Title

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Experimental Investigation on Top-down and Bottom-up Processing in Graph Comprehension and Decision

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Abstract

Graph comprehension requires both bottom-up processing from the graph representation and top-down processing guided by knowledge and attitude. In the current study, we investigated which of the bottom-up process phases: extraction, interpretation, and decision: were affected by the top-down processing derived by the impressions and social attitudes. The experimental results showed that the top-down processing driven by impressions temporarily formed in specific contexts affected both the extraction of information and the following decision phase whereas top-down processing driven by attitude formed over a long time based on social norms affected only the decision phase. In the latter case, a decision was made without any need for bottom-up processing.

Keywords: graph representation, decision, bottom-up processing, top-down processing

Introduction

People make decisions by perceiving and understanding external resources. Visual representations such as graphs are effective for such processes. Visual representations are known for making the understanding of information easier, as graphs and diagrammatic presentations including scatter plots reduce cognitive errors (Ancker, Senathirajah, Kukafka, & Starren, 2006; Lipkus & Hollands, 1999). On the other hand, graphical representations can also bias interpretation: e.g., Woller-Carter et al. (2012) confirmed that an intentionally biased graph produces information reading errors.

Previous studies have confirmed that understanding graphs is best achieved from both top-down and bottom-up processing. Freedman and Shah (2002) proposed a CI model for graph comprehension based on the text understanding CI model proposed by Kintsch (1988). The model assumed that there was an interaction between the two information processing stages; bottom-up from the visually represented information encoded in the external resources and top-down from knowledge stored in long-term memory.

Many studies have shown that the bottom-up processing of graphs depends on the graphical representations. Shah and Carpenter (1995) found that the contents of reading information changed depending on which of the independent variables were assigned to the x-axis or the graph legend. Sanchez and Wiley (2006) found that fascinating and attractive visual information distracted participant focus from the crucial information related to the primary task, which implied that such information should be carefully restrained to ensure participant focus on the target information.

In top-down processing, many experimental findings have been reported that have found that a participant's knowledge and attitudes toward the topics significantly influence an understanding of the information in the graphs. Freedman and Smith (1996) found in their experiments with scatter plot graphs that the participants read the information not only using the bottom-up processing that arises from perceiving plot patterns in the graph, but also using top-down processing which is based on pre-formed knowledge. Kanzaki and Miwa (2012) found that in experiments with line graphs, information reading was performed with both bottom-up and top-down processing, but the top-down processing did not violate the reading of the bottom-up processing.

CaMeRa (Tabachneck-Schijf, Leonard, & Simon, 1997) demonstrated two stages of bottom-up processing. In the preceding extraction stage, primary symbolic information was drawn from the visual representation of the graph: e. g., a y-axis value in the experimental condition in which an experimental manipulation was made was greater than the value in the control condition, and there was a substantial difference between the two conditions. Such difference perceptions at this stage were formed based mainly on the perceptual information processing in the working memory without accessing domain knowledge in declarative memory. In the following interpretation stage, the experimental results represented on the graph were interpreted with an integration of the symbolic information drawn from the graphical representation and knowledge stored in declarative memory: e.g., a medical material x is effective for improving activity y.

In actual situations, the final decision stage, may follow from an understanding of the information drawn from the graph: e. g., sales promotion for the medical material x was decided on.

Figure 1 shows the bottom-up processing series: extraction, interpretation, and decision.

The first aim of the current study was to confirm the bottom-up processing series shown above. In particular, we examined whether internally extracted information, such as mentally represented difference between experimental conditions, that is constructed from information represented on the graph as an external resource, drove the following bottom-up information processing. We should note that how information is extracted from external resources is generally different for each person who reads the graph, implying that there is a possibility that different internal information could be extracted from identical external resources. Therefore, in

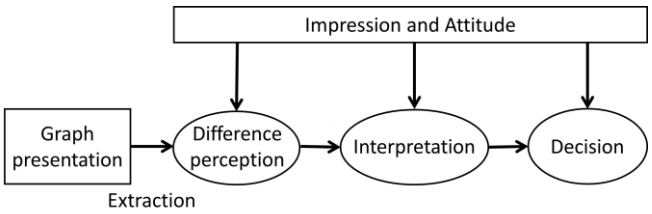

Figure 1: Top-down/ bottom-up processing model of graph comprehension and decision.

this study, we set up difference perception stage in which internal information is constructed from "extracted" information on the graph.

In Experiment 1, we constructed an experimental setting in which we had participants represent perceived difference independently from the external resource. Through the experiment, we explicitly confirmed that based on the internally represented information, the following interpretation and decision stages were performed.

Next, we considered impressions and attitudes to be the factors that drove the top-down processing. Impressions are usually temporarily constructed with insufficient information based on stimuli presented in a situation or a context (Wang & Nelson, 2014). On the other hand, attitudes seem to be more continuously formed based on social and moral norms, and are directed toward people, places, and social policies (Greenwald & Banaji, 1995).

The second aim of this study was to understand which of the initial or final bottom-up processing stages was affected by the top-down processing derived from impressions and attitudes. The research question was whether top-down processing affected only the final decision stage, or also affected the initial extraction. Many studies on human perception have indicated that top-down processing derived from beliefs and knowledge bias human perception; however, previous studies on graph comprehension have investigated top-down processing using the dependent variables related to the latter bottom-up processing phases.

In Experiment 2, we performed an experiment to examine the top-down processing derived from impressions; and in Experiment 3, we further investigated the top-down processing based on attitudes.

Experiment 1

Experiment 1 consisted of Experiments 1a and 1b.

Participants

56 undergraduates (29 males and 27 females: M_{age} = 18.64, SD_{age} = 0.82) from Nagoya University participated in Experiment 1a. The experiment was performed in small groups of at most eight members. 54 undergraduates from Nagoya University (30 males and 24 females: M_{age} = 18.46, SD_{age} = 0.97) participated in Experiment 1b. The experiment was performed as class practice in a cognitive science class.

Materials

In Experiment 1a, an experimental context was introduced in which an ingredient A that was expected to improve biological vitality was assumed, and the effect of ingredient A was examined using a laboratory rat experiment with a hamster wheel. Participants were presented with a graph that indicated the number of cases out of 20,000 in which the rats continued to perform the hamster wheel task for more than three minutes. Figure 2 shows the presented graphs in which there is a substantial difference in the number of cases for the experimental rat group in which ingredient A was given to the rats and the control group in which it was not.

Figure 3 shows the graphs used in Experiment 1b. The graphs had perceptual features identical to those in Experiment 1a but the information content was different. The perceptual features of the graphs implied that there was a difference in the number of cases between the two conditions; however, the reality was the same. The scalability of the y-axis of the graphs was manipulated; as a result, across all graphs, the numbers of cases were only 1190 (5.95%) for the experimental group and 1110 (5.55%) for the control group.

Procedure

Based on the presented graphs, participants were instructed to indicate their opinion as an expert advisor about a nursing tonic that an assumed company was developing to improve biological vitality.

The experimental procedure consisted of the following four stages.

Graphical presentation Participants were assigned to one of three groups. Each group consisted of 18, 19, and 19 participants respectively in Experiment 1a and 19, 18, and 17

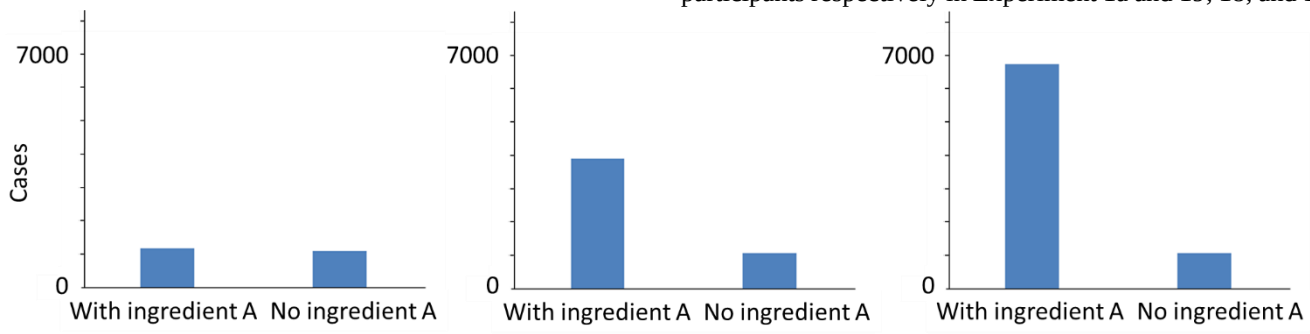

Figure 2: Graphs used in Experiment 1a.

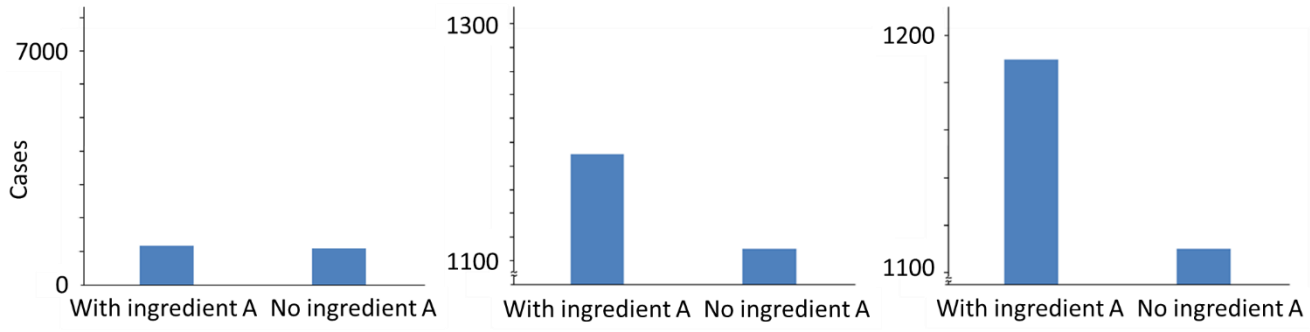

Figure 3: Graphs used in Experiment 1b.

participants in Experiment 1b. The participants in each group were presented with one of the three graphs shown in Figures 2 or 3. A score of 1 to 3 was assigned to each of the three types of graphs for the following regression analysis.

Difference perception After the graphical presentation, participants estimated the degree of difference in the number of cases between the two conditions and were asked if there were any differences in the two conditions on a five-point scale from 1 (strongly disagree) to 5 (strongly agree).

Interpretation Then, the participants were required to estimate to what degree ingredient A was effective in improving biological vitality on a five-point scale.

Decision Finally, the participants were asked whether ingredient A should be included in the nursing tonic the company was developing on a five-point scale.

The experiment took about 30 minutes.

Result

Single regression analyses were performed with the score recorded in one of the four experimental stages as the independent variable and the score in the following stage as the dependent variable. Figure 4 shows the results of Experiment 1a. There were significant relationships found between the presented graphs and the difference perceptions (β = .51, $t(54)$ = 4.36, p < .001, R^2 = .26), the difference perceptions and the interpretations (β = .42, $t(54)$ = 3.35, p < .01, R^2 = .17), and the interpretations and the decisions (β = .48, $t(54)$ = 4.01, p < .001, R^2 = .23). The same analyses were performed for Experiment 1b and Figure 5 shows the results, in which there were significant relationships found between the difference perceptions and the interpretations (β = .42, $t(52)$ = 3.30, p < .01, R^2 = .17), and the interpretations and the decisions (β = .58, $t(52)$ = 5.11, p < .001, R^2 = .33); however, no significant relationships were detected between the presented graphs and the difference perceptions (β = .14, $t(52)$ = 1.01, p = .32, R^2 = .02).

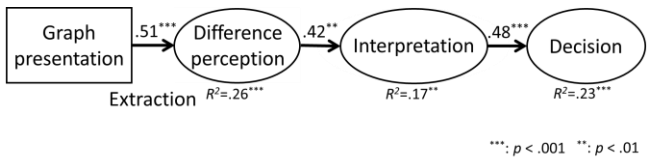

Figure 4: Results of the single regression analyses for Experiment 1a.

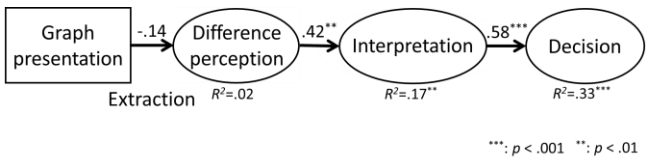

Figure 5: Results of the single regression analyses for Experiment 1b.

Experiment 2

Experiment 2 was performed to investigate how top-down processing driven by impressions affected each of the bottom-up processing phases confirmed in Experiment 1. Experiment 2 consisted of the former and the latter sessions. For each participant, the former session was followed by the latter session; and between the two sessions, a 5 minute break was inserted.

Participants

60 undergraduates (30 males and 30 females: M_{age} = 18.87, SD_{age} = 0.65) from Nagoya University participated in Experiment 2. The experiment was performed in small groups of at most eight members.

Materials

The former session in Experiment 2 was performed to replicate Experiment 1b. In the latter session, the graphs were the same as those in Experiment 1b, but a further experimental setting was introduced to manipulate the participants' impressions toward the medical material in which a fictional ingredient, a "proten" or a "rubison," rather than ingredient A was assumed. For the manipulation, reading material that described one of the two pharmaceutical companies was used to give the participants positive impressions about the one company developing the "proten" and negative impressions of the other company developing the "rubison."

In Experiment 2, two experimental contexts were introduced, with the assignment of each of the two contexts to the former or the latter session being counterbalanced. One context was the same as that in Experiment 1: i.e., the development of a medical ingredient to improve biological vitality was introduced. The other context was the

development of an ingredient to recover physical strength after fatigue. In the latter case, a rat experiment was assumed with a 100 meter running test.

Procedure

Based on the graphs that indicated the experimental results, participants were instructed to indicate their opinion as an expert advisor about a nursing tonic to improve biological vitality, or as an expert advisor about an energy drink to recover physical strength after fatigue.

The experimental procedure consisted of the following five phases.

Impression manipulation Before the graphical presentation stage, in the former session, participants answered a questionnaire about their impressions of an ingredient A that had been developed by an company X they belonged to. In this stage, no information about the ingredient was provided. They estimated, on a five-point scale, their impressions about ten items, such as "ingredient A is reliable," with a higher estimation score meaning more positive impressions toward ingredient A.

The following four experimental stages, graphical presentation, difference perception, interpretation, and decision, were the same as in Experiment 1. Participants were assigned to one of three groups. Each group consisted of 20 participants respectively. The participants in each group were presented with one of the three graphs. In the final decision stage, participants were asked to decide whether ingredient A should be included in the nursing tonic or the energy drink, on a five-point scale.

In the latter session, the impressions of the ingredients "proten" or "rubison" were manipulated using reading materials in which information about company Y which is developing the ingredient was given. First, the participants were presented with a text describing the information about the company Y. One text included characteristics of an excellent company (e.g., There is an excellent welfare program in company Y.), to persuade participants to have a positive impression of the ingredient "proten." The other text had characteristics of an evil company (e.g., There is no welfare program in company Y.), and persuaded participants to have negative impressions toward the ingredient "rubison." One of the two texts was presented to each participant. Then, the participants answered the same questionnaire as used in the former session, in which they were asked to give their impressions of the ingredient "proten" or "rubison."

From the graphical presentation through to the decision stages, the same procedure was utilized as in the former session.

The total time for Experiments 2 was about an hour.

Result

Multiple regression analyses were performed with two independent variables; i.e., a score recorded in one of the four experimental stages and an impression score; and a dependent variable; i.e., a score from the following phase. Figure 6 shows the results from the former session. The results replicated Experiment 1b. There were significant relationships found between the difference perceptions and interpretations (β = .59, $t(57)$ = 5.50, p < .001, R^2 = .38), and the interpretations and the decisions (β = .66, $t(57)$ = 6.30, p < .001, R^2 = .42); however, no significant relationship was detected between the presented graphs and the difference perceptions (β = .23, $t(57)$ = 1.82, p = .07, R^2 = .11). There were no relationship found between the impressions and any of the three bottom-up processing phases; difference perception, interpretation, or decision (β = .24, $t(57)$ = 1.95, p = .06, R^2 = .11; β = .09, $t(57)$ = .84, p = .40, R^2 = .38; β = .05, $t(57)$ = .49, p = .63, R^2 = .42).

The same analysis was performed for the latter session. Figure 7 shows the results, from which it can be seen that the difference perceptions were affected by the impressions (β = .28, $t(57)$ = 2.25, p < .05, R^2 = .11) but not by the graphical presentations (β = .18, $t(57)$ = 1.42, p = .16, R^2 = .11), the interpretations were not affected by the impressions (β = .21, $t(57)$ = 1.99, p = .05, R^2 = .44) but by the difference perceptions (β = .58, $t(57)$ = 5.61, p < .001, R^2 = .44), and the decisions were affected by both the impressions (β = .31, $t(57)$ = 3.27, p < .01, R^2 = .57) and the interpretations (β = .58, $t(57)$ = 6.20, p < .001, R^2 = .57).

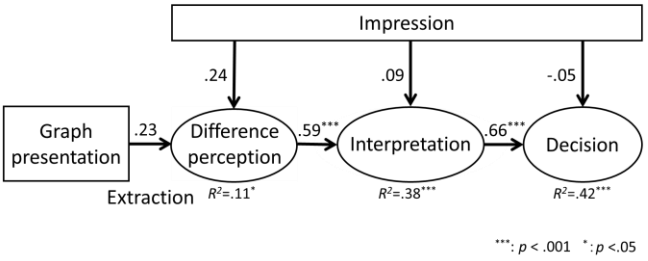

Figure 6: Results of the multiple regression analyses for the former session in Experiment 2.

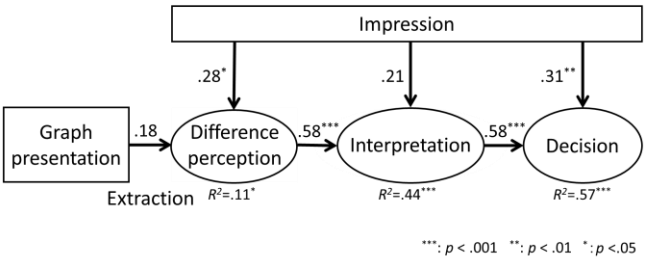

Figure 7: Results of the multiple regression analyses for the latter session in Experiment 2.

Experiment 3

Experiment 3 was performed to investigate how top-down processing driven by attitudes affected each of the bottom-up processing phases. In Experiment 3, we investigated how the participants' social attitudes toward smoking affected their decisions about a smoking cessation policy.

Participants

55 undergraduates (33 males and 22 females: M_{age} = 18.51, SD_{age} = 0.86) from Nagoya University participated in Experiment 3. The experiment was performed as class practice in a cognitive science class.

Materials

An experimental context was introduced in which a health survey was conducted in an assumed city X. Participants were presented with graphs that indicated the survey results. Specifically, the graph showed how many of the 20,000 respondents suffered from pulmonary problems. The perceptual features of the graphs were the same as those in the preceding experiments. It was assumed that one group had a family with a smoker and the other group did not.

Procedure

One week before the experiment, the participants answered a questionnaire to measure their social attitudes toward smoking. They estimated, on a five-point scale, their attitudes toward smoking behavior for 10 items, such as "smoking is only malevolent for society," with a higher estimation score indicating greater negative attitudes toward smoking.

Participants were assigned to one of three groups. Each group consisted of 18, 17, and 19 participants respectively. The participants in each group were presented with one of the three graphs. In the final decision stage, participants were asked to indicate their opinion, as a health consultant, about whether or not employees in an assumed company should be prohibited from smoking both inside and outside the company.

Result

The same multiple regression analyses as those in Experiment 2 were performed. Figure 8 shows the result. The difference perceptions were not affected by the graphical presentations or by the attitudes (β = .03, $t(52)$ = .23, p = .82, R^2 = .002; β = .03, $t(52)$ = .20, p = .84, R^2 = .002), the interpretations were affected only by the difference perceptions (β = .66, $t(52)$ = 6.61, p < .001, R^2 = .48) but not by the attitudes (β = .16, $t(52)$ = 1.63, p = .11, R^2 = .48), and the decisions were affected only by the attitudes (β = .50, $t(52)$ = 4.18, p < .001, R^2 = .28) but not by the interpretations (β = .09, $t(52)$ = .71, p = .48, R^2 = .28).

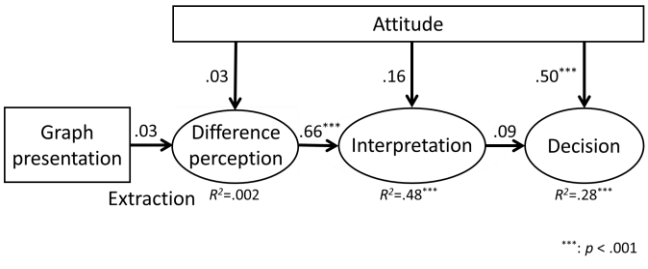

Figure 8: Results of the multiple regression analyses for Experiment 3.

Discussion

The first aim of this study was to confirm a series of the bottom-up process phases, information extraction from graphs as an external resource, interpretation, and decision.

In Experiment 1a, bar graphs with assumed experimental results in two conditions were used. In Experiment 1a, we manipulated the differences in the values of the independent variable in two experimental conditions, and confirmed that bottom-up processing was driven by internally represented differences extracted from the graph as the external resource. In Experiment 1b, we used another set of graphs in which the values for the independent variable were equivalent, and obtained the same results as in Experiment 1a, indicating that bottom-up processes also arise based on the participants' internally represented differences. It is important that bottom-up processing is performed from internally represented information that is extracted from an external resource, and independent of the actual information represented in the external resource.

In Experiment 1b, we used graphs in which the visually represented differences were equivalent to the actual differences in the graphs used in Experiment 1a, even thought there was no actual difference in the two conditions. As a result, no correlation was found between the internal differences represented by the participants and the pseudo differences in the graphs. This indicated that the participants in this study were not affected by the visual biases included in the external resource when extracting the information in the graphs. Previous studies have found that the reading quality of graphical information depends on critical thinking capabilities (e.g., Woller-Carter et al., 2012). The critical thinking abilities of the participants in our experiments appeared to be relatively high, which needs to be considered when interpreting the experimental results in this current study.

In Experiment 2, we manipulated the participants' impressions of the target topic. First, we found the same bottom-up process that had been confirmed in Experiment 1b in which top-down processing was not assumed.

The first finding was that the final decision was made based on both top-down processing derived from impressions and bottom-up processing from the extraction of information from the external resource. Previous studies have consistently confirmed that impressions significantly affect decision making. Kostopoulou et al. (2017) experimentally found that in medical diagnoses by home doctors, the first impression of the patients affected diagnostic planning decisions. Jaros et al. (2000) reported that a perceptual impression of foods at a glance affected food selection.

The latter session in Experiment 2 confirmed that top-down processing using impressions affected the extraction phase in the initial bottom-up processing phase. The halo effect is when the impressions about one specific characteristic affect the estimation of other characteristics that may not even be related to the initial characteristic (e.g., Murphy et al., 1993). In the latter session, we manipulated the impression of the office environments of an assumed

company that had developed a medical ingredient. The participants' estimation about the ingredient depended on the manipulated impressions, even though the efficacy of the ingredient had no explicit relationship with the office environments.

In Experiment 3, we manipulated another factor that drives top-down processing; that participant attitudes are formed over a long period based on moral and social norms. The experimental results showed that different from Experiment 2, the final decision was made only based on the participants' attitudes toward the target topic, rather than depending on the interpretation drawn from the bottom-up processing.

This finding about the relationship between attitude and decision was consistent with findings in previous studies. It has been found that attitudes are crucial in predicting behavior (Conner & Armitage, 1998), and that there is a strong relationship between attitudes and behavior (Fazio et al, 1982).

An important point from Experiment 3 is that when making the final decision, top-down processing was not concerned with the bottom-up processing output. The topic dealt with in the current study was smoking; therefore, as this was a familiar social topic for everyone, this may have driven the strong top-down processing.

The results in Experiment 3 showed that the top-down processing did not affect the bottom-up processing initial extraction phase, implying that such initial bottom-up processing may be isolated by top-down processing.

In the current study, we examined two factors; impressions and social attitudes; that drive top-down processing. In summary, when one factor that is formed temporarily is followed by a specific context, impressions take a central role in the comprehension and decision making about graphical information, indicating that bottom-up processing functions are compatible with top-down processing. On the other hand, when another top-down factor is socially formed over a long period, such as social attitudes, bottom-up processing tends to be separated from top-down processing, with top-down processing predominating.

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