrate that a large majority of subjects did not process the same number of dimensions for every choice pair. Rather, the number of processed dimensions depended systematically upon the similarity of a choice pair, indicating that the subjects' information processing adapted to some characteristic of the choice alternatives.

Since the multidimensional descriptions used in the experiment referred to popular German news magazines, the subjects may have been more or less familiar with the choice alternatives. It may be

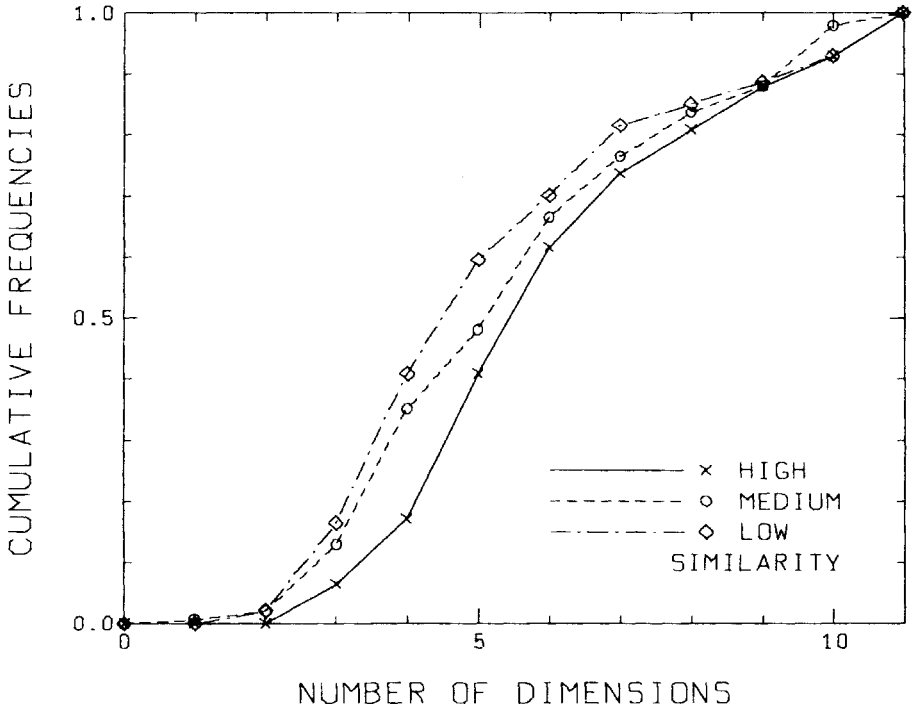


Figure 2. Cumulative frequency distributions of the number of inspected dimensions for three classes of choice pairs.

suspected that the decisionmakers' familiarity with the alternatives may influence the amount of information being processed<sup>2</sup> (Phelps and Shanteau, 1978). Since in the present experiment the subjects were recruited from a comparatively homogeneous population (students), it was assumed that such differences in the familiarity with the alternatives would be negligible. However, in order to assess the stability of the experimental results, it is certainly worthwhile to examine whether (the degree of) selective and adaptive information processing depends upon the naturally existing differences in the familiarity with the choice alternatives. Furthermore, the stability of the present results was examined by testing whether the cognitive choice processes are influenced by a subject's expectation that he will actually receive one of the chosen news magazines.

A person who regularly reads a news magazine is more likely to have developed some preconceptions about this and other news magazines.

<sup>2</sup>Van Raaij, W. F. (1976). Consumer choice behavior: An information-processing approach. Unpublished doctoral dissertation, Tilburg.



During the choice task these preconceptions could facilitate the identification of the choice alternatives. Therefore it could be argued that subjects who are more familiar with news magazines would first identify one or both of the presented alternatives before making a choice. Under these assumptions the identification of alternatives would be an essential component of the cognitive choice processes. Consequently, the observed selective and adaptive information processing could be attributed to a subject's identification processes rather than to the choice processes. In order to examine the empirical validity of this argument, as well as the role of possible preconceptions about the choice alternatives, a second experiment was performed.

## EXPERIMENT 2

Except for the following modifications, this experiment was identical to the first one. The subjects were divided into two groups: Subjects who had subscribed to (or regularly read) at least one of the six magazines (subscribers) and subjects who did not regularly read any of the six magazines (non-subscribers). In order to evaluate whether subjects usually identify the alternatives before they make a choice, two of the choice pairs were once more presented to the subjects at the end of the experiment. Rather than choosing an alternative, subjects were now asked to uncover as many feature pairs as they wanted in order to identify the name of the alternatives. Thus the number of inspected feature pairs can be compared between choice and identification tasks for the same alternatives.

### Method

Forty-two subjects were recruited according to the rules used in Experiment 1. Subjects were paid 10 Marks per hour for participating in the experiment.

The same materials, apparatus and procedure were used as in the first experiment, with the following exceptions: After the choice tasks, subjects had to answer some questions. They were asked which magazines they regularly read or subscribed to and whether they had identified any magazine during the choice task. The answers to these two questions were used to form the two subject groups who supposedly differed by their familiarity with German news magazines. Eighteen subjects did not regularly read any of the 6 news magazines, and 24 subjects were regular readers of 1 to 3 magazines (average 1.5). Since exactly three of the subjects who had stated that they regularly read one of the news magazines were not even reminded of any particular magazine in the choice tasks, these subjects were also classified as non-subscribers. Thus the subjects were divided into 21 subscribers and 21 nonsubscribers. About half of the subjects ( $n=10$ ) in each group were told that they would receive one of the magazines they had chosen during the experiment as a gift. At the end of the experiment a copy of one of the selected magazines was then given to them.

After answering these questions, subjects were presented with one choice pair from the low-similarity category and one choice pair from the high-similarity category. As in the choice tasks, they had to uncover feature pairs step by step, however, with a different goal: Instead of choosing one of the alternatives, they now attempted to identify the alternatives by name. The number of dimensions inspected and the identification responses were recorded.

## Results

This experiment replicated the previous results in all aspects for subscribers as well as non-subscribers. Subscribers inspected 6.31 features ( $SD = 1.86$ ), whereas non-subscribers inspected 5.82 features ( $SD = 1.58$ ), on average. This difference is not significant,  $t(40) = 0.91$ ,  $p > 0.05$ . Again, the majority of subjects processed a variable number of dimensions: Only 10% of the subscribers, and none of the non-subscribers, inspected nearly all features. Distributions of Type 2 were found for 14% and 18% of the subscribers and non-subscribers, respectively. The majority of subjects, i.e. 76% of the subscribers and 81% of the non-subscribers, inspected a variable number of feature pairs, resulting in distributions of Type 3.

A ( $2 \times 3$ ) two-way ANOVA on the average number of inspected dimensions with subject group (subscribers vs. non-subscribers) and similarity of choice alternatives as the two independent factors did not yield a significant difference between subscribers and non-subscribers [ $F(1, 208) = 3.47$ ,  $p > 0.05$ ,  $MSE = 10.29$ ]. Again the number of processed dimensions increased systematically with the similarity of the alternatives of a pair [ $F(2, 416) = 15.65$ ,  $p < 0.001$ ,  $MSE = 1.88$ ]. However, there was no significant interaction ( $F < 1$ ).

Of the four alternatives given in the identification task, subscribers correctly identified an average of 1.5 alternatives (38%), while non-subscribers correctly identified 0.9 of the alternatives (23%). An average of 0.7 and 0.8 incorrect journal names (17% and 19%) were given as identification responses by subscribers and non-subscribers, respectively. As would be expected, these numbers show that subscribers were somewhat better able to identify the journals by name [ $t(39) = 1.85$ ,  $p = 0.07$ ]. The size of the difference shows that with respect to preconceptions about news magazines the two subject groups were also rather homogeneous.

Subscribers and non-subscribers inspected significantly more features [ $F(1, 40) = 76.21$ ,  $p < 0.001$ ,  $MSE = 1.82$ ] in the identification (8.33 and 8.07, respectively) than in the choice tasks (5.95 and 5.31, respectively). Neither the difference between the subject groups ( $F < 1$ ) nor the interaction ( $F < 1$ ) was significant.

Table II

*Subscribers' and Non-Subscribers' Mean Number of Processed Dimensions and Identifications for the Choice Pair which Contained the Magazine "Stern"*

	Stern-subscribers	non-subscribers
Mean number of inspected dimensions		
choice task	6.07	5.00
identification task	8.77	8.29
Identification performance		
mean number of correct answers	1.00 (0.61)	0.62 (0.29)
mean number of incorrect answers	0.46 (0.23)	0.48 (0.33)

*Note:* The identification performance for the magazine *Stern* only, is shown in parentheses.

The majority of subscribers, namely 13 subjects, had stated that they regularly read the magazine *Stern*. The above analysis was repeated for this subset of the subscribers (*Stern*-readers) versus the non-subscribers for the single choice pair containing the *Stern* as an alternative in the identification task. The results, which are shown in Table II, clearly indicate that even when a highly familiar magazine such as *Stern* is involved, subscribers and non-subscribers processed less information in the choice than in the identification task [ $F(1, 336) = 14.43, p < 0.001, MSE = 1.95$ ]. Subscribers, however, processed more information than non-subscribers [ $F(1, 168) = 7.98, p < 0.01, MSE = 9.40$ ]. There was no interaction,  $F < 1$ .

Whether or not subjects were promised a magazine as a gift did not influence the experimental results at all: There was neither a main effect ( $F < 1$ ) nor an interaction with the similarity of a choice pair ( $F < 1$ ).

### GENERAL DISCUSSION

The present results clearly show that decisionmakers inspected more information when attempting to identify the alternatives of a pair than when choosing between them. Even with this additional information, subscribers and non-subscribers usually were unable to specify the magazines' names. Therefore, it is safe to conclude that for the reported experiments decisionmaking was generally not preceded by the identification of the alternatives. We were initially surprised that even for magazine pairs for which subjects refrained from responding in the identification task, only selected feature pairs had been processed. For

these pairs subjects supposedly did not see any chance of identifying an alternative. This again demonstrates that the identification of the alternatives was not necessary for choosing between them. The tendency for decisionmakers who are more familiar with the alternatives to process more dimensions than did unfamiliar subjects fits with the results of Phelps and Shanteau (1978), who found that expert judges used about 9 to 11 dimensions.

Adaptive and selective choice processes, however, occurred for both subject groups regardless of their familiarity with news magazines independently of whether the decisionmaker would or would not receive one of the chosen magazines as a gift. Adaptiveness and selectivity may therefore be important characteristics of human choice processes.

By using think-aloud methods, converging evidence for the stability of these characteristics has recently been supplied by Schmalhofer and Schäfer (1985). Given the reported experimental evidence, the question arises as to how this result can be explained. A parsimonious explanation may be offered by the criterion-dependent choice models recently proposed by Aschenbrenner, Albert, and Schmalhofer (1984) that share central assumptions with random walk models (Wald, 1950).

### Criterion-Dependent Choice Models

Criterion-dependent choice models share the following assumptions. A choice is derived by one or several sequential processing steps. For multidimensionally described choice pairs, a processing step would consist of the evaluation of a feature pair on one dimension. During this evaluation, the attractiveness difference between the two features is determined and added to the attractiveness differences already determined by the previous processing steps. The number of processing steps performed for making a choice depends upon a criterion that indicates that one alternative is better than the other by some amount: The information processing of a choice pair is terminated by a choice as soon as the accumulation of the calculated attractiveness differences reaches or surpasses this criterion.

If for some choice pairs the criterion cannot be reached, a choice is made when no additional new information about the alternatives is available to be processed. In either case, the accumulated attractiveness differences determine which alternative is chosen.

Because for different choice pairs, the criterion may be reached after a different number of processing steps, these models can explain why the number of processed dimensions should depend upon the characteristics of a choice pair. For similar alternatives, the attractiveness differences of one or several dimensions may be comparatively small, and therefore

more such attractiveness differences must be accumulated before the criterion is reached than for choice pairs with large attractiveness differences favouring the same alternative on the several different dimensions. These models could thus explain why the number of processed dimensions increased with the similarity of a choice pair.

The central postulate of criterion-dependent choice models is that information processing is terminated as soon as a criterion is reached or surpassed. Therefore, the most extreme accumulated attractiveness differences must always occur in the last processing step. In order to test this hypothesis, some supplementary assumptions about the calculation of attractiveness differences and their accumulation over several processing steps are required. We assume that the attractiveness difference of a feature pair on one dimension can be approximated by the difference of a subject's individual attractiveness ratings of the two respective features. For example, consider the magazines *Capital* and *Der Spiegel*: If a subject rated the attractiveness of the prices of 6.00 DM and 4.00 DM for a magazine as 3 and 5, respectively, the attractiveness difference between *Capital* and *Der Spiegel* on the dimension "price" would be approximated by the value  $3 - 5 = -2$ . The accumulation of attractiveness differences over several processing steps is similarly approximated by the summation of the difference scores of the processed dimensions.<sup>3</sup>

For brevity, the sum of difference scores after  $j$  dimensions have been processed will be termed the counter value after  $j$  dimensions. This criterion-dependent choice model thus predicts that the most extreme counter value is always obtained for the processing step that terminates the choice process. The most extreme counter value is a positive or negative number whose absolute value is larger than the absolute value of any other counter value.

In order to test this prediction, the backward order position of the most extreme counter value was determined for every choice pair and every subject. Since the second experiment completely replicated the results of the first one, only the data of the first experiment are analysed. From the attractiveness ratings and the record of the inspected dimensions, the counter value of every single processing step was determined. Similarly to a backward learning curve (Kintsch, 1970), it was then determined how frequently the most extreme counter value occurred in each position in backward order (i.e., was the most extreme counter

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<sup>3</sup>A measurement analysis of the present criterion-dependent model, which postulates the summation of attractiveness difference scores shows that the underlying attractiveness values must constitute an interval scale. Since the collected ratings may well violate this prerequisite (Albert, D., unpublished data and measurement analyses) these ratings may only be considered a rough approximation rather than a well specified estimation of the subjects' attractiveness values.

value in the last, second-to-last, or one of the other positions). These empirically determined frequencies were compared to the frequency predictions that were derived under the assumption that the most extreme counter value is equally likely to occur in each position. This assumption served as the null hypothesis. The predictions of the null hypothesis and the empirical data are shown in Figure 3. A  $\chi^2$  test showed that the most extreme counter value was significantly more likely to occur in the last position than would be expected under the null hypothesis,  $\chi^2(9, N=240)=485.2, p < 0.001$ . This result thus supports the central assumption of the criterion-dependent choice models.

The criterion-dependent choice model may also be used to predict the subjects' individual choices. For those 397 choice pairs where less than 11 dimensions had been processed, the sign of the most extreme counter value predicts which alternative should have been chosen. For these choice pairs, 80% of the observed choices were correctly predicted

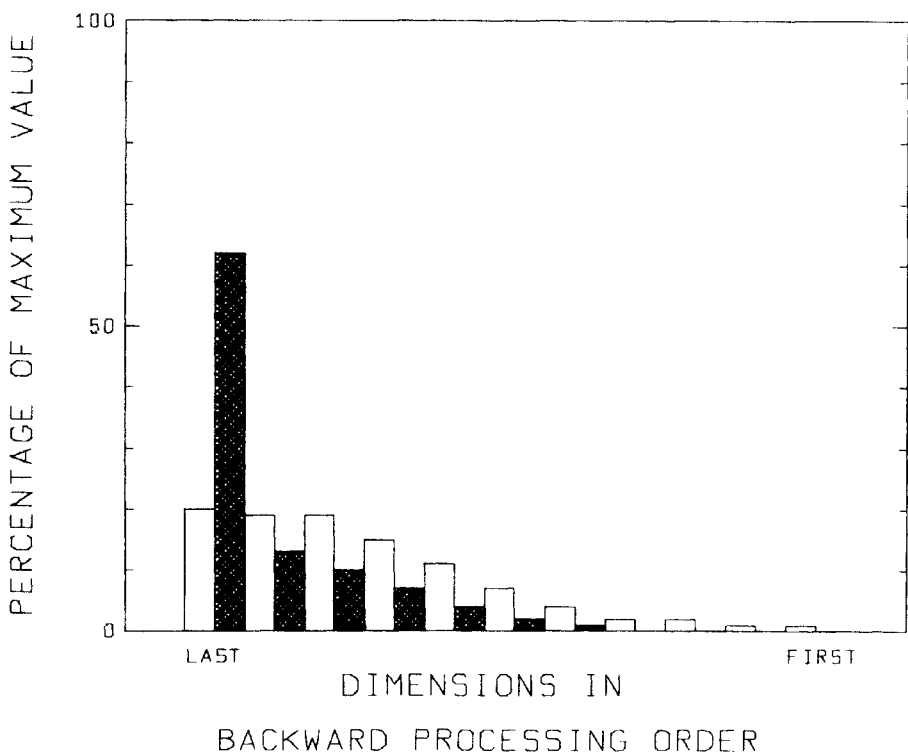


Figure 3. Frequency distributions of the maximum counter values for the 11 dimensions in backward processing order.

Note: Black columns are the observed frequencies, white columns are the frequencies which are predicted under the assumption of the null hypothesis.

by the model. There were 23 cases where all 11 dimensions were inspected. In these cases, the last rather than the most extreme counter value should predict a subject's choice. For these pairs, 83% of the choices were correctly predicted. It thus appears that criterion-dependent choice models can account quite well for the reported data.

The few incorrect predictions do not necessarily indicate a structural difference between the model predictions and the observed data. Since the particular choice model that was examined in this study is deterministic, the deviations between the predicted and the observed data could also be due to some error component, possibly introduced by inaccuracies in the empirically determined attractiveness ratings, which the present model did not take into consideration. Whether the incorrect model predictions are better accounted for by the assumption of some error component or by a different rule for calculating the attractiveness differences on a dimension was investigated by additional post hoc analyses.

In order to evaluate whether primacy or recency weights (Wallsten and Barton, 1982) in the accumulation of the attractiveness differences could account for the incorrect model predictions, average attractiveness differences were calculated for every processing position of the dimensions in forward and backward order. For the incorrectly predicted choices, the average attractiveness difference of the dimension that was processed in the last processing step was 0.23 in favour of the chosen alternative. For the dimension in all other positions of the forward and backward processing order, the rejected alternative was more attractive on average. Although these results may indicate a recency effect, the incorrect model predictions can be completely accounted for neither by primacy nor by recency-weights, which would more strongly emphasize the attractiveness differences of the dimensions that were processed first and last.

Since, instead of the present cardinal attractiveness differences, respective scores could also be determined according to the specifications of the majority rule (May, 1954), it could be suggested that instead of the amount by which one alternative is better than the other on a dimension it only matters whether an alternative is better, equal or worse on a dimension. Instead of the summation of cardinal attractiveness differences, such a rule would thus only count how often an alternative was better than the other on the processed dimensions (summation of ordinal differences). However, since for the incorrectly predicted choices the attractiveness ratings showed higher values for the rejected alternative's features for 72% of the processed dimensions, such a rule could also not completely account for the incorrectly predicted choices.

Whereas for the incorrectly predicted choices the chosen alternatives showed higher attractiveness ratings on only 28% of the processed dimensions, for the correctly predicted choices the chosen alternatives showed higher attractiveness ratings for 56% of the feature pairs of the processed dimensions. The average attractiveness difference between the chosen and rejected alternatives on the processed dimensions was 1.09 and  $-0.40$  for the correctly and incorrectly predicted choices, respectively. For the incorrectly predicted choices, the rejected alternatives thus show higher average attractiveness ratings than the chosen alternatives. Also, the absolute value of the average attractiveness difference on the processed dimensions is clearly smaller for the incorrectly predicted choices than for the correctly predicted choices. The incorrect predictions could thus well be explained by the assumption that the attractiveness ratings were not completely identical to the subjects' respective attractiveness values at the time of the choice process. In particular, assume that the true attractiveness values of alternatives  $x$  and  $y$  of the features processed in the  $i$ -th processing step are  $v(x_i)$  and  $v(y_i)$ . The respective empirical ratings are given by:

$$\begin{aligned} r(x_i) &= v(x_i) + \varepsilon(x_i) \\ &\text{and} \\ r(y_i) &= v(y_i) + \varepsilon(y_i) \end{aligned}$$

where  $\varepsilon(x_i)$  and  $\varepsilon(y_i)$  shall be identically and independently distributed random variables, with a symmetric distribution around an expected value of zero.<sup>4</sup> Consequently,  $r(x_i)$  and  $r(y_i)$  would also be random variables. Thus a random variable  $\delta_i = \varepsilon(x_i) - \varepsilon(y_i)$ , where  $\delta_i = \delta$  for all  $i = 1, \dots, 11$  would be responsible for the deviations between the true attractiveness difference  $v(x_i) - v(y_i)$  and the empirically determined rating difference  $r(x_i) - r(y_i)$ . The error variables  $\delta$  could often produce a (empirically determined) most extreme counter value that our analysis would record for some other than the last processing step. In some cases, the errors may even accumulate over several processing steps in one direction, so that the empirically determined most extreme counter value would even differ by its sign from the "true" most extreme counter value. According to the proposed post hoc explanation, such

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<sup>4</sup>For example, if only discrete attractiveness values are assumed, it could be postulated that for all features  $x$ :

$$v(x_i) \in \{3, 4, 5\}$$

and that

$$Pr[\varepsilon(x_i) = -1] = .30; Pr[\varepsilon(x_i) = 0] = .40; Pr[\varepsilon(x_i) = 1] = .30.$$

In order to avoid the introduction of more mathematical symbols, our notation will not distinguish between a random variable and a particular realization of that random variable.



incorrect choice predictions would be less likely to occur than errors in the empirically determined position of the most extreme counter value. Since this relation was indeed observed in the present results, the value fluctuation assumption appears to sufficiently account for the errors of the model predictions. Since the incorrect choice predictions are presumably due to the accumulation of error influences, the absolute value of the most extreme counter values should be clearly smaller for the incorrectly predicted choices than for the correctly predicted choices: with the respective average values being 4.5 and 7.4, this prediction was also confirmed by the present data. Inaccuracies in the determination of the attractiveness ratings (which would also be expected from the Thurstonian assumptions; Thurstone, 1927) thus appear to supply the best account for the incorrect, as well as the correct, model predictions.

## GENERAL CONCLUSIONS

It may be concluded that despite some inaccuracies in the determination of the feature attractiveness values, the criterion-dependent choice models were found to account for the reported data quite well. These models also offer an explanation and a detailed prediction of the selectivity and adaptiveness of the cognitive choice processes, which were demonstrated in two experiments.

The criterion-dependent choice models are similar to multidimensional scaling (MDS) models (Borg, 1981; Shepard, 1974) in that objects are assumed to have an underlying multidimensional structure. Multidimensional scaling techniques serve to identify a uniform multidimensional representation from similarity or other judgments for all objects under consideration. MDS thus assumes that the same number of dimensions is employed in every single judgment. However, by the current process tracing method it was demonstrated that the number of psychologically relevant dimensions in a given task may systematically vary from one pair of objects to the other. Based upon the reported results it may be expected that MDS could benefit from taking such selectivity and adaptiveness characteristics into account. Such characteristics could also be employed for further assisting human decision-making (Jungermann, 1980) by reducing the effort of making a choice while preserving its quality. Attempting to incorporate selectivity and adaptiveness heuristics into decision support systems such as MAUD (Humphreys and McFadden, 1980) may therefore be a promising enterprise.

## REFERENCES

- Aschenbrenner, K. M., Albert, D. and Schmalhofer, F. (1984). Stochastic choice heuristics. *Acta Psychologica*, **56**, 153–166.
- Borg, I. (1981). *Anwendungsorientierte multidimensionale Skalierung*. Berlin: Springer.
- Humphreys, P. & McFadden, W. (1980). Experiences with MAUD: Aiding decision structuring versus bootstrapping the decision maker. *Acta Psychologica*, **45**, 51–69.
- Jungermann, H. (1980). Speculations about decision-theoretic aids for personal decision making. *Acta Psychologica*, **45**, 7–34.
- Kintsch, W. (1970). *Learning, memory, and conceptual processes*. New York: Wiley & Sons.
- May, K. O. (1954). Intransitivity, utility, and the aggregation of preference patterns. *Econometrica*, **22**, 1–13.
- Payne, J. W. (1982). Contingent decision behavior. *Psychological Bulletin*, **92**, 382–402.
- Phelps, R. H. and Shanteau, J. (1978). Livestock judges: How much information can an expert use? *Organizational Behavior and Human Performance*, **21**, 209–219.
- Schmalhofer, F. and Schäfer, I. (1985). *Lautes Denken bei der Wahl zwischen benannt und beschrieben dargebotenen Alternativen*. Institutsbericht Nr. 45, University of Heidelberg.
- Shepard, R. N. (1974). Representation of structure in similarity data: Problems and prospects. *Psychometrika*, **39**, 373–421.
- Slovic, P., Fischhoff, B. and Lichtenstein, S. (1977). Behavioral decision theory. In M. R. Rosenzweig and L. W. Porter (Eds.), *Annual review of psychology (Vol. 28)*. Palo Alto, Calif.: Annual Reviews.
- Thurstone, L. L. (1927). A law of comparative judgment. *Psychological Review*, **34**, 273–286.
- Vickers, D., Caudrey, D. and Willson, R. (1971). Discriminating between the frequency of occurrence of alternative events. *Acta Psychologica*, **35**, 151–172.
- Wald, A. (1950). *Sequential analysis*. New York: Wiley & Sons.
- Wallsten, T. S. and Barton, C. (1982). Processing probabilistic multidimensional information for decisions. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **8**, 361–384.

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