信号検出理論を用いた結合錯誤問題の再解釈

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Illusory Conjunction Interpreted as Signal Detection

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Abstract: The probability of illusory conjunction is known to distribute bimodal, especially when experimental stimuli contain additive items which shared common integrative features with a target. In this study, I investigated some reasons why this bimodal distribution took place and tried to explain the phenomenon in terms of signal detection theory. Results demonstrated that discriminability of stimulus itself did not distribute bimodal. I suppose, consequently, that the bimodal distribution of illusory conjunction depends not only on subjects' cognitive criteria derived from the higher level decision process and but also on lower visual information like an anisotorpy of visual field.

Keywords: Illusory Conjunction, Feature Integration Theory, Signal Detection Theory, Additive feature Effect, Anisotoropy of Visual Field

INTRODUCTION

Illusory conjunction occupies an important position in Feature Integration Theory proposed by Treisman and Gelade(1980), and Treisman(1988), in the sense that experiments of illusory conjunction seem to be able to treat information obtained from feature integration more directly than those of visual search and texture segregation. Although a neural network model has been proposed(e.g., Horn, Sagi, and Usher, 1991), the problem of bimodal distribution of illusory conjunction has not been solved yet. In this study, I investigated why the probability of illusory conjunction bistribute bimodal.

According to Feature Integration Theory (Treisman and Gelade, 1980) and other evidence from psychophysics and physiology (Livingstone and Hubel, 1988), our visual system can process retinal images through several separate channels(i.e., luminance, color, motion, binocular disparity, and texture). These channels process a retinal image almost independently from each other. Accordingly, a role of the first stage of

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visual information processing is to separate an object into several features, and it is necessary in the later stage to integrate the outputs which each channel could process. Illusory conjunction can be thought of as a failure of integrating the outputs from several channels in the first stage. Or alternatively, I can regard it as poor mechanism that location information is registered during the identification of features. To investigate how illusory conjunction occurs and what condition can affect the probability of illusory conjunction will give us some useful information about our visual system.

Ivry and Prinzmetal (1991) have shown dominant factors to constrain the formation of illusory conjunctions. (1) Illusory conjunction are more likely to occur between items that are adjacent in a display in comparison with items that are distant. (2) Illusory conjunctions are affected by the spreading of attention. Illusory conjunction are inversely related to distance, but this effect is diminished when the candidate features are presented within the spread of attention. (3) Perceptual organization can also modify the effect of distance between items. Illusory conjunctions between features within the same perceptual group were more likely than conjunctions between features in different perceptual groups (Prinzmetal, 1981). (4) Feature integration can be affected by grouping determined by purely cognitive factors, linguistic factors. (5) Temporal proximity can affect illusory conjunction. (6) Illusory conjunctions are affected by feature similarity. In addition to these points, our preliminary observations showed that there seems to be some other factors to constrain the formation of illusory conjunctions. They are an eccentricity (stimulus distance from central fixation point), an anisotoropy of visual field, and so on. As one can imagine, illusory conjunction may be the result of many complex factors.

Besides these points, the probability of the occurrence of illusory conjunction has another problem that the distribution of its probability may differ among subjects. The individual differences might have caused the bimodal distribution (Treisman and Paterson, 1984). For example, when one subject see several orthogonal lines '\' and right angles 'L' simultaneously, he or she may see illusory triangles because these items are components to form a triangle shape. For another subject, on the other hand, no triangles can be seen at all in the same stimulus situation. Some subjects may see illusory triangles only when an additive item 'circle' is contained in the stimulus display. Others can see illusory triangles even when he or she sees the display not containing additive items. Notice that 'circle' shares a common feature as 'enclosure' with the target symbol 'triangle'. This facilitative effect of additive items differed among subjects (Treisman and Paterson, 1984). The bimodal distribution may be due to the individual differences as our example illustrates.

Since it is not yet clear how many factors interact with the occurrence of illusory conjunction, no plausible model has been proposed to explain the bimodal distribution of illusory conjunction. This study was intended to investigate tow points below.
(1) Whether the bimodal distribution depends on a lower level outputs, or higher cognitive mechanism. If the bimodal distribution depends on the low level output,

an effect of anisotoropy of visual field will be significant as in the previous visual detection experiments. Thus, the probability of illusory conjunction will show a constant difference between when items are presented in the left side of visual field and when items are presented in the right side. (2) Whether the facilitative effect of additive items yield or not. I have related illusory conjunction with some of the assumptions made in Signal Detection Theory.

AN INTERPRETATION OF ILLUSORY CONJUNCTION BASED ON SIGNAL DETECTION THEORY

This study was intend to interpret the ratio of illusory conjusory on bases of Signal Detection Theory by assuming the illusory conjunction is psychologically real. Here I assume below;

(1) Each stimulus is in accordance with normal distribution on a hypothetical psychological continuum.

(2) On its continuum, variances of stimulus are all the same and equal 1.0^2

(3) Subjects' criteria of decision are constant over all experiment conditions.

(4) When a target was presented, the averages of correct ratios are equal in all conditions.

Among these assumptions, (1) and (2) are used in original Signal Detection Theory. The assumptions (3) and (4) have been hypothesized dy previous studies of illusory conjunction. Main concern is whether discriminability shows bimodal distribution or not under the assumptions (3) and (4).

Figure 1 shows the hypothetical relations between discriminability and decision criterion. There are four figures (a)–(d) in Fig. 1. Each figure contains two contours of normal distributions. The right contour of distribution stands for the trials in which target are presented (called 'Signal' in terms of Signal Detection Theory). The left contour of distribution represents the trials where the targets are not presented to the subject (called 'Noise'). Discriminability is defined as the distance between the two peaks. The vertical lines in Fig. 1 show a subject's decision criterion. For example, if a stimulus fall into the right side of this criterion, subjects will report that the target was presented. On the other hand, if a stimulus fall into the left side of criterion line, subjects will report that target was not presented whatever stimulus was presented. The filled areas in Fig. 1 indicate a kind of error (called 'false alarm' in Signal Detection Theory). It is worth noticing that there are two possibilities when illusory conjunction ratio is low. One is the case in which the distance of two distributions are far apart, and the other case is that decision criterion is within the signal distribution. When illusory conjunction ratio is high, there also may be two possible intepretations. One is the case that distance of two distributions is near enough, and another is the case that criterion is left enough.

In the previous studies, two types of errors has been distinguished: a feature errors, and conjunction errors[2]. The following equation have been used to estimate the true ratio of illusory conjunction per se.

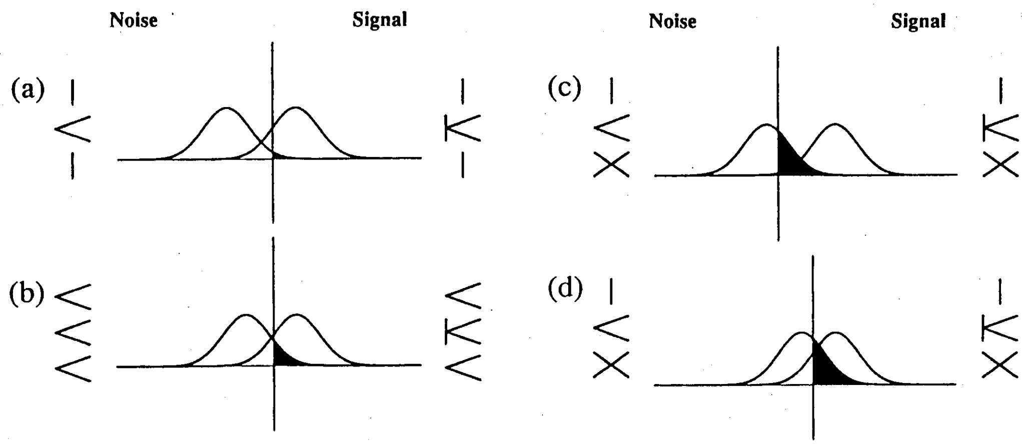

Figure 1. Hypotetical relations between discriminability and decision criterion
Left contour of the distribution stands for target absent trials 'Noise', and right represents target present trials 'signal'. Filled area indicates false alarm. Discriminability is defined as the distance between the two peaks. The vertical lines show subject's decision criterion. For example, if a stimulus fall into the right side of this criterion, subjects would report that the target was presented. On the other hand, if a stimulus fall into the left side of criterion line, subjects would report that target was not presented whatever stimulus were presented. It is worth noticing that there are two possibilities when illusory conjunction ratio is low. One is the case in which the distance of two distributions are far apart, and the another case is that decision criterion is within the signal distribution. When illusory conjunction ratio is high, there may be two possible interpretations. One is the case that distance of two distributions is enough near, and another is the case that criterion is enough left.

Subjects were required to report whether target 'K' was presented in the stimulus display (stimulus used in this experiment are drawn at each side of distribution). a) feature error, b) conjunction error, c) a case that criterion varied in additive feature condition, d) a case that distance vairied in additive feature condition.

$$\text{ICest}=\text{P(conjunction error)}-\text{P(feature error)}. \quad (1)$$

In terms of Signal Detection Theory, both feature and conjunction errors are regarded as false alarms. Considering the assessment of observers' discriminability (i.e., the subjective discriminability among subjects), the ratio of correct responses could be better taken into account. If all other conditions are held constant, the relation between an estimated illusory conjunction ratio and discriminability(d') will decrease monotonously. It is worth noticing the following. False alarm does not necessarily mean that illusory conjunction is illusory, or ambiguous.

Here, problems are (1) whether bimodal distribution of illusory conjunction is derived from discriminability, or from decision criterion. (2) Does additive item affect discriminability or decision criterion, or both ? If decision criterion varies individually

[2] a feature error indicates that a subject reported a feature not presented in real display, in the case that a subject reported a triangle when stimulus contained right angles 'L' and vertical lines 'I'. On the other hand, a conjunction error (a true illusory conjunction) means a recombination of features among presented items, in the case that a subject reported a triangle when stimulus contained right angles 'L' and oblique line '\'.

among subjects, apparent ratio of illusory conjunction may distribute bimodal, but discriminability may not distribute bimodal. In this case, bimodal distribution is derived from higher cognitive mechanism. On the other hand, if discriminability itself should distribute bimodal, low level perceptual system, including an anisotoropy of visual field, may cause this bimodal distribution.

EXPERIMENT

Subject. Fifteen undergraduate students of psychology at Bunkyo university participated in the present experiment. The subjects received course credit for their participation. All of the subjects had normal or corrected-to-normal vision.

Apparatus. A personal computer (NEC PC9801RX, DOS machine) was used for controlling experiment and generating stimulus on CRT screen (640×400 pixel display, TC-TV455 from NEC). The refresh cycle of CRT display was 56.4 Hz (about 17 ms), therefore exposure duration could be controlled 17 ms step. Program was written in Turbo C++ 1.01 and Turbo Assembler 2.0 (Borland).

Stimulus. One stimulus contained three items, one digit, and three black squares. The stimulus display for a representative trial is depicted in Figure 2 (in real display, all stimulus were white drawn on black background). Subjects were seated approximately 57 cm from CRT display, and all sizes are given in degrees of visual angle. There were four types of items like 'I', '<', 'X', and 'K' subtending about 0.9 degree × 0.9 degree. Target to be detected is consistently 'K' like an alphabet symbol through the experiment. A center digit was randomly chosen among '7', '8', and '9' by computer, therefore chance level of correct ratio was 1/3. There was no particular relation between the central digit and the displayed items. On the other side of 3 items, three black squares (same size as each item) were aligned vertically.

Experiment contained three factors (three stimulus type conditions, two location conditions, and target present/absent conditions). Stimulus conditions are (1) feature lack condition '<<<'; This type of items lacks vertical line to form a target 'K'. (2) Conjunction condition 'I<I'; unequal symbol '<' were put between two vertical lines 'I'. This type of item were sufficient to form a target 'K'.(3) Additive feature condition 'I<X'; a 'X' was displayed in addition to a vertical line 'I' and an unequal symbol '<'. 'X' has common feature with target in the sense that four line segment converge.

Location condition stands for the stimulus position (left or right). Three squares were presented on the same distance from a center digit at the counter side of stimulus.

At all conditions mentioned above, when target was presented, center item was replaced by 'K'. Half of all trials contained target item 'K' and another half did not contain the target.

Three stimulus types, two location types, target preset/absent, and 40 repetitions yielded total 480 trials. Order of stimulus presentation was randomized. Since half of all trials contained a target 'K', and another half of all trials did not contain the target, chance level of correct was 1/2. To set the occurrence probability of target 1/2 has an advantage that subject can not use a knowledge concerned with a prior probability of stimulus.

Exposure duration of a stimulus set was about 71 ms (4 frames) and was holding constant through the experiment by the followng two reasons. First, if exposure duration would change as the subjects correct ratio varied, other extraneous variables might be confounded. For example, some subject can be allowed saccadic eye movement, and others can not. In original studies of illusory conjunction (Treisman and Schmidt, 1982; Triesman and Paterson, 1984), exposure duration was varied at each subject and at each experimental condition to hold correct ratio constant. But exposure duration was critical just within a threshold to occur saccade in the studies cited above. Second, from the assumption of Signal Detection Theory, to hold other condition constant is convenient for calculating discrimability.

Procedure. One trial initiated a short beep tone. After listening beep tone, subject pressed space bar on keyboard to start a trial. 500 ms after pressed a space bar, a stimulus like Fig. 2 was presented briefly (71 ms) followed by checkerboard mask pattern (maximum and minimum luminances of checkerboard pattern corresponded to those of stimulus and background). At first, subjects were required to report the digit in the center of CRT. Next, they were required to report whether a target 'K' was presented or not. All responses were recorded through keyboard. Subjects were not instructcd where a target 'K' would be presented, but whenever 'K' was presented it was positioned in the middle of two distractor items.

After 40-60 practice trials (number of practice trials were decided for subject to be able to do any trial without seeing keyboard), each subject fulfilled the experiment his or her own pace. The stimulus used practice trials were randomly chosen from 480 stimuli pool. Total time to finish all trials was about 1.5-2 hours.

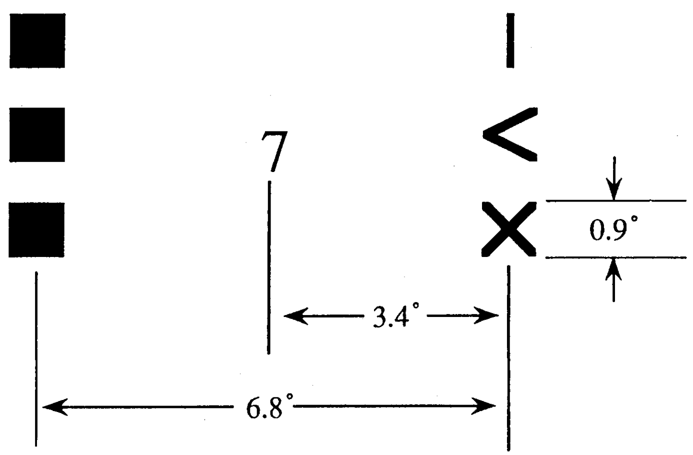

Figure 2. Stimulus display for a representative trial

RESULT AND DISCUSSION

About correct detection ratio of center digit.

Irrespective of the stimulus types, the subjects detected all digit correctly. The correct ratio ranged from 94% minimum to 98% maximum. There were statistically no significant relation between digit detection ratio and target detection ratio. This high correct ratio means that experimental procedure succeeded in controlling subjects' attention.

Distribution of discriminability.

The box-and-whisker plot in Fig. 3 shows the distribution of discriminabilities in each condition. I used this exploratory data presentation because the contours of discriminability distributions were unknown. Figure 3 shows that the discriminabilities were constantly higher when the stimulus was presented in left side than when the stimulus was presented in right side. Therefore, illusory 'K' might have occurred more frequently when the stimulus was presented in the right side of visual field than when the same stimulus was presented in the left side. It is well known that a figure presented in left side of visual field can be detected faster than the same figure presented in right side in simple visual target detection experiments. On the other hand, a letter presented in left side of visual field can be detected slower than the same letter presented in right side in simple letter perception experiment. If one can allow to connect the results of visual target detections and simple letter preceptions with the results in the present study, the stimulus used in the present study were perceived as a figure, not as a letter. judging from these points, a mechanism similar to simple target detections might have occur in our experimental situation. This result may be connected to the laterality of the brain.

As for stimulus condition, additive feature condition 'I<X' was the most difficult for the subjects, conjunction condition 'I<I' was next difficult, and feature lack condition '<<<' was the easiest. Since these differences among stimulus type conditions were statistically significant (see the following section), additive feature could facilitate the formation of illusory 'K'. This means that discriminability would be influenced by three kinds of stimulus conditions.

According to Signal Detection Theory, the respective distributions of signal and noise are hypothesized as normal distributions with mean 0 and variance 1.0^2, where discriminabliity (d') correspond to the normalized distance between the two peaks of the distributions, and the variance of the distance between the two peaks is equal to 2.0. From these assumptions one can see that the following equation of χ^2 distribution with n−1 degree of freedom holds;

$$\frac{nS^2}{\sigma^2} = \frac{n\Sigma(d'-\mu d')^2}{2} \qquad (2)$$

In the equation, n stands for the number (n) of data, S^2, sample variance of d', and σ^2, population variance of d'. By using this equation, one can test whether d'

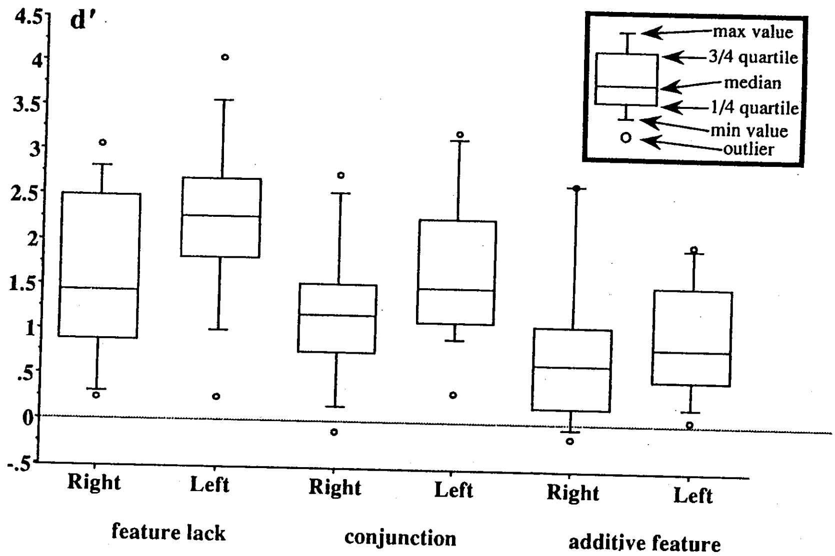

Figure 3. **Box-and-Whisker Plots for Discriminability in each stimulus condition**
Each condition has 15 data. A center line in each box indicates median. Vertical length of box indicates 1/4 and 3/4 quartile. Line length indicates a maximum and minimum value except outliers. Open circle indicates a outlier. The medians of discriminablities d' were constantly smaller when the stimuls was presented in the right side of visual field than when the stimulus was presented in the left side.

distributes normally or not. From the result of this χ^2 test, it could not reject the null hypothesis in the three stimulus conditions. For this reason, I can not claim that d' itself distribute bimodal. This result suggests that even if an estimated illusory conjunction ratio distribute bimodal (Treisman and Paterson, 1984), the bimodal distribution may not be derived from stimulus discriminability, but derived from the different decision criteria on which each subject bases their decision.

Analysis of variance of d'.

A three-factor analysis of variance of discriminabilities was performed. The result showed that all main effects were significant [Stimulus type, $F=17.29$, d.f.$=(2,28)$, $p<0.05$; anisotoropy, $F=11.89$, d.f. $= (1,28)$, $p<0.05$; Subject, $F = 10.03$, d.f. $= (14,28)$, $p<0.05$]. No interactions were significant [Stimulus type × Subject, $F = 1.77$, d.f.$= (28,28)$, $p>0.05$; Anisotoropy × Subject, $F = 1.31$, d.f. $= (14,28)$, $p>0.05$]. A multiple comparison (Duncan's method) showed that significant differences existed at each stimulus type. These results from analysis of variance suggest that stimulus type and anisotoropy of visual field was dominant factors which affect the occurrence of illusory conjunction, and that the additive feature item facilitated to form illusory conjunction.

An interpretation to connect the present results with the previous ones (Treisman and Paterson, 1984) is as follows. Illusory conjunction appears to depend on two kinds of outputs, one from lower level perception, and the other from the higher decision process. Since discriminability itself was not in accordance with bimodal distribution, the dimodal distribution of illusory conjunction ratio seems to be due to higher cognitive decision process. On the other hand, since anisotoropy of visual field affect the discriminability, the discriminablity could be regarded as reflecting the influence from the output of lower visual stage. Judging from the fact that the additive feature item in the present experiment affects discriminability, the result of Triesman and Pateson (1984) can be interpreted as the mixed effects of outputs from two stages (lower perception, and higher decision process). But it is not clear why additive feature item affects discriminability.

In comparison with estimated illusory conjunction ratio, discriminability used in the present study may be advantageous in that our experiment can clarify the relationship between correct ratio and error ratio. Furthermore, the sufficiently brief exposure time (71 ms) can minimize chance effect, so that extraneous variable like saccade was inhibited.

SUMMARY

To investigate why the probability of illusory conjunction is in accordance with bimodal distribution, I tried to explain the bimodal distribution in terms of Signal Detection Theory. The results could not reject the hypothesis that discriminability of stimulus itself distribute normally. I suppose that the bimodal distribution of illusory conjunction depends on subject's cognitive criterion in higher decision process. It is possible to add new factors to constrain the formation of illusory conjunction such as discriminability of stimulus set, subject's decision criterion, and anisotoropy of visual field.

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