



On Effects of Changing Multi-attribute Table Design on Decision Making: An Eye-Tracking Study

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Abstract. Information tables are often used for decision making. This study considers multi-attribute table designs from a diagrammatic perspective. We used two experiments to show how the decision-making strategies and performance are changed based on table design changes, using the eye-tracking method. We employed a multi-attribute catalog table with alternatives presented along the horizontal axis and attributes along the vertical axis in Experiment 1 and the opposite layout in Experiment 2. In each experiment, we used four different types of representations of the attribute values, and these values were restricted to two levels for comparison with previous works. The four types used were: (i) numerical representations, (ii) textual representations, (iii) black-and-white representations with black representing better values, and (iv) black-and-white representations with white representing better values. Our results suggest, among others, that (1) placing the alternatives along the vertical axis makes the table easier to decide in comparison to the opposite layout, and that (2) the two-stage decision strategy is taken with numerical representations and textual representations, while a single stage strategy is taken with the black-and-white representations. We also showed how the graphic black-and-white representations made decision-making easier, and how the order changes of alternatives and of attributes of a table influenced decision makers' decision.

Keywords: Multi-attribute table design · Decision making · Eye-tracking

1 Introduction

It has previously been reported that the presentation of information in graphical-diagrammatical form often facilitates users' information processing, compared with presentations in textual form. This is also the case in the context of decision making. For example, Savage [1] showed that changing the Allais Paradox task presentation to a "table" presentation instead of the original textual presentation increased the number of subjects making rational decisions in the sense of expected utility theory [2–4].

Existing studies introduced bar charts as graphical representations for multi-attribute decision making (decisions among alternatives with multiple attributes) [5, 6]. Their studies showed some advantages to presenting alternatives in the form of bar charts; however, the disadvantage of the bar-chart presentation method is that it requires multiple charts corresponding to the number of attributes, meaning that many pages of bar charts are needed for one multi-attribute decision-making process.

A table is a typical among graphical presentation showing multiple alternatives of many attributes in one view. As noted by Savage [1] in the Allais Paradox task—a typical example of decision making under uncertainty—a table representation is effective in decision making. It can be said that a table's multi-attribute presentation of many alternatives makes it easier to make a decision. A typical example of a multi-attribute table is a consumer product catalog, which is commonly used in both traditional print and e-commerce. These tables are typically a matrix in which multiple product alternatives are presented on one axis and multiple product attributes to be compared on the other axis. In many decision-making situations—such as choosing services, policies, and election candidates—a multi-attribute table presentation is often considered to have the advantage of making it easier to decide.

Tables are the most basic of graphic displays; however, incorporating additional graphic presentation techniques into this format is also expected to be effective. There is a large body of research on decision making based on multi-attribute tables. For example, Payne et al. and Takemura conducted a study on decision-making strategies by presenting a multi-attribute table [7–10]. One utility based decision-making strategy is the additive strategy, which involves examining every attribute value for each alternative and calculating the utility for each alternative. However, as the additive strategy requires high cognitive load in a multi-attribute task, decision makers often adopt a two-stage decision-making strategy. In the first stage, they compare the most important attribute value for each alternative to narrow down the range of alternatives. In the second stage, utilities of the remaining alternatives are calculated and compared to make a decision. Previous studies have proposed that in the simulation method and the information-monitoring method, the two-stage strategy is effective in actual decision making [7–10].

In a typical setting of multi-attribute table decision-making research, the product names of the alternatives are arranged on the horizontal axis at the top of the table and the attributes are arranged on the vertical axis. Considering additive strategy, the table should be viewed vertically; however, when employing the two-stage strategy to reduce the cognitive load, the alternatives are narrowed down by viewing horizontally in the first stage with a vertical shift to calculate utility in the second stage.

Russo and Rosen [11] introduced the eye-tracking method, which investigates multi-attribute decision-making strategies by considering eye-movement. In this paper, we employ the eye-tracking method and report new findings on the effect of the graphical representation of multi-attribute tables. Our experimental settings were based on a product catalogue multi-attribute table with five alternatives and five attributes of digital cameras. The attribute level is simplified to two levels.

In our study, the following graphical presentation effects were examined: displays with two levels of numerical values and displays with two levels of binary color coding

(black-and-white). The experiments investigated the effect on the decision-making process of reversing the horizontal and vertical axes. These experimental settings have not been used in previous multi-attribute decision-making research, and our study is the first to do so. A cognitive experiment comparing two levels of values in a black-and-white display and in a textual display was conducted by Shimojima and Katagiri [12], where the two levels were binary (i.e., true and false) and the tasks were limited to cognitive tasks. Morii et al. [13] introduced graphical representation in multi-attribute decision-making research by showing attribute values in black-and-white squares only, based on the work of Shimojima and Katagiri [12]. In [13] their black-and-white attribute tables, the values of attributes were also limited to two (with a certain threshold for each attribute) and each cell of the table was colored either black or white on a white background. They compared two methods of systematic color assignment: “quantitatively-coherent” and “qualitatively-coherent”. These methods refer to the ways in which the black-and-white distinction represented the quantitative amount distinction and the ways in which it represented the quality distinction, respectively. Their main findings were that the qualitatively-coherent tables (in which, for example, the better attribute “price” value was colored as black even if the price value itself was smaller, for the black-is-better coherent tables) made decision-making easier than quantitatively-coherent tables (in which the better attribute “price” was colored as white as the price was lower) and that participants used the two-stage strategy. In the experiments of this paper, we employed the qualitatively-coherent tables, which were known easier for decision making by this former work. We also included tables with numerical values, as those are the most usual as the merchandise product catalogs, and tables with textual values, to make the setting similar to the setting of [12], where tables with textual single-letter symbols were considered for cognitive tasks, while we used numeral and textual values in a more natural setting for decision making tasks. Furthermore, a recent study [14], analyzed the comparison between vertical and horizontal display of products from the perspective of marketing research using an eye-tracking method [14]. The results showed that horizontal display enhanced variety seeking. Horizontal (vs. vertical) displays are easier to process due to a match between the human binocular vision field. However, their study focused on product displays without relating to attribute displays. Our study examines the effect of reversing the horizontal and vertical axes from the perspective of multi-attribute decision making with tables, not just product display level. We posed the following hypotheses:

Hypothesis (1) Tables using the vertical axis for the alternatives (Fig. 1-2 type) make participants’ decision-making easier than tables using the axes the other way around (Fig. 1-1 type) even if the information content is exactly the same (e.g., Fig. 1-1 and Fig. 1-2), presuming that the easier horizontal eye-movement helps the standard additive utility search along each alternative.

Hypothesis (2) Tables using the black-and-white graphic representations (e.g., Fig. 1-3 and Fig. 1-4) make decision-making easier in comparison to tables using the numerical representations (e.g., Figure 1-1 and Fig. 1-2) and to tables using the textual representations (see Method Sect. 2.2). This is partly because we use black for representing the better in Fig. 1-3 values out of the two values *coherently*, which makes the utility-based normative decision easy; this is suggested partly from our former work [13], and partly from former work on purely cognitive tasks [12].

Hypothesis (3) The typical two-stage decision-making strategy of Payne [7–9] is taken with numerical and textual tables when the alternatives are placed along the horizontal axis (e.g., Fig. 1-1). A single-stage strategy is taken with these representation types of tables when the alternatives are placed along the vertical axis (e.g., Fig. 1-2) due to ease implied with our Hypothesis (1). A single-stage strategy is taken with the black-and-white graphic (Fig. 1-3, Fig. 1-4), whichever roles the two axes take, which is consistent with Hypothesis (2).

Hypothesis (4) Since by changing the order (permutation) of alternatives and attributes, the tables with the same information content look different (e.g., between Fig. 1-3 and Fig. 1-4); thus, decision making is influenced by changing the order (for example, in Fig. 1-3, one could easily see the superiority of D over E, B, and A because of the staircase-like pattern, which is not the case in Fig. 1-4, although the information content of the two is the same). We also expect certain differences on influence from the order changes among types of tables (numerical, textual, and black-and-white tables).

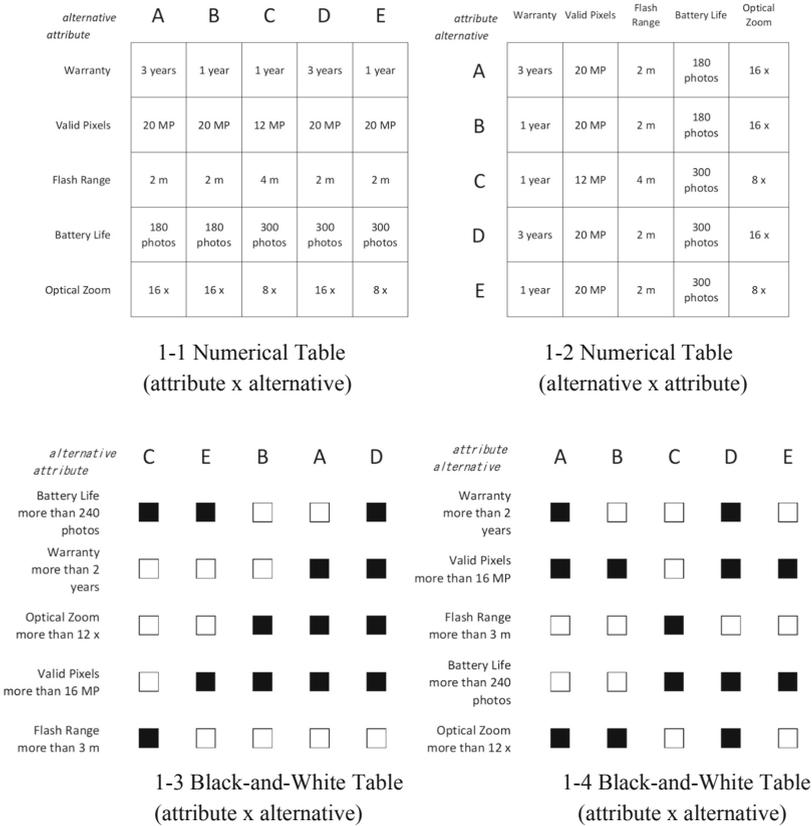


Fig. 1. Images of multi-attribute tables for digital cameras used in our experiments.

Our main findings were as follows:

1. We found that there was an effect of switching the roles of the axes, which supported Hypothesis (1); our experiments showed that placing the product-alternatives along the vertical axis made decisions easier than did placing them along the horizontal axis.
2. Our multi-attribute decision-making tasks using color (black-and-white) tables suggested that the response latency, eye-movements, and cognitive load were lower than those of numerical and textual tables. This supported Hypothesis (2).
3. Our eye-movement data analysis showed that fixation shifts with the numerical and textual value tables, when the alternatives were placed along the horizontal axis, suggested that participants took the two-stage strategy, which supported Hypothesis (3). We also found that, even though placing the alternatives along the vertical axis made the decision easier (as stated in 1 above), the participants' fixation shifts were still consistent with the two-stage strategy, which contradicted Hypothesis (3). With the black-and-white graphic tables, the eye-movement data suggested that the participants took a single-stage strategy, which supported Hypothesis (3).
4. We found that the influence of permutations of alternatives/attributes of the tables on decision making depended on types of representations (i.e., numerical representation, textual representation, and black-and-white representation).

These results provide a basis for considering a multi-attribute table design not only for merchandise catalogs but also for a wide range of decision tables of services, administration, policy choice, and election candidates, as well as various situations in education, and so on. This is discussed in the last section of this paper.

The rest of this paper presents the methods, results, and discussion.

2 Method

2.1 Participants

Forty-eight Asian students (16 males, 19–26 years old) with normal or corrected-to-normal vision were assigned to two experiments. All participants provided written informed consent in accordance with the protocol approved by the ethics committee of Keio University. Participants were individually tested and were remunerated with JPY 1,100 (approximately USD 10) for their participation.

2.2 Apparatus and Stimuli

The eye-tracking system EyeLink 1000 (SR Research Ltd., Ontario, Canada) was used to record participants' eye-movements. The stimuli were presented at the center of a 23-in. display (Mitsubishi Electric Corp., RDT234WX, Tokyo, Japan). The display was viewed from a distance of 75 cm and the head was stabilized. The display resolution was $1,920 \times 1,080$ pixels and the visual angles were 37.5° horizontally and 21.6° vertically. A fixation was defined as velocity, acceleration, and duration of eye-movements with respective thresholds of $30^\circ/\text{s}$, $8000^\circ/\text{s}^2$, and 100 ms.

In the experiments, a multi-attribute table of digital cameras was presented at the center of the display and the information search process was recorded by the eye-tracking

system up to selecting an alternative by pressing a key. The multi-attribute table used in Experiment 1 consisted of five alternatives and five attributes, with the alternatives arranged horizontally and the attributes arranged vertically. Figure 2 shows the samples of the four types of multi-attribute tables.

- Type 1: attribute value was expressed by a numerical value
- Type 2: attribute value was expressed by a value “equal to or greater than” the reference value or “less than” the reference value with these textual words
- Type 3: a better-quality attribute value was indicated by a black square, and a worse white
- Type 4: a better-quality attribute value was indicated by a white square, and a worse black.

Note that exactly the same information contents could be expressed among the three Types, 2, 3 and 4, and their numerical instances could be expressed by Type 1 (as shown below).

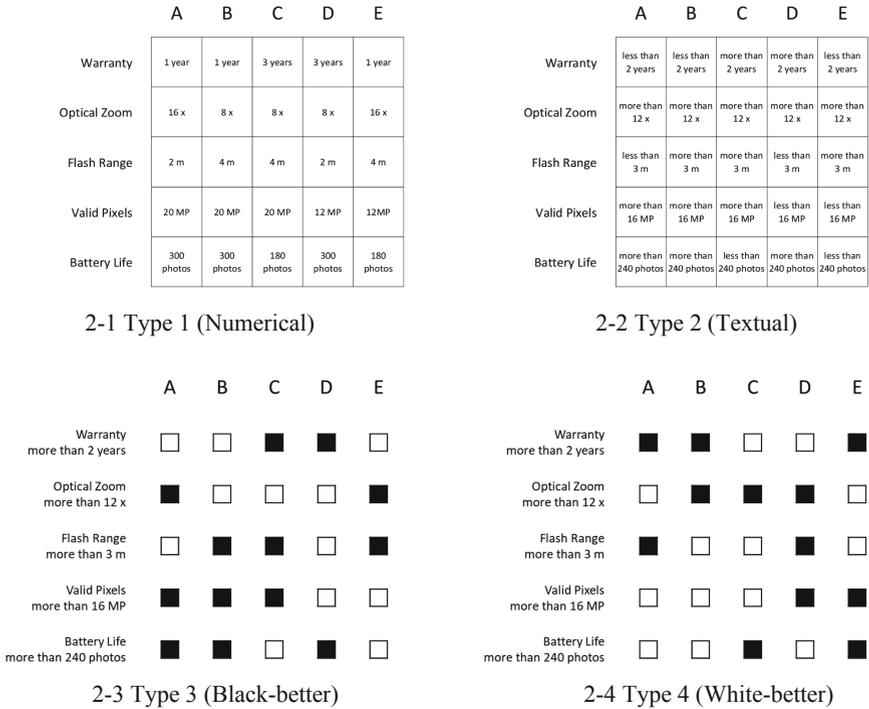


Fig. 2. Sample of multi-attribute tables used in Experiment 1. Our multi-attribute tables were described in Japanese. Actually, ‘more than’ and ‘less than’ in each cell of Type 2 were expressed ‘以上’, ‘未滿’ in Japanese two characters, respectively (e.g., 16MP 以上, 16MP未滿). The exact meaning of ‘以上’ is ‘more than or equal to’. This is the case for the attribute expressions of Type 3 and Type 4.

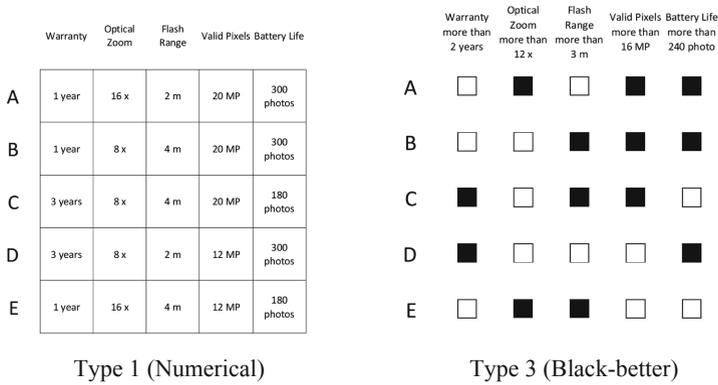


Fig. 3. Sample of multi-attribute tables in Experiment 2.

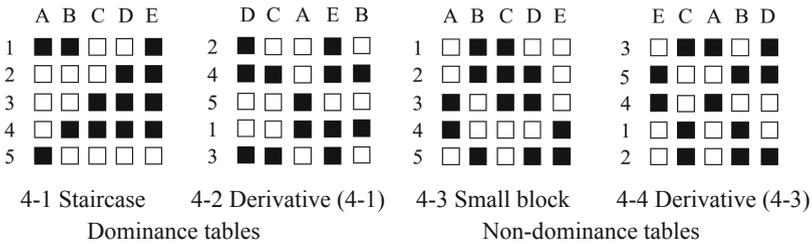


Fig. 4. Sample tables in the dominance and the non-dominance tables in the case of Type 3. To illustrate the permutation of alternatives and attributes, the names of alternatives shown in the alphabet were indicated so that 4-2 corresponded to 4-1 and 4-4 corresponded to 4-3. In the actual experiment, the alternatives were always named A, B, C, D, and E from the left.

In Experiment 2, the arrangement of the vertical axis and the horizontal axis was switched (i.e. 5 alternatives × 5 attributes). Figure 3 shows the samples of Type 1 and Type3 in Experiment 2 that correspond to Type 1 and Type 3 in Fig. 2.

Both in Experiment 1 and Experiment 2 for each Type (Type 1 to Type 4), we used two classes of tables, the “dominance tables” class and the “non-dominance tables” class. A “dominance table” consisted of one alternative having only one better attribute, two alternatives having two better attributes, one alternative having three better attributes, and one alternative having four better attributes which was dominant over three other alternatives except one alternative which had two better attributes (e.g., Fig. 4-1 and Fig. 4-2 in the case of Type 3). We called this a “dominance table” in this paper as it had one alternative which was dominant over almost all other alternatives except one (e.g., alternative E over B, C, D, except A in Fig. 4-1 and in Fig. 4-2 in the case of Type 3). A “non-dominance table” consisted of five alternatives that having no superiority/dominance relationship to each other, with three alternatives having three better attributes and two alternatives having two better attributes (e.g., Fig. 4-3, Fig. 4-4 in the case of Type 3). A table of this class was called a “non-dominance table” because of the non-dominance relationship among all five alternatives. Our stimuli-generation procedures were as follows: we took a dominance table with a “staircase” pattern of

1-2-3-4 betters (e.g., Fig. 4-1 in the case of Type 3) as a *basic dominance table* and a non-dominance table with a “small block” of 2-3-2 betters (e.g., Fig. 4-3 in the case of type 3) as a *basic non-dominance table*. Other stimuli tables of the dominance tables class (of the non-dominance tables class resp.) were then generated from the basic dominance tables (from the basic non-dominance tables, resp.) by permutations (i.e., changing the listing orders) of the alternatives and of the attributes. A generation from Fig. 4-1 to Fig. 4-2 (from Fig. 4-3 to 4-4, resp.) of Type 3 illustrates an example of the results of generation procedures of the dominance tables (of the non-dominance tables, resp.) The procedures were the same for Type 1, Type 2, and Type 4.

Use of the dominance tables (the non-dominance tables) was called the dominance condition (the non-dominance condition) in the following chapters.

2.3 Procedure

After general information was provided and the experimental procedure described, participants sat on a chair in front of a computer screen, and the calibration procedure was completed before starting the experiment. Every participant was exposed to four blocks of 32 trials; four types of multi-attribute tables were used in each block. The first three blocks were Type 2 (Textual), Type 3 (Black-better), and Type 4 (White-better) and the three trial sequences were counter balanced. The last block was Type 1 (Numerical). The order of the trials in each block was also randomized for each participant.

At the beginning of each block, an example of the stimulus table was shown, and the experimenter provided verbal instructions. As an example, the instruction for Type 3 was as follows: “For each attribute, black cells mean TRUE and white cells mean FALSE for the attribute labels.” The test block was started if there were no questions from participants.

In the test trial, after a fixation cross was presented for one second, five alternatives were presented in a multi-attribute table. Participants were asked to choose the most desirable alternative by pressing the corresponding key, without any time pressure. If the participant made their choice by pressing the key, the next trial began with no inter-trial interval. Participants’ eye-movements were recorded during the experiment. In the eye-movement data analysis, we divided each trial into the first half and the second half at the median of each trial (from the stimulus onset to the key pressing). We analyzed how the decision-making processes were different between in the first and second halves.

3 Results

3.1 Response Latency

Figure 5 shows that Experiment 1 (attributes \times alternatives) had a shorter response latency than Experiment 2 (alternatives \times attributes). An analysis of variance (matrix arrangement \times representation pattern (Type 1 to 4) \times table class (dominance condition and non-dominance condition)) showed that the main effect of the matrix arrangement was significant ($F [1, 46] = 4.639 < .05$). This result was consistent with Hypothesis (1). The main effect of the presentation patterns was significant ($F [3, 138] = 16.925 <$

.001). As a result of the subtest, the response latencies in Type 3 (Black-better) and Type 4 (White-better) were shorter than those of Type 1 (Numerical) and Type 2 (Textual). This result was consistent with Hypothesis (2). Furthermore, the main effect of the table class ($F [1, 46] = 55.356 < .001$) was significant. There was a significant interaction between the representation pattern and the table class ($F [3, 138] = 14.469 < .001$). In the dominance condition, the response latencies under Type 3 (Black-better) and Type 4 (White-better) were shorter than those in Type 1 (Numeric) and Type 2 (Textual). In the non-dominance condition, the response latencies for Type 1 (Numeric), Type 3 (Black-better), and Type 4 (White-better) were shorter than those in Type 2 (Textual). These results partially supported Hypothesis (2).

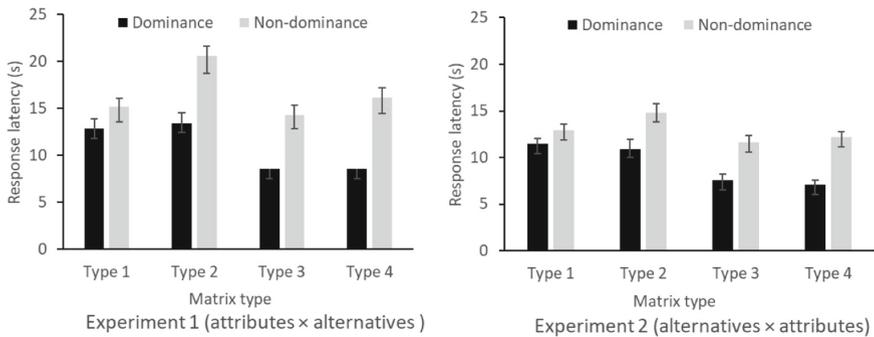


Fig. 5. The mean response latency for each type with error bars denoting standard errors of the mean.

3.2 Number of Consistent Choices

In this experiment, 32 multi-attribute tables were presented for each table type. For the breakdown of the 32 multi-attribute tables, four basic tables were arranged for the dominance-tables and the non-dominance-tables, and four multi-attribute tables with the same meaning (information content) but with different arrangements were created by changing the positions of the alternatives and attributes from each basic table. This enabled us to calculate whether all of the four choices matched for each basic table. The number of same choices among the four differently arranged tables with the same meaning/information content was called the *number of consistent choices*. This number was used as an indicator of utility-based choice, as the higher number indicated participants' better performance according to their own utility, independently of the apparent differences of looking among the same content tables. Figure 6 shows the number of consistent choices for each experiment.

The analysis of variance showed that the main effect of the table class was significant ($F [1, 46] = 90.330 < .0001$). The number of consistent choices in the dominance condition was higher than that in the non-dominance condition. There was also a significant interaction between the matrix arrangement and the table class ($F [3, 138] = 5.615 < .001$). The result of the subtest showed that in the dominance condition, the number of consistent choices for Type 3 (Black-better) and for Type 4 (White-better)

was higher than that for Type 1 (Numeric). In the non-dominance condition, there was no difference by representation pattern. This result was consistent with Hypothesis (2) under the dominance condition. Furthermore, the effect of the table class for each type was examined, and the number of consistent choices was higher in the dominance condition than in the non-dominance condition for Type 2(textual), 3 (Black-better) and 4 (White-better), however no significant difference was found for type 1 (numerical). We examined the difference between the number of consistent choices among the staircase tables (the basic tables) and that among the derivative tables without staircase-like pattern in the dominance condition. We did not find any difference between the two. We predicted that the staircase-like looking tables supported participants utility-based decision making easier as stated in Hypothesis (4), but our results could be seen that all graphic dominance tables supported utility-based decision without being influenced from order change manipulations, in comparison to the numerical tables. The influence from changing the order of alternatives and attributes to decisions was the same higher level for the both two classes in Type 1. On the other hand, in Type 2, 3, and 4 the influence from changing the order to decisions in the dominance condition was less than (higher number) that in the non-dominance condition. These clarified what we expected in Hypothesis (4) to some extent.

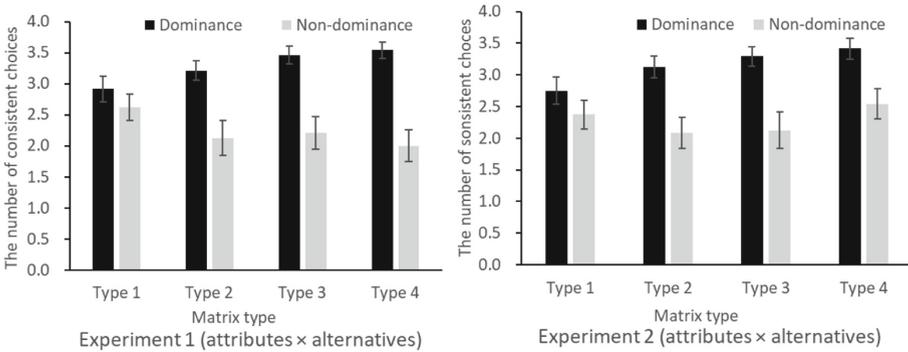


Fig. 6. The number of consistent choices for each experiment.

3.3 Fixation Shift Patterns

We omitted the eye-movement data of seven participants whose fixations were not measured (four in Experiment 1 and three in Experiment 2) and calculated the number of fixation shifts per condition for each participant. The area of interest was set to correspond to each cell of the multi-attribute table. A vertical shift was defined as a fixation shift within the same row, and a horizontal shift was defined as a fixation shift within the same column. Examples of a horizontal shift and a vertical shift are shown in Fig. 7. The average number of fixation shifts per experiment is shown on Fig. 8.

The result of the analysis of variance showed that the main effect of matrix arrangement was significant and that Experiment 2 (alternative × attribute) had fewer shifts than Experiment 1 (attribute × alternative; $F [1, 39] = 4.592 < .05$). This result supported

Hypothesis (1). The main effect of the representation pattern was significant ($F [3, 117] = 36.511 < .001$). As a result of the substest, the number of fixation shifts in Type 3 (Black-better) and Type 4 (White-better) were fewer than those of Type 1 (Numerical) and Type 2 (Textual). This result supported Hypothesis (2). The main effect of shifts patterns was also significant ($F [3, 117] = 20.556 < .001$). Vertical shifts were fewer than horizontal shifts. Furthermore, the interaction of three factors (matrix arrangement \times representation pattern \times fixation shift pattern) were also significant ($F [3, 117] = 2.709 < .05$).

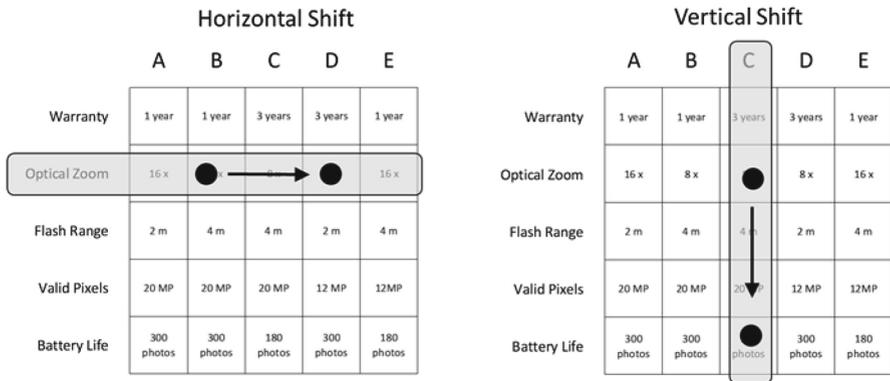


Fig. 7. Sample of a horizontal fixation shift and a vertical fixation shift.

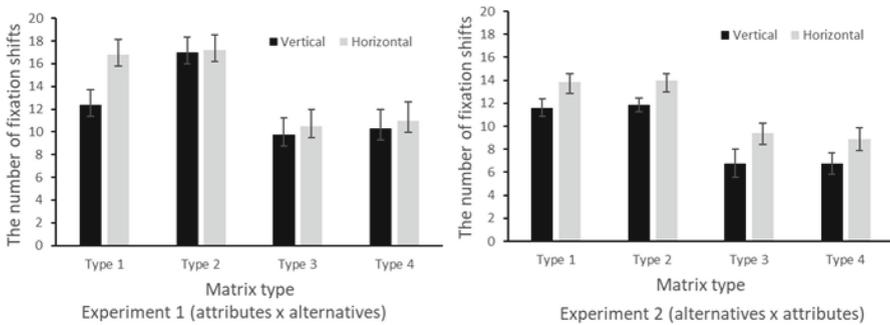


Fig. 8. The number of fixation shifts for each experiments.

To compare the shift pattern differences more accurately, we calculated the transition score based on Payne’s study [7]. This score is defined as follows:

$$Transition\ Score = \frac{S_{ver} - S_{hori}}{S_{ver} + S_{hori}}$$

S_{ver} is defined as fixation shifts within the same column, whereas S_{hori} is defined as fixation shifts within the same row. This score ranges from -1.0 to $+1.0$, with a

higher value indicating more vertical fixation shifts while a lower value indicates more horizontal fixation shifts.

The average number of transition scores per experiment is shown on Fig. 9. The analysis of variance showed that the main effect of the matrix arrangement was significant ($F [1, 39] = 8.572 < .01$). Participants' fixations shifted horizontally more frequently in Experiment 2 (alternative \times attribute) than in Experiment 1 (attribute \times alternative). There was also a significant interaction of three factors ($F [3, 117] = 11.924 < .001$). The subtests showed the fixation shift patterns in Type 1 and Type 2 were changed between those in the first half and those in the second half. These results suggested that participants adopted a two-stage strategy in Type 1 and Type 2. The results of Experiment 1 supported Hypothesis (3) for Type 1 and Type 2, while the result of Experiment 2 showed the opposite of Hypothesis (3); namely, although the changing the roles of the axis (from the horizontal listing of the alternatives to the vertical) made the decision-making easier (which supported Hypothesis (1)), our result suggested still two-stage strategy was taken in Types 1 and 2, which we had not predicted.

Our results of Experiment 1 and Experiment 2 supported Hypothesis (3) for the Type 3 and type 4, whichever axis was used for the alternative listing.

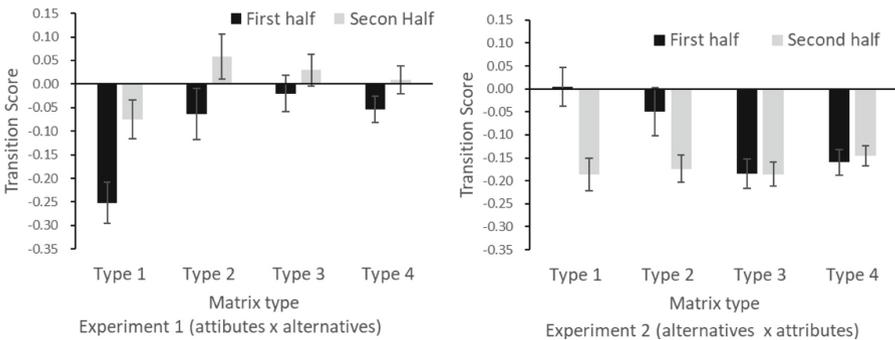


Fig. 9. Transition score for each block type.

4 Discussion

The purpose of our study was to investigate some table designing effects on individuals' decision-making processes. Our results show as follows.

1. Effect of changing the roles of the vertical and horizontal axes.

One of the major findings of this paper is the effect of switching the roles of the vertical and horizontal axes of multi-attribute tables for decision making, by Experiments 1 and 2 (see Fig. 2 and 3). Our results concerning response latencies in 3.1 (see Fig. 5) and fixation shift patterns of participants (see Fig. 8) in 3.3 revealed that, in all Types 1, 2, 3, and 4, the tables with vertical alternatives (Fig. 3) had a shorter response latency, a lower number of fixation shifts, and increased horizontal fixation shifts than a table with vertical

attributes (Fig. 2). These results support Hypothesis (1). This might suggest that the table design of Fig. 3 facilitates decision makers' decisions. This was an unexpected finding in the multi-attribute decision-making studies from the 1970s, as no researchers in the field have been aware of this basic issue of the table design. In fact, using the most advanced theoretical studies with computer simulation, no theoretical difference has been assumed between the style designs from Fig. 2 and those of Fig. 3. The advantage of Fig. 3 makes sense, as our eye-movements are based on horizontal directions, and it facilitates ideal decision making based on the utility of each alternative. This finding is, in our opinion, important in the sense that it is not only concerned with commercial product catalogs but also political election candidate tables, travel scheduling choice tables, public policy tables, and others. In fact, although many former studies on multi-attribute decision making have used the Fig. 2 style, most e-commerce tables with scrolling functions use the Fig. 3 style because of the display constraints of electronic devices without knowing the basic psychological research such as this. Our results give some justification for the current prevalent style of the choice of axes in e-commerce.

2. Two-stage strategy for (Type 1, 2) and one-stage strategy for (Type 3, 4).

In particular, with the numerical tables (Type 1) in Experiment 1 and 2, we observed that the fixation shift patterns (Fig. 9) changed from the first half of the trial to the second half. Our result supports Hypothesis (3). This indicates a two-stage decision-making strategy, which means that the alternatives were narrowed down by an in-attribute search, regardless of the alternatives of the vertical axis and the horizontal axis.

We observed that even when the roles of the axes were switched (so that the alternatives were arranged along the vertical axis and the attributes were arranged along the horizontal axis), although the switching facilitated participants' decision makings as we pointed out in 1 above, the participants still followed the two-stage strategy (Fig. 9), which contradicts our Hypothesis (3); we had predicted that easier decision making (with the easier additive utility search suggested by Hypothesis (1)) would simplify the strategy. Although the two-stage strategy had often been noted in prior research by theoretical simulation results and traditional information board methods, our work relating the two-stage strategy is, as far as we know, one of only a few studies in the natural setting of decision makers' decision environment using the eye-tracking method.

We also examined the effect of color (black and white) representations of attribute values. Our results concerning a response latency (Fig. 5) and the number of shifts (Fig. 7) revealed that the black-and-white tables (Type 3 and 4) had a shorter response latency and a lower number of fixation shifts than the numerical tables (Type 1) and the textual tables (Type 2). These results support Hypotheses (2). One important finding of this study is that eye-movement patterns—which are consistent with the two-stage strategy found when numerical values (and textual values) are used for attribute values—are not found in black-and-white graphic displays of attribute values (Fig. 8 and 9). This result supports Hypothesis (3), indicating that decisions are made using a single-stage strategy in the condition of a graphic representation. Moreover, similar to the results of a previous cognitive experiment [12], reduction of cognitive load by black-and-white display was also observed in the context of our multi-attribute decision-making tasks. (Ease of utility-based decision making was suggested for the dominance table class of graphic tables,

while this was not the case for the non-dominance tables, as we reported in 3.2). In [13], we used only color graphic tables in which both qualitatively-coherent color tables (i.e., smaller value, say, of price is black for the black-better table) and quantitatively-coherent color tables (i.e., small value of price is white, because of smallness, for the black-bigger table), and we found participants' tendency of two-stage strategy with the stimuli of both tables. On the other hand, in the experiments of this paper, we used the qualitatively-coherent color tables, and we found a single strategy, which suggests different ways of designing among the same black-and-white framework change decision makers' strategy.

3. Colored attribute value tables partially help utility-based decision independently of order manipulations of alternatives/attributes.

We used two classes of tables; the dominance tables class and the non-dominance tables class; a dominance table having certain strong dominance relations, in the sense of utility, among some alternatives, and a non-dominance table having no dominance relation at all among the alternatives. We examined influence of order changing of alternatives and of attributes for the same table contents to participant's decision. Our results, using the number of consistent choices in 3.2, showed that participants' decisions using graphic black-and-white tables were less influenced by changing the alternatives/attributes enumeration orders of the same table contents in comparison to that of using the numerical, for the case of dominance tables. On the other hand, no difference was found for the non-dominance tables. This suggested a positive answer to Hypothesis (4) partly. Among the different appearances of black and white shapes of the same content tables, we found no difference on the number of consistent choices, which contradicted Hypothesis (4) partly. This suggests that the graphic black-and-white tables make the utility relations in a table clearer to help decision maker's decision independently of possible order manipulation of the alternatives/attributes. We believe that further research in this direction would provide useful information as to how to design tables to assist decision maker's decision with less possible biases of listing order manipulation of alternatives/attributes. We plan to use the partial utility measure of participants for further research.

In fact, our results on the non-dominance tables (tables in which all five alternatives are competing each other without any partial dominance relation) suggest that decision makers' decisions could be easily manipulated by the layout designs of a multi-attribute table. For example, table designers or companies could put specific alternative on the top or in the center in order to manipulate or interfere with decision makers' decision. How to provide table designs that are fair for decision makers' rational decisions or their own utility-based decision is, in our opinion, an important research subject for the diagram study research community.

We would like to add one last remark regarding our main findings. As we stated above, the effect of changing the roles of the axes (see 1 above) was a characteristic finding from the five decades of research on multi-attribute decision making since the 1970s. One interpretation of this result may suggest that table designers should design tables in the Fig. 3 style (as the current e-commerce tables typically do). We emphasize this application of our main result in 1 above. However, taking into account our results in 2 above with regard to the two-stage strategy, we could consider the possibility of the opposite interpretation for fair table designs for decision makers. The results in 2 above tells us that when we use numerical (or textual) tables, even if switching the roles of the axes, decision makers still seem to take a two-stage strategy rather than a single (only utility-based) strategy. If so, decision makers’ first stage of narrowing down the five alternatives to a few alternatives is an important process. Additionally, the decision maker should take time for this first stage, and use of axes in the Fig. 3 style might decrease this important process, costing too much. From this interpretation, the two-stage strategy associated with the Fig. 2 style use of axes might have its significance. Hence, there are two possible opposite interpretations of our finding 1 above.

	Product A	Product B	Product C	Product D	Product E
					
Valid Pixels	12 MP	20 MP	24 MP	20 MP	20 MP
Optical Zoom	5x	8x	4x	5x	4.2x
F Number	2	2.8	2.8	1.8	1.8
Focus Distance	25mm	24mm	28mm	24mm	24mm
Touch Panel	●	●	●	●	
GPS	●		●		
Blue Tooth		●	●		
USB Charge	●	●		●	
Water Proof		●			●
Selt Timer	●		●	●	●

10-1 Commonly used table

	Product A	Product B	Product C	Product D	Product E
					
Price	¥44,200	¥132,800	¥95,400	¥94,800	¥79,600
Valid Pixels	12 MP	20 MP	24 MP	20 MP	20 MP
Optical Zoom	5x	8x	4x	5x	4.2x
F Number	2	2.8	2.8	1.8	1.8
Focus Distance	25mm	24mm	28mm	24mm	24mm
Shutter Speed	1/2000	1/4000	1/2000	1/1600	1/2000
Battery Life	340 photos	260 photos	200 photos	230 photos	235 photos
Weight	257g	302g	253g	340g	304g
Best Sellers	1	2	3	4	5
Customer Rating	4.0	4.0	3.5	3.0	3.0

10-2 Highlight table

Fig. 10. Sample of attribute tables in our future work.

Based on the results of this paper, in the future, we hope to run the following two natural extensions of the current study, which are both combinations between Type 1 and Type 3. (1) We could study the most commonly used catalog designs to confirm the various graphic effects that we obtained in this paper. A typical type of catalog is the type of Fig. 10-1 where the numerical attributes (Type 1 in this paper) and the graphic yes-no values (Type 3 or 4 in this paper) for function values are combined. One could add horizontal belts to support horizontal eye-movements. Hence, this sort of commonly used table design is a combined design we studied in this paper. It is plausible that we could explain why the commonly used table designs are useful and justifiable from basic psychological research from a diagrammatic viewpoint. (2) Another way to combine our basic types to make a practically useful table would be to have a “highlight table,” where

certain important attribute values are “fairly” highlighted, combining Type 1 (numerical values) with the colored backgrounds of some important values such as in Fig. 10-2. This is a combination of Type 1 and Type 3 and could be used to design tables with high quality features, leading to fair and easy decisions. The graphic effects of Type 3 are expected to support typical value-based tables.

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