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Properties of the Decision Environment and Display Organization in Choice

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Abstract

This paper describes two experiments and a simulation, aimed at investigating the impact of specific features of the decision environment and of the organization of the information display on choice processes and outcomes. The first experiment compared a matrix organization with a Cartesian graph, while also manipulating the distribution of the decision weights and the dominance structure of the problems. It was conducted to test the predictions of models derived from different choice frameworks, but none of the models were able to provide a full account of the results. Therefore, an alternative explanation was put forward, relying on the simulation of a variant of the lexicographic heuristic (LEX-2). The second experiment supported the existence of LEX-2 and explained a counter-intuitive display-related effect brought out by the first study.

Theories and Models of Choice

The first experiment presented in this paper takes into account both the influence of the display and the role of two significant properties of the decision environment: the distribution of importance weights and the dominance structure of the decision problems. Two prominent choice frameworks were selected and their predictions are clearly set out. The theories will be described in general terms in the following sections, while their specific predictions will be presented further on in the paper.

The Adaptive Decision Maker Framework

The adaptive decision maker framework (Payne, Bettman, & Johnson, 1988, 1993) regards choice as a constructive process. According to this theory, the decision maker (henceforth DM) is sensitive to the specific properties of the decision environment and is able to construct a choice strategy or to select it from memory in an adaptive way. The basic assumption of the framework is that the DM will use a heuristic that assures a satisfying trade-off between the anticipated accuracy of the decision and the anticipated effort required in the choice process, *given the specific features of the decision environment*. This framework has recently included in the main decision goals the need to avoid negative emotions and the desire to justify the decision (Bettman, Luce, & Payne, 1998).

The properties and the performance profiles of different choice strategies have been analyzed through simulations, and the predictions of the framework have received a good degree of experimental support (Payne et al., 1993). This research effort has provided us with knowledge about the effects of different task and context variables on strategy selection. The dominance structure of the decision problem is one of the variables that has been taken into account. It was shown that the presence of dominated options in the choice set allows noncompensatory heuristics to perform reasonably well (Payne et al., 1993). Another significant variable is the distribution of the DM's importance weights. These weights represent the importance that the DM gives to the various features of the available options. The weight distribution, together with the value functions describing the DM's subjective evaluation of the attribute values, defines the DM's subjective utility function.

Kleinmuntz and Schkade (1990, 1993) analyzed the impact of the information display variables on choice tasks. Their cost-benefit proposal complements the adaptive decision maker framework. According to them, strategy selection is also sensitive to the features of the display: "*This cost-benefit perspective implies that information displays define a cognitive incentive system for decision makers, whereby displays influence the effort and accuracy of each available strategy and, therefore, induce decision makers to use different strategies*" (Kleinmuntz & Schkade, 1993, p. 224). Kleinmuntz and Schkade (1994) highlighted the role of three features of the display: the organization of the information items, their form, and their sequence.

The information display may affect choice strategies through the reduction of the cognitive effort required. For instance, if comparisons are simplified by the display, the effort involved in comparison-based heuristics will be reduced, increasing the likelihood that a (sufficiently accurate) procedure of this kind will eventually be adopted. Alternatively, some strategies could be more prone to error with some specific displays. In these cases, accuracy concerns may lead the DM to avoid potentially unsound procedures. The effects of the display variables on strategy selection are mediated by the anticipation of the effort required and the accuracy of the different strategies. It has been shown that these estimates (in particular the accuracy anticipation) may be incorrect (Fennema & Kleinmuntz, 1995). The cost-benefit approach predicts that the DM will learn to select the best strategy from experience, using the feedback on the experienced effort and accuracy collected during previous choices. However, despite the evidence for adaptive decision behavior, there are also indications that the DMs are not very sensitive to accuracy feedback (Brehmer, 1980).

The Search for a Dominance Structure Theory

Montgomery (1983, 1989) proposed the Search for a Dominance Structure theory (SDS), postulating a tight linkage between decision and action. A decision is seen in the context of an intention to act, which is defended and supported by the DM. Therefore, it is important that the DM is able to find good reasons for his/her choices. Being able to identify a dominance structure provides a particularly strong justification for choice: if an alternative dominates the other options in the set, this choice will be very easy to defend. Therefore, the DM will be motivated to find a dominance structure and, if this does not exist, he/she will restructure the problem, in order to bring about such a structure out. According to the SDS theory, the dominance structure found by the DM may be close or far from a strict dominance relationship: this distance will depend on the type of problem presented and on the specific type and sequence of restructuring operations applied by the DM.

In the process that leads to the definition of a dominance structure the DM will go through the following stages (Montgomery, 1983): (a) pre-editing, (b) search for a promising alternative, (c) dominance testing, and (d) dominance structuring. Different known decision rules may have a local function in this process, depending on the stage in which they are used. In the pre-editing stage, the DM selects alternatives and attributes to set up the problem representation. The less important attributes and the less valuable options may be discarded. During the search for a promising alternative, the DM identifies an option that could have some chance of dominating the others (or to be better). This promising option is then evaluated through an absolute or relative test. The absolute test may be carried out using a procedure similar to a satisficing heuristic (Simon, 1955). The relative test is based on pairwise comparisons of the attribute values of different alternatives, and it can be considered as a real test of dominance. If the promising alternative receives a good evaluation (i.e. the dominance test succeeds), the DM will choose the current option. If the dominance test fails, the DM will enter the dominance structuring stage. In this stage a decision problem can be restructured in many ways. The de-emphasizing operation is used to reduce the importance of a disadvantage or of a difference between alternatives concerning the promising option. The bolstering operation increases the advantages of the promising option or decreases the advantages of the other options. The cancellation operation rules out a disadvantage through the association with a (logically connected) advantage. Finally, the collapsing operation ties together different attributes in a single dimension (for instance, using a time or money scale). If the dominance structuring process is not able to find a satisfying solution, the DM starts again from the pre-editing stage or searches for a new promising alternative.

Experiment 1

According to Kleinmuntz & Schkade (1993), the comparisons of graphs and tables typically confounded the manipulation of form and organization, contrasting graphic organization with pictorial form and tabular organization with numeric form. Therefore, in this experiment the form of the values is kept constant (numeric) and only their organization is varied. A 2D Cartesian graph and a table were compared, starting from the assumption that a Cartesian representation may facilitate the detection of dominance. Two contextual factors were manipulated: the presence of dominated options in the choice set and the relative importance of the attributes.

Method

Participants and Procedure Sixty undergraduates (30 males and 30 females; mean age = 24) were required to perform a series of multiattribute choices. They were asked to imagine being a travel agent who must select a flight for a series of customers with different preferences. The task was to examine the information provided on the computer screen and to select the best option for each specific customer. The customers' preferences were represented by attribute weights. The decision problems were presented through the PsyScope program. All the choices and the decision times were recorded.

Experimental Design The experimental design was a nested design. Two within-subjects variables were fully crossed: the distribution of weights (uniform, two-level), and the presence of dominated options in the choice set (dominated present, dominated absent). The third variable, the type of display, was varied between-subjects and nested within the distribution of weights (Table 1). Sixty participants were randomly assigned into four groups.

Table 1: Nesting of the display type within the distribution of weights.

	Uniform weights	Two-levels weights
Group 1	neutral graph	compatible graph
Group 2	neutral graph	incompatible graph
Group 3	neutral table	compatible table
Group 4	neutral table	incompatible table

Stimuli The choice problems were of moderate complexity, being composed of four alternatives (available flights) and four attributes (price of the ticket, travel duration, connections, and comfort). The attribute values were presented on a five-point numeric scale, common to all the attributes. The lowest value of the scale represented the best subjective value for the potential customer. All of the attribute values were randomly generated from a normal distribution with a mean of 3 and a standard deviation of 1.

Depending on the experimental condition, some problems contained (or did not contain) dominated options, according to the definition of strict dominance. Also the attribute weights varied across conditions, but they were always presented in percentage form. In the uniform condition, the weights were equal for all the attributes (.25). In the two-level condition, two weights were high (.40) and the other two were low (.10). The association between the weights and the specific attributes in the two-level conditions was randomized. Seven problems for each of the four 'within' cells were generated. They were presented to the participants in 4 blocks, randomizing both the block order and the sequence of problems within each block.

Three types of graph were constructed: ‘compatible’, ‘incompatible’ and ‘neutral’. The alternative flights are always represented by capital letters (A, B, C, D) placed within the graph and the attribute weights are always presented in a table in the upper part of the graph. The values of two of the attributes are represented by the placing of the letter within the graph, and the names of these attributes are printed on the corresponding axes. The values of the other two attributes are represented within the graph, by attribute-value strings (like ‘TIME=3’) which are printed near the letter. In the neutral graphs (with uniform weights) two of the attributes are randomly associated with the axes while the other two are displayed through attribute-value strings. In the compatible graphs the two most important attributes (weight=.40) are represented on the axes and the remaining two by attribute-value strings. In the incompatible graph condition the situation is completely reversed.

Three types of tables were constructed: neutral, compatible and incompatible. In all of the tables the alternatives (capital letters) are represented on the rows and the attributes on the columns. The first row of the table contains the attribute names and the second one the attribute weights, in percentage form. The other rows display the attribute values associated with the different alternatives. In the ‘neutral’ table with uniform weights there is a random attribute-column association. When the weights are not uniform and the table is compatible, those attributes with the greatest weights are associated with the first two columns of data. On the contrary, if the table is incompatible, the values of the most important attributes are contained in the last two columns. Figure 1 presents the same decision problem through a compatible table and a compatible graph.

Hypotheses

Several hypotheses have been formulated, deriving from models taken from the adaptive decision maker framework (henceforth ADM) and from the SDS theory.

ADM 1. According to the ADM framework, the participants should adopt a variant of the lexicographic strategy (LEX-2) in the conditions with two-level weights and an equal weight strategy (EQW) in the conditions with uniform weights. LEX-2 chooses the option with the best values on the two most important attributes. This would represent an adaptive response to the environment demands and assure a good effort-accuracy trade-off. Simulations carried out in similar environments (Payne et al., 1993) lead to the prediction that accuracy will always be high and the effort (response time) will be greater in the conditions with uniform weights (EQW requires more effort than LEX). The most difficult condition may be the one without dominated options and with uniform weights.

ADM 2. This model is a variant of the previous one, and it is based on the assumption that the most difficult condition is the one without dominated alternatives and with two-level weights. This may be due both to the lack of clearly inferior alternatives and to the need to consider a more complex weighting scheme. Therefore, if these problems are perceived as being particularly difficult, it is possible that the participants will try to adopt a more complex and accurate strategy, like the weighted additive rule (WADD). Due to the use of WADD, both the accuracy and the response time (RT) will be higher in this specific condition.

ATTRIBUTI	COSTO	CLASS	CAMBI	TEMPO
PESO	40%	40%	10%	10%
A	3	1	3	2
B	4	4	3	1
C	3	3	5	3
D	4	3	3	3

ATTRIBUTI	COSTO	CLASS	CAMBI	TEMPO
PESO	40%	40%	10%	10%

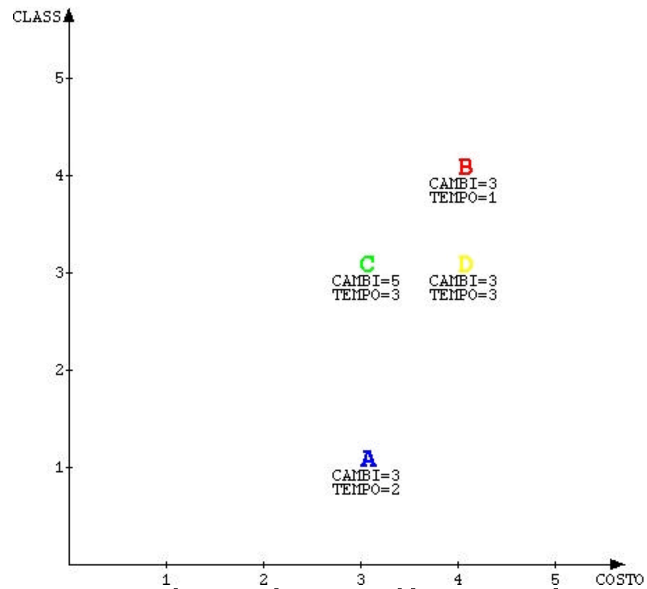

Figure 1: The same decision problem presented in a compatible table and in a compatible graph.

SDS. Starting from the Search for a Dominance Structure theory it is possible to specify different models, which can be used to generate quite different predictions. In the flight choice task it is assumed that the pre-editing stage will be skipped, given that the problems are already presented in a structured form. In the search for a promising alternative, when the weights are not uniform the participants will use a selective, noncompensatory heuristic. When the weights are uniform they will adopt a less selective heuristic. This is in compliance with the weak constraints put forward by SDS on this stage. According to the SDS theory, the dominance test can be of two different types. Therefore, two simple models have been specified (SDM-sat and SDM-dom). Finally, it was hypothesized that only if the dominance test fails will the participants enter the dominance structuring stage. The SDM-sat model predicts only a main effect of the dispersion of weights on the RT (due to the different heuristics used in the search for a promising alternative). The SDS-dom model also predicts a main effect of dominance: if there are dominated alternatives in the choice set, the dominance testing phase will take less time and the restructuring process will be completely avoided. According to the theory, accuracy may be lower if a clear dominance structure is absent, as the use of bolstering or de-emphasizing operations may lead to a sub-optimal choice.

Display-related predictions. The main prediction of a cost-benefit framework regarding the display manipulation is that in the two-level dominance possible environment, the participants using the compatible graph will make faster decisions. This will happen because they will apply a 'perceptual' variant of the lexicographic strategy on the two most important attributes (represented on the axes). In other words, the participants will be able to take advantage of the display in this specific condition, applying an efficient strategy that requires them to use only simple perceptual operations (to locate the alternative closest to the origin).

Results

No significant difference was found between the conditions with a table display, therefore these data were pooled.

Accuracy A relative loss score was computed from the participants' choices. This score is the difference between the utility of the best alternative in the choice set and the utility of the selected alternative, divided by the difference between the best and the worst alternatives in the set. Therefore, the lower the loss score, the greater the accuracy of the participants' choices. The analyses were conducted on the means of loss scores for the different blocks. No effect of the display type was found. A significant interaction between the dispersion of weights and the dominance structure was highlighted by the ANOVA (Figure 2; $F(1,57)=36.278$, $MSE=.011$, $p<.0001$).

The condition with two-level weights and no dominated options in the choice set was significantly more difficult. Participants were very accurate in all of the other conditions. This pattern of results was not predicted by any model.

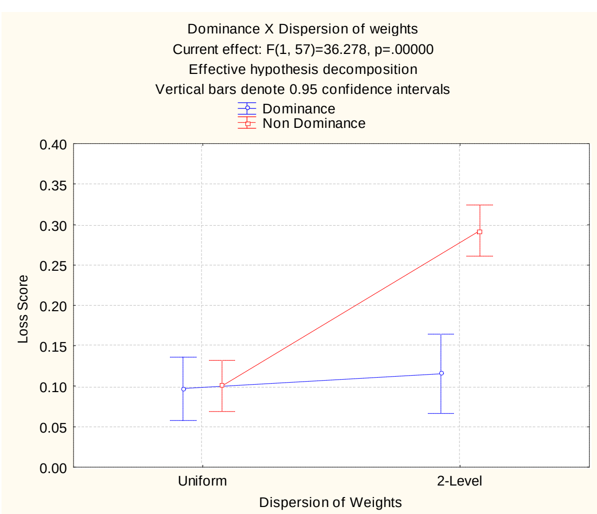

Figure 2: Interaction between dominance structure and dispersion of weights on the loss score.

Response Time A significant interaction between the dispersion of weights and the dominance structure was shown by the ANOVA (Figure 3; $F(1,57)=11.46$, $MSE=10968$, $p<.01$). The condition with uniform weights and the absence of dominated options was significantly slower than the others. Again, none of the models were able to predict this specific interaction.

Finally, an ANOVA on the conditions with two-level weights showed a main effect of the display type ($F(2,57)=10.545$, $MSE=45025$, $p<.001$). However, the slowest display was the one that was expected to foster the most efficient perceptual strategies. The compatible graph ($M=20125$ ms) was slower than the table ($M=13281$ ms, $p<.001$) and the incompatible graph ($M=14814$ ms, $p<.01$).

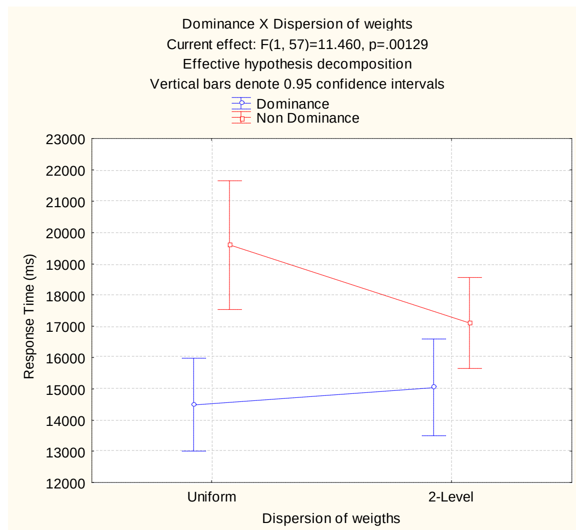

Figure 3: Interaction between dominance structure and dispersion of weights on the response time.

Discussion

There was a strong facilitating effect of dominance, which interacted with the dispersion of importance weights in an unpredicted way.

Indications of both adaptive behavior and potential failures in adaptivity were obtained. In the condition without dominated options and uniform weights the participants were able to make good choices with a significant increase in effort. On the contrary, in the conditions without dominated options and with two-level weights, participants presumably used faster but less accurate strategies.

Finally, the 'adaptive' hypothesis on the display type in the conditions with two-level weights is not supported.

Two issues have been opened up by this experiment: (a) what kind of choice processes could have produced the weights by dominance interactions? (b) why a potentially useful display is not able to elicit an adaptive behavior?

Choice Simulation

The interactions obtained in the first experiment can be explained by a deeply revised version of the ADM 1 model. The participants may have used the LEX-2 heuristic with two-level weights, but *they may have failed to apply it in an accurate way in the dominance absent environment.* Different explanations for this behavior could be put forward. For instance, while applying LEX-2 in a negatively correlated environment, participants might not be able to properly handle the trade-offs needed to make a choice (Hogarth, 1987), perhaps resorting to LEX. In the environments with uniform weights, ADM 1 assumed that participants will have used the EQW strategy. This prediction seems compatible with the data collected in the dominance absent condition, but it is clearly not supported by the data in the dominance present condition. Therefore, it may be assumed that, in the latter condition, *the participants were able to exploit a very fast 'perceptual' detection of dominance to make their choice.* The revised model is presented in Figure 4.

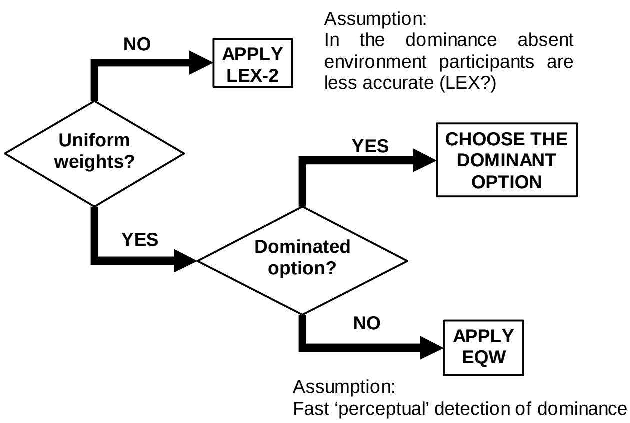

Figure 4: The revised ADM model.

The new assumptions made in the revised model can be tested experimentally or by simulation. The remaining part of this paper focuses on the first assumption; future work may investigate the decision maker's capacity to detect and exploit the dominance relationships. Testing the first assumption requires proving the following: (a) LEX-2 is accurate in the two-level environments; (b) DMs use it in these conditions; (c) DMs are less accurate in applying LEX-2 when dominance is absent. In this paper evidence supporting the theoretical accuracy of LEX-2 and its real use in the two-level dominance present condition will be provided. Further experiments are necessary to show that this heuristic is also used in the dominance absent condition and to shed light on the reasons for its low real accuracy.

A set of LISP procedures simulating the choices of different heuristics (WADD, EQW, LEX, LEX-2, DOM) was written. The WADD procedure always picks out the best option and it is used as a reference for the evaluation of the performance of the other heuristics. The procedures were applied to two groups of 200 problems. Each group of problems was randomly generated from the same normal distribution and scale used for the construction of the stimuli in the first experiment. The first group of problems contained dominated options, which were instead not present in the second group. In the simulation, two attributes were randomly assigned the .40 weights while the other two were assigned the .10 weights. The dominance rule (DOM) was applied only to the problems with dominated options, using both uniform and two-level weights. The loss score and the percentage of problems in which only the best option in the set was selected are presented in Table 2.

Table 2: Choice simulation results. *SE* in parentheses.

	Dominance Present		**Dominance Absent**	
Strategy	Optimal Choice	Loss Score	Optimal Choice	Loss Score
LEX-2	73%	.035 (.006)	71%	.047 (.007)
LEX	35%	.193 (.015)	38%	.249 (.02)
EQW	68%	.078 (.009)	43%	.214 (.018)

Dominance Strategy (DOM)		
Environments	Optimal Choice	Loss Score
Two-level weights	55%	.151 (.016)
Uniform weights	57%	.117 (.016)

As can be seen, the LEX-2 strategy is quite accurate in both the environments. Given that it also requires less effort than EQW and WADD, this heuristic represents a good solution. It should be noted that the LEX-2 loss score in the dominance present condition is slightly lower than the real (experimental) loss score, and this may be due to some minor errors in the application of the strategy. On the contrary, the LEX-2 loss score in the dominance absent condition is much lower than the real one (that is close to the LEX score). To explore the viability of an explanation based on the difficulty in handling trade-offs while using LEX-2 in the two-level environments, the frequency of problems in which the strategy had to face a trade-off between attributes was counted. As expected, the proportion of trade-offs was significantly higher in the dominance absent condition (.80 vs. .71, p=.018 one-tailed). Finally, the performance of the DOM strategy properly agrees with the data collected in the uniform condition.

Experiment 2

A brief summary of a second experiment will now be presented. This experiment was designed to try to explain the counter-intuitive display effect obtained in the first experiment and to provide, at the same time, more direct evidence for the existence of the LEX-2 heuristic.

The basic hypothesis was that in the Cartesian graph conditions participants do not rely uniquely on perceptual operations: they explicitly encode the numeric values from the axes in order to perform further comparisons between alternatives (Benbasat, Dexter, & Todd, 1986). If the most important attributes are on the axes and the participants rely on these, this unnecessary encoding and the following comparisons will increase the RT.

Sixty-four undergraduates (50 males and 14 females; mean age = 23) were randomly assigned to four groups (compatible graph, semi-compatible graph, incompatible graph, and table). To provide the strongest test of the hypothesis, a single decision environment was employed in which the adoption of a perceptual strategy could be maximally advantageous: all of the decision problems had two-level weights and dominated options.

Participants underwent through 3 training trials. Then a block of 5 trials with verbal protocols and another five-trial block without protocols were executed. The block order was counterbalanced within each group. For each participant, each block consisted of problems which were randomly selected from the same set of basic problems, and generated using the same criteria as in the first experiment. Before the block of trials with verbal protocols, participants were given instructions, warm-up exercises (Ericsson & Simon, 1993), and one training trial with verbalization.

Despite slight differences, the accuracy was always very high. There was also a global speed up of response times, probably due to the longer practice peridod in a single environment. The display effect obtained in the previous experiment was substantially replicated: the pattern of the RT means in the trials without protocols was as predicted (compatible graph: 13806 ms; semi-compatible graph: 11866 ms; incompatible graph: 10362 ms; table: 11681 ms) and there was a significant difference between the compatible and the incompatible graph ($t(27)=1.73$, $p<.05$, one-tailed). The analysis of verbal protocols showed that the prevailing acquisition strategy in both the conditions is mainly limited to the two most important attributes (in more than 75% of participants). This pattern is compatible with the LEX-2 strategy. Furthermore, the proportion of statements indicating a numeric encoding of the values on the axes (like "*A has 3 for the price and 2 for the quality*") was significantly higher in the compatible graph group than in the incompatible graph group (.73 vs. .20, $p=.009$). More detailed analyses showed that, in the compatible group, perceptual comparisons (like "*B is the flight closest to the origin*") were prevailing in only five participants. Furthermore, only in the protocols of two participants was it possible to find exclusively perceptual operations, without any other kind of comparison. These indications suggest that participants in the compatible graph condition frequently used numerical encoding of values and non-perceptual comparisons.

Conclusions

The first main result of this study is that participants are not always accurate, even if their overall choice performance is good. In one condition (two-level dominance absent environment) their choices appeared to rely on fast but inaccurate heuristics. This may be due to an accuracy-effort trade-off, to the application of an inaccurate strategy, or to the incorrect or partial application of a valid decision procedure (LEX-2). According to the experiments and to the simulation, the last explanation seems more likely, but only further experiments may provide a conclusive answer.

The results on the display organization suggest that decision makers rely on number-based comparisons even if the information is presented in graphs and only perceptual operations are required. A lack of confidence in the use of Cartesian graphs for choice may explain this effect. If this were to be the case, display design theories should try to combine effort-accuracy principles and theories of attitudes and expertise in situated decision making.

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