Cross-over interaction and the set-size effect in information integration: Are they mutually exclusive?¹

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The path-analytic averaging (PAA) model of information integration predicts that the two most important findings in the information integration literature, cross-over interaction and the set-size effect, are mutually exclusive. Previous tests of the PAA model have examined cross-over interaction and the set-size effect separately; the present experiment tested both simultaneously, by asking 40 undergraduates to rate the desirability of candidates for secretarial positions based on one or two items of information. Findings supported the exclusivity prediction in experimental conditions in which no fan spread of the two-item slopes occurred. When fan spread was elicited, however, exclusivity was not so clearly supported.

Key words: information integration, cognitive algebra, set-size effect.

Research on information integration has repeatedly produced two important findings, cross-over interaction and the set-size effect. Cross-over interaction refers to the finding that the impact of a given item of information upon the overall judgment is stronger when that item is presented alone to the subject than when that item is presented together with another item of information. The set-size effect is the finding that the overall judgment becomes more extreme as the number of information items having the same scale value increases. These two findings have traditionally been explained in terms of the averaging model of information integration, which assumes that the two effects occur simultaneously. However, a modified averaging model, called the path-analytic averaging (PAA) model (Yamagishi & Hill, 1983) predicts that under certain conditions the two effects are mutually exclusive. Each of these models will be presented, and a study will be des-

cribed which was designed to critically test the predictions derived from these models.

The Traditional Model

According to the traditional (relative-weight) averaging model (e.g., Birnbaum, 1976), the overall judgment Y_2 based on two items of information is:

$$Y = (w_0X_0 + w_1X_1 + w_2X_2) / (w_0 + w_1 + w_2) \quad (1)$$

where X_1 and X_2 are scale values of information items 1 and 2, X_0 is the scale value of an "initial neutral impression," and w_1 , w_2 and w_0 are weights of these items, respectively. This model predicts that the overall judgment based on a single item of information with a high (low) scale value is greater (less) than the judgment based on two items of information with high (low) and medium values. Thus the effect of varying the scale value of a single item, $w_1/(w_0 + w_1)$ (called the "single-item slope," shown as the dashed line in Fig. 1a), is predicted to be steeper than the effect of varying the scale value of that item while it is presented together with a "constant" second item, $w_1/(w_0 + w_1 + w_2)$ (called the "two-item slope," shown

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as the solid lines in Fig. 1a). This is called *cross-over interaction*, since the two slopes are expected to intersect as shown in Fig. 1a.

When the overall judgment based on a single item of information with a high (low) scale value is compared with the judgment based on two items of information, both having the same high (low) value, the averaging model predicts that the former judgment is less (or greater) than the latter. This results from the inclusion of the "initial neutral impression" X_0 which is averaged with the presented value. In other words, the overall judgment becomes more extreme as the number of information items of the same value increases, yielding the *set-size effect*. In Fig. 1a, the set-size effect is represented by the discrepancy between high-high (low-low) and high-alone (low-alone) judgments.

Thus, according to the traditional averaging model, the two major findings in information integration research, cross-over

interaction and the set-size effect, are simultaneously produced by the fact that the overall judgment based on one item of information with a high (low) scale value, when it is presented alone, falls in between (1) the judgment based on two items of information when both items have a high (low) scale value (the set-size effect) and (2) the judgment based on two items when one item has a high (low) scale value and the other has a medium scale value (cross-over interaction).

The PAA Model

Yamagishi and Hill (1981, 1983; Hill & Yamagishi, 1981) emphasized the role of missing (not presented) but still important information items in making an overall judgment, and argued that when information items are mutually independent (i.e., they are not intercorrelated in the minds of subjects), cross-over interaction and the set-size effect are mutually exclusive. Figures 1b and 1c illustrate these

Fig. 1a. Predictions of the averaging model. Solid lines represent the overall judgment Y_2 as a function of X_1 for low, medium and high values of X_2 . The dashed line represents the effect of X_1 presented alone. Both cross-over interaction and the set-size effect are expected.

Fig. 1b. Predictions of the path-analytic averaging model, in the condition in which only X_1 is important when X_1 is presented alone. Solid lines represent Y_{22} as a function of X_1 for low, medium, and high values of X_2 (both X_1 and X_2 are important items). The dashed line represents Y_{11} , the overall judgment as a function of X_1 when it is the only important item. Cross-over interaction is expected, but not the set-size effect.

Fig. 1c. Predictions of the path-analytic averaging model, in the condition in which both X_1 and X_2 are considered important when X_1 is presented alone. Solid lines represent Y_{22} as a function of X_1 for low, medium and high values of X_2 . The dashed line represents Y_{12} , the overall judgment as a function of the only presented item X_1 when both X_1 and X_2 are important (i.e., when X_2 is considered important but missing). The set-size effect is expected, but not cross-over interaction.

predictions. In Fig. 1b, cross-over interaction occurs but not the set-size effect; in Fig. 1c, the set-size effect occurs but not cross-over interaction. The difference between the two figures stems from differences in the meaning of the single-item slopes. In Fig. 1b, the single-item slope represents the impact of a single item of information upon the overall judgment when *only that item is considered important* in making the judgment. In Fig. 1c, on the other hand, the single-item slope represents the impact of an item when only that item is presented but a *second item is also considered important*. In both figures, the two-item slopes have the same meaning; judgments are being based on two items of information and both items are important. Hence the comparison between the single-item slope and the two-item slope in Fig. 1b reflects a change in both the number of items deemed important and the number of items presented. In Fig. 1c, however, only the number of items presented changes; the number of items deemed important remains the same.

This distinction between the number of items presented and the number of items deemed important is a key assumption of the PAA model. The model predicts that the overall judgment is based not only on the presented items of information, but also on inferences about information items deemed important but missing:

$$Y_{nm} = \frac{\sum_{i=1}^n w_i X_i + \sum_{i=n+1}^m w_i \hat{X}_i}{\sum_{i=1}^m w_i} \quad (2)$$

where the X_i are the presented items, the $\hat{X}_i$ are the inferred items which are *missing but considered important*, and the w_i are the weights of the presented and inferred items. Y_{nm} indicates that the overall judgment is based on n items of presented information while m items of information are considered important by the subject in making the judgment.

The predictions in Figs. 1b and 1c are

derived from the PAA model (Equation 2) as follows:

Figure 1b. When the overall judgment is based on two presented items of information, and these two items are the only important items,

$$Y_{22} = (w_1 X_1 + w_2 X_2) / (w_1 + w_2) \quad (3)$$

Note that the term for the inference of the missing information (or the initial impression) does not exist in Equation 3. This is because no important information is missing. When only the first item is considered important and only that item is presented,

$$Y_{11} = w_1 X_1 / w_1 \quad (4)$$

When the two information items have the same value, the above two judgments (Equations 3 and 4) are equal. For example, when the values of X_1 and X_2 are both high, H ,

$$Y_{22} = (w_1 H + w_2 H) / (w_1 + w_2) = H, \text{ and} \\ Y_{11} = w_1 H / w_1 = H$$

Thus the pattern in Fig. 1b, in which no set-size effect occurs but cross-over interaction is expected, is predicted when judgments based on two items presented (both important) are compared with judgments based on one item presented and *only that item is important*.

Figure 1c. On the other hand, when only the first item is presented but *the second item is still considered important*, Equation 2 becomes:

$$Y_{12} = (w_1 X_1 + w_2 \hat{X}_2) / (w_1 + w_2) \quad (5)$$

The value of the inferred missing information $\hat{X}_2$ depends on the assumed correlation between X_1 and X_2 (cf. Yamagishi & Hill, 1981; Hill & Yamagishi, 1981). However, when the assumed correlation between X_1 and X_2 is zero, it would be reasonable to infer a medium value for the missing information. If this is the case, Y_{12} becomes identical with Y_{22} for the me-

dium value of the second item. This is illustrated in Fig. 1c, in which there is a set-size effect but no cross-over interaction.

Yamagishi and Hill (1983), however, found that some subjects make inferences about the missing information that are less than medium (or the scale midpoint). When the value of X_2 is less than medium, Y_{12} will not overlap with Y_{22} for the medium value of the second item. However, even when the inference of the missing information is other than medium, the single-item slope Y_{12} and the two-item slopes are still predicted to be parallel. This is because the slopes, expressed in terms of the partial derivative of the overall judgment with respect to X_1 , are identical. That is,

$$\frac{\partial Y_{22}}{\partial X_1} = \frac{\partial Y_{12}}{\partial X_1} = \frac{w_1}{w_1 + w_2} \quad (6)$$

Thus the pattern in Fig. 1c, in which the set-size effect occurs but not cross-over interaction, is predicted from the PAA model when judgments based on two items presented (both important) are compared with judgments based on one item presented and a *second item is important but missing* (and the two items are not intercorrelated).

Yamagishi and Hill (1983) found the set-size effect to occur only when the number of presented items increased while the number of important items was kept constant (e.g., Y_{12} vs. Y_{22}). Another study (Hill & Yamagishi, 1981) found that, given no correlation between the two information items, cross-over interaction was obtained when Y_{11} (the only important item) was compared with the two-item slopes; no cross-over interaction was observed when Y_{12} (one of two important items) was compared with the two-item slopes. However, these two types of effects were not tested in the same study.

The present experiment was designed to test these two effects simultaneously in the same study. Specifically, it was predicted that (1) the overall judgment based on a

single item of information with a high (low) scale value would be equal to that based on two items of information with the same high (low) values, when the item presented in the single-item condition is considered to be the only important item in making the judgment (Fig. 1b), and (2) that the single-item slope will be parallel to the two-item slope, when the second item is still considered important even when it is not presented (Fig. 1c). Thus, this experiment provides a more stringent test of the PAA model than previous tests of the model which were carried out separately for cross-over interaction and the set-size effect.

In addition, the experiment was designed to test whether the two effects would be exclusive both when the two-item slopes are parallel to each other (as shown in Fig. 1) and when non-additivity in the form of a fan-spread pattern occurs.² There is no reason that the PAA model assumption that people infer and use missing but important information in making an overall judgment should be limited to the additive type of information integration. If the assumption is generalizable beyond additive type of information integration tasks, cross-over interaction and the set-size effects are expected to be mutually exclusive in the non-additive type of information integration tasks.

To test the generalizability of this assumption, we experimentally *created* a fan spread pattern of non-additivity by instructing subjects that both of the information items are "necessary conditions" for the overall judgment. An example of this "necessity" of the two items would be the judgment of the qualification of a translator; to qualify as a Japanese-English translator one must be skilled in both languages. The extent of one's skill in

² Non-additivity has frequently been found in prior studies of information integration (e.g., Anderson & Butzin, 1974; Birnbaum, 1973, 1974; Kun, Parsons, & Ruble, 1974; Oden & Anderson, 1971; Singh, Gupta, & Dalal, 1979).

English matters little if one has little skill in Japanese; but if one is highly skilled in Japanese, English skill does matter. Thus, this instruction is expected to make the two-item slope steeper as the value of the second item increases, resulting in a fan spread pattern of interaction.

Method

The experiment employed the hiring paradigm developed by Yamagishi and Hill (1983; Hill & Yamagishi, 1981). In particular, subjects were asked to make judgments concerning the desirability of hiring candidates for secretarial positions based on information presented (or missing) about two skills, typing and bookkeeping.

Design

The design included a between-subjects factor and three within-subjects factors. The between-subjects factor was a variation in instructions designed to produce either fan spread or no fan spread among the two-item slopes. The within-subjects factors were (1) the number of "important" skills, i.e., those required for the position for which the candidate is applying (1 vs. 2), (2) the number of presented skills (1 vs. 2), and (3) the scale value of the presented skills (low, medium, and high). The between-subjects factor was crossed with all three within-subjects factors, but the within-subjects factors were not fully crossed with each other.

Procedure

Upon arrival at the laboratory, each subject was led to a compartment which was equipped with a computer terminal. All instructions and stimulus presentations were displayed on the terminal screen, which was connected to a minicomputer.

In the instructions, subjects were told (1) that some positions required both typing and bookkeeping skills while other positions required only typing skill, and

(2) that the two skills were not correlated. In order to manipulate the presented information separately from the required information, subjects were told the following:

All candidates took a typing test, which is highly reliable. That is, the typing test they took is known to predict their typing skill very well. The candidates who applied for positions which do *not* require bookkeeping skill did *not* take a bookkeeping test. The candidates who applied for positions which require both typing and bookkeeping skills took *one of the two versions of a bookkeeping test*. Bookkeeping test A is highly reliable. That is, it is known to predict the candidate's bookkeeping skill level very well. However, bookkeeping test B turned out to be highly *unreliable*. That is, it became clear that the test *cannot* predict the candidate's bookkeeping skill level at all. Thus, for those candidates who took version B of the bookkeeping test, the test score is not presented. This is because the test score of version B is misleading.

After these instructions, subjects received a series of stimulus presentations and prompts for responses. The order of stimulus presentation was completely randomized. For each candidate, subjects were told simultaneously on the screen which skill(s) were required for the position for which the candidate was applying, plus the test score(s) on the skill(s) when the scores were available. When scores were not available due to unreliability of the version of the test the candidate had taken, subjects were told so. The test scores were displayed both numerically and graphically by presenting each skill score at the appropriate position on a line with end points labelled 0 and 100. After the stimuli were displayed on the screen for 15 s, subjects were prompted to enter their responses on the terminal. When the response had been entered, stimuli for the next candidate were displayed on the

screen.

Stimulus manipulations. The manipulation of fan spread versus no fan spread was performed by specifying the role of the two skills required for the job. Specifically, it was emphasized to the subjects in the fan spread condition that when the job required both skills, having either one of them was useless:

When the position requires both skills, a candidate has to be good at both skills to qualify. That is, being good at one skill won't help insofar as the candidate is poor at the other.

In addition, the necessity of both skills was emphasized again on the screen when stimuli were displayed in the fan spread condition. (The emphasis was omitted when stimuli were displayed in the no fan spread condition or only typing skill was required for the job.)

Within-subjects manipulations were performed through display of different sets of skill requirements and test scores. The number of required skills was manipulated by specifying whether only typing or both typing and bookkeeping skills were required for the position for which the specific candidate was applying. The typing skill was always required, and the test score was always available. When the bookkeeping skill was also required, the bookkeeping test score was available for some candidates but not for others. When the required bookkeeping score was not available, it was clearly indicated on the screen that the test score was not available due to the unreliable nature of the specific version of the test that the candidate took but that bookkeeping skill was still required for the position.

When the skill scores were available, the scores were low (ranging from 10 through 20), medium (45 through 55), or high (80 through 90). For each candidate the exact scores were determined randomly within these ranges. Thus the same condition could be replicated with slight variations in the exact scores, without giving

subjects the impression that they were re-evaluating the same candidate. The above stimulus conditions produced 15 different combinations: Nine combinations consisting of the 3×3 levels of the two skills (when both skills were required and presented), plus three levels of typing skill when only typing skill was required, and three levels of typing skill when two skills were required but only the typing test score was available. For each combination, three candidates were evaluated. Thus subjects evaluated a total of 45 candidates. The whole experiment took about 30 min on the average including the instructions.

Dependent measure. The dependent measure was the judged desirability of each candidate on a scale ranging from 0 to 100. Subjects indicated their judgments by entering numbers into the computer using the terminal keyboard.

Subjects. Subjects were 40 undergraduates (20 males and 20 females) recruited from sociology classes and through an advertisement in a campus newspaper at University of Washington.

Results

Fan Spread Versus No Fan Spread

Results of the experiment clearly indicate the effectiveness of the fan spread manipulation. In the no fan spread condition (Fig. 2a), the two-item slopes did not significantly deviate from parallelism ($F(4, 76) = 1.15, ns$). On the other hand, the two-item slopes in the fan spread condition (Fig. 2b) showed a significant interaction ($F(4, 76) = 21.95, p < .001$).

Both Skills Required

When bookkeeping skill information was not available in the single-item condition but was still considered important, it was predicted that the single-item slope and the two-item slope for the medium value of the second item would be parallel.

No fan spread condition. In the no fan

spread condition (Fig. 2a), the two slopes did not deviate significantly from the parallelism prediction (interaction $F(2, 38)=0.03, ns$).

Fan spread condition. In the fan spread condition (Fig. 2b), the interaction was significant ($F(2, 38)=3.48, p<.05$), but the direction of the interaction was *opposite* to that predicted by the averaging model. That is, the single-item slope was *less* steep than the two-item slope for the medium value of the second item. This interaction may reflect a tendency on the part of some subjects to make "conservative inferences" of the missing information, inferring less than the medium value for the missing information (cf. Yamagishi & Hill, 1983; Hill & Yamagishi, 1981). When the inferred value of the second item is less than the medium value, the single-item slope Y_{12} is expected to be located below the two-item slope for the medium value of the second item, and the former slope is expected to be less steep than the latter slope. This conservative inference is evidenced by the fact that the

single-item slope Y_{12} was located below the two-item slope for the medium value of the second item; the main effect representing this downshifting was significant ($F(1, 19)=11.77, p<.01$).

Only Typing Required

No set-size effect was predicted when candidates applying for positions *requiring only typing* skill are compared with candidates applying for positions requiring both typing and bookkeeping skills. That is, when the single-item slope represented the evaluation of candidates applying for positions requiring only typing skill, it was predicted that the high-(low-)typing candidates would receive the same desirability judgment as the high-(low-)typing and high-(low-)bookkeeping candidates applying for positions requiring both of these skills.

No fan spread. In the no fan spread condition, the average judgment score of the high-typing candidates applying for positions requiring only typing skill (87.97) and that of the high-typing and high-

Fig. 2a. Overall judgment of desirability as a function of typing skill level in the no fan spread condition.

Fig. 2b. Overall judgment of desirability as a function of typing skill level in the fan spread condition.

bookkeeping candidates (89.59) were not significantly different from each other (paired $t(19)=0.71$, *ns*), as predicted. The difference between the low-typing candidates (16.41) and the low-typing and low-bookkeeping candidates (15.88) again failed to be significant ($t(19)=1.63$, *ns*).

Fan spread condition. In the fan spread condition, the average judgment score of the low-typing candidates applying for positions requiring only typing skill (10.75) was not significantly different from that of the low-typing and low-bookkeeping candidates (10.78), again as predicted ($t(19)=0.04$, *ns*). However, the average judgment score of the high-typing candidates (86.02) was significantly lower than that of the high-typing and high-bookkeeping candidates (92.36), contrary to the prediction ($t(19)=3.40$, $p<.01$). Examination of individual responses revealed that this difference between the high-typing alone vs. high-typing and high-bookkeeping was not due to a few extreme cases; rather, one half of the subjects ($N=10$) judged the high-high candidates as more desirable by more than five scale points than the high-alone candidates. The other half revealed smaller differences; two subjects judged high-high as more desirable than high-alone by more than one but less than five points; the difference was less than one scale point in either direction for six subjects; and two subjects judged high-alone candidates as more desirable than high-high by between one and five points.

Discussion

Results of the present experiment indicated that cross-over interaction and the set-size effect were mutually exclusive in an additive type of information integration task. That is, when cross-over interaction occurred the set-size effect did not occur; and when the set-size effect occurred cross-over interaction did not occur. This finding cannot easily be explained by the previous averaging model

unless the weight for the "initial impression" (w_0 in Equation 1) is varied as a function of the number of important items. That is, w_0 has to be zero when candidates applying for positions requiring only typing are compared with candidates applying for positions requiring both typing and bookkeeping, since $(w_0X_0+wH)/(w_0+w)=(w_0X_0+2wH)/(w_0+2w)$ only when $w_0=0$ (given that $X_0=0$ and $w_1=w_2=w$). However, the weight for the initial impression w_0 cannot arbitrarily be ignored since it is required to explain the set-size effect. What is needed, then, is a *theory to explain why and when the weight for the "initial impression" changes*. This is what the PAA model has to offer.

According to the PAA model, the initial impression is reconceptualized as the "missing" but important information (see Yamagishi & Hill, 1983). As a result, the PAA model explains the change in the weight for the "initial impression" as a function of the number of important items and the number of presented items; the weight for the "initial impression" is reduced as the number of missing but important information becomes smaller. Although previous research (Yamagishi & Hill, 1981) suggested that the inference of missing information is important only when the missing information is correlated with the presented information (so that the inference can be based on the presented information), it is now clear that missing information is important in making the overall judgment even when the two types of information are not correlated.

However, the predictions of exclusivity were not so clearly supported in the condition in which fan spread occurred among two-item slopes. Although the low-typing candidates applying for positions requiring only typing skill were judged equal to the low-typing and low-bookkeeping candidates, the high-alone candidates were judged less desirable than the high-high candidates; thus the set-size effect was observed for the high skill can-

didates but not for the low skill candidates (this asymmetry in the set-size effect has also been reported in previous research, Kaplan, 1970; Yamagishi & Hill, 1983). This anomaly in the findings existed in only one half of the subjects; the other half of the subjects did not show much difference in their judgments of the high-alone candidates and the high-high candidates. This asymmetry in the set-size effect cannot be explained by either the PAA model or other models of information integration. Thus, further research is needed to investigate individual differences in information integration in order to account for such anomalies when fan spread occurs.

In the present experiment, only two pieces of information were used. In the past studies using a large number of information items, the polarity of all-negative and all-positive judgments was about 80–85% of the total scale distance (84% with 9 items in Anderson, 1967; 82% with 6 items in Anderson, 1968; 80%, 85% with 6 items in Kaplan, 1970; 82% with 32 items in Sloan & Ostrom, 1974), while the polarity in the present experiment with two information items was about 74%. Thus, judgments in the present experiment might have been more extreme with a larger number of items, and the comparison of Y_{11} with, say, $Y_{100-100}$ might have produced the set-size effect. However, the difference between Y_{11} and Y_{1-100} would still be substantial and significant, and the conclusion concerning the role of missing information (implied in the comparison of Y_{nn} and Y_{nm}) would not be invalidated even when minor set-size effect emerges with a large number of items.

The results of the present experiment, together with those of previous studies (Yamagishi & Hill, 1981, 1983; Hill & Yamagishi, 1981), clearly support the basic assumption of the PAA model that people infer missing but important pieces of information and integrate them with known pieces of information in making overall judgments. Although experimen-

tal tests of this assumption so far have been conducted in the context of integration of quantitative information, the same assumption may hold concerning integration of qualitative information, such as sex, race, occupation, party affiliation, etc. We have started generalizing the PAA model into non-additive integration tasks in this study, but further investigation of various integration tasks including both quantitative and qualitative information is still needed.

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