J.H. Criswell, H. Solomon, & P. Suppes (Eds.), Mathematical Methods in Small Group Processes. Stanford: Stanford University Press, 1962, pp. 334-361.

The Stanford Institute for Mathematical Studies in the Social Sciences dkjlkjsdf

APPLIED MATHEMATICS AND STATISTICS LABORATORIES
STANFORD UNIVERSITY

Reprint No. 64

Analysis of Social Conformity in Terms of Generalized Conditioning Models

PATRICK SUPPES AND MADELEINE SCHLAG-REY

Reprinted from
Mathematical Methods in Small Group Processes
1962

22

Analysis of Social Conformity in Terms of Generalized Conditioning Models

Patrick Suppes and Madeleine Schlag-Rey,
Stanford University

1. Introduction

The claim is often made that social interaction between several persons can be analyzed within the framework of stimulus response theory. Granted a sufficiently broad definition of stimulus and response, it would be hard to find psychologists who would disagree with this thesis. The difficulty with too broad a statement is that it becomes identical with the general methodological position, commonly labeled *behaviorism*, adhered to by social psychologists and sociologists who vary widely in their theoretical orientation. The stimulus–response psychologist who wishes to replace a general methodological thesis about social behavior with a detailed scientific theory must descend from the plateau of generalities to the lower level of detailed experimentation. This paper is the record of one such descent.

The analysis of social conformity in situations requiring the expression of a perceptual judgment has become a familiar paradigm for testing social psychological theory. The experiment we report in this paper is in this tradition. It builds directly on the earlier work of Sherif [11], Asch [1], Cohen [4], and Suppes and Krasne [13]. The theoretical ideas developed here are related to those set forth in Suppes and Atkinson [12, ch. 12]. Research that is related but less relevant to ours is to be found in Deutsch and Gerard [5], Flament [8], [9], and Di Vesta [6].

It is pertinent to review briefly the main ideas leading up to the present study. The great merit of Sherif was to consider the processes of social influence on a scale of behavior more elementary than that of attitudes or opinions. In introducing the study of simple perceptive judgments, he made the processes of social influence accessible to experimentation. Persuaded that the effects of social interaction on perceptual judgment would be

This research was supported by the Rockefeller Foundation and by the Group Psychology Branch of the Office of Naval Research under Contract NR 171-064 with Stanford University.

Reprinted from MATHEMATICAL METHODS IN SMALL GROUP PROCESSES, edited by John H. Criswell, Herbert [illegible], and Patrick Suppes, Published by Stanford University Press. © 1962 by the Board of Trustees of the Leland Stanford Junior University.

greatest when the object to be judged has little structure, Sherif utilized the ambiguous autokinetic effect. This effect consists of the illusion of movement of a fixed point of light surrounded by total darkness.

Asch's studies, on the other hand, have demonstrated that social pressure is equally capable of affecting perceptual judgment when it is applied to a situation whose perceptual elements are perfectly structured and non-ambiguous. It will be recalled that Asch's studies consisted of asking subjects to judge the relative length of lines after judgments of the same kind had been made by seven other subjects who were in reality accomplices of the experimenter. He found that the true subjects, that is, the last ones to make a judgment, showed a marked tendency to conform to the judgment of the majority, even when it did not agree with the true perceptual situation. However, not all subjects conformed to the judgment of the majority; he observed rather wide individual differences in this respect.

The temporal or dynamic aspects of the process of social influence have been examined by Asch [2] and Cohen [4]. Asch found little systematic tendency—probably for two reasons. In the first place his experiment consisted only of 18 trials; secondly, there was considerable variation in the perceptual situation from trial to trial. Cohen made all his trials identical and increased the number to 36. He analyzed his experiment in terms of a model consisting of a Markov chain with four states. Two of the states are transient and two are absorbing. There is a transient and absorbing state of nonconformity and a transient and absorbing state of conformity. The most obvious prediction of this model is that ultimately all subjects will be making either completely conforming responses or responses which are completely correct perceptually. Unfortunately, the number of trials selected by Cohen was not sufficient to obtain this behavior, and it is perhaps an open question whether or not this fundamental property of his model can actually be verified in an experimental situation of the Asch-type.

As far as we know, the first experiment having an adequate number of trials in the study of social conformity is that of Suppes and Krasne [13]; they ran each subject for 250 trials. However, the experimental conditions they used do not permit a direct comparison with the results of Asch and Cohen. The experiment of Suppes and Krasne, like the original Asch experiment, is concerned with perceptual judgment of parallel lines of unequal length, some vertical, some horizontal. The subject is asked to indicate the longer of two lines. As for certain subjects in the original experiment of Sherif, the social pressure is exerted *after* each individual has given his response. This pressure is exercised by the experimenter, who announces the correct judgment at the end of each trial. As in the case of the response of the majority in the Asch experiment, the result announced by the experimenter is in reality erroneous on certain trials. Operating within the framework of stimulus-sampling theory, Suppes and Krasne postulate two kinds of reinforcement on each trial. One kind is the social rein-

forcement provided directly by the experimenter at the end of each trial. The other is the perceptual reinforcement, not directly observable, which reinforces the response that the subject perceives as correct. The basis of this second reinforcement is secondary reinforcement from habitual perceptual discrimination made by subjects outside the experimental situation and prior to the experiment.

Suppes and Krasne use a one-element stimulus-sampling model familiar from the literature [3], [7], [12]. To handle the two kinds of reinforcement defined above, they postulate that on each trial one of three mutually exclusive and exhaustive conditions obtains: (1) The social reinforcement is effective; (2) the perceptual reinforcement is effective; and (3) neither reinforcement is effective. The probabilities of the social reinforcement or the perceptual reinforcement being effective are two parameters estimated from the response data.

The results of the experiment of Suppes and Krasne demonstrate that the presence of the majority is not necessary in order to influence individual responses, even when the perceptual judgment is easy. Because the social pressure exerted by the experimenter is exerted after the subject makes his response and because he is not a peer of the subjects, a direct comparison with the results of Asch and Cohen is not possible. In a certain sense, their experiment is related to the work of Janis, Hovland, and Kelley [10], who have studied the influence of "experts" in the transmission of information. In the experiment of Suppes and Krasne the experimenter plays the role of such an expert. The estimation of the parameters of conditioning—θ_I for the perceptual reinforcement and θ_G for the social reinforcement—confirm that the greater the perceptual ambiguity of the situation the greater the effectiveness of social influence. They observe that the ratio θ_I/θ_G is always smaller when the perceptual discrimination is more difficult. An advantage of the theoretical approach of Suppes and Krasne is that they assimilate the effects of social influence into a general theory of behavior. On the other hand, the quantitative agreement between their empirical results and theoretical predictions is not as exact as one would like. The discrepancies that exist in their study have partly inspired the present research. As will be discussed shortly, we introduce in this paper a wider class of models in order to attempt to account for detailed sequential properties of the data. In all likelihood, these models would also provide a better account of the data of Suppes and Krasne.

1.1 Aim of Our Research. Several questions do not seem to be adequately answered by the studies we have reviewed. The two principal questions we have considered are the following.

First, how and to what extent are the responses of an individual faced with making a perceptual judgment influenced by the knowledge of responses given by another individual, when

(a) the discrimination is easy;

(b) the discrimination is objectively impossible;

(c) the social information is communicated *before* the subject responds;
(d) the social information is communicated *after* the subject responds?

Secondly, is the relation between the ambiguity of the perceptual stimuli and the effect of social information the same according to whether this information is communicated before or after the response of the subject? To permit an exact study of the simple knowledge of responses given by another individual we have attempted to minimize the social factors utilized by Asch, Cohen, and Suppes and Krasne. Our experiment was conducted with pairs of subjects who were each other's peers. We have utilized neither the effect of a majority nor the prestige of an expert. Our objective has been to develop models to analyze such simple dyadic situations in terms of the general concepts of stimulus sampling and conditioning.

2. Method

In order to realize the objectives of this study, we have used an experimental situation in which the subjects are given a long sequence of trials demanding perceptual judgments. Each subject received 320 trials in approximately 43 minutes. The duration from the beginning of one trial to the next was eight seconds. The subjects were asked to judge and respond accordingly as to which of two lights illuminated at the same instant extinguished first.

In one experimental condition the interval of time separating the extinction of the two lights was sufficiently great for the probability of response to be .933 in the absence of social influence. This condition is analogous to that of Asch.

In the other experimental condition there was no actual interval of time between the extinction of the two lights, which makes an objective judgment as to which light extinguished first impossible. This condition is analogous to that of Sherif.

Two subjects participated together in a given experimental session. The experiment was presented to them as a test of perception. The instructions which they received were designed to convince them that their simultaneous participation was determined by budgetary rather than scientific considerations and that the information which they received from each other was only given in order to indicate to each when he ought to respond.

The subjects were isolated from one another but both saw the same stimuli; that is, both saw the same pair of lights.

On each trial each subject was told that his response was communicated to the other by a small light on the apparatus of his neighbor. The information actually received by the other was in reality controlled by the experimenter. The assertion that each subject was receiving information as to the response of his neighbor in order to permit proper functioning of the apparatus was challenged by no subject.

As stated, the subjects always responded in the same order. Subject A, who responded first and received after his own response information con-

cerning the response of his neighbor, was in an experimental condition corresponding to that of Sherif and of Suppes and Krasne. The other subject, B, replied after seeing on his apparatus which response subject A made. The experimental condition for the B subjects corresponded to the experimental condition of Asch.

The combination of the two scales of difficulty of judgment ($\delta = .9$ and $\delta = .5$) and the two conditions for receiving information before or after responding determined four experimental conditions: A.9, B.9, A.5, B.5.

2.1 Choice of Subjects. The population from which voluntary subjects were recruited consisted of classes of rhetoric from five secondary schools, public and private, in Liège, Belgium. All subjects were male and between the ages of 17 and 19. All were in the last year of the secondary school. One hundred and two subjects participated in the main body of the experiment and 15 other subjects took part in the preliminary psychophysical studies. The experimental results for 76 subjects of the 102, with 19 subjects in each of the four experimental groups, are reported here. The elimination of 26 subjects was due solely to malfunction of the equipment. Each subject in the experimental group was matched with one in the three other experimental groups in order to receive exactly the same sequence of perceptual and social stimuli. This meant that when a malfunction occurred for one subject at least another pair of subjects had to be run to replace him in the grouping.

2.2 Perceptual Stimulus. We have preferred to use the judgment of the order of extinction of two lights to that of the comparison of lines projected on a screen (Asch, Cohen, and Suppes and Krasne) for several reasons. The stimuli are extremely simple and are able to differ on a trial from one another only on a single variable, the order of their extinction. This avoids the kind of interference possible from the diversity of orientation in space of horizontal and vertical lines as well as problems associated with the large visual field of lines projected on a screen. Secondly, the degree of ambiguity of the stimulation is easily controlled in a continuous manner by regulating the interval of extinction of the two lights. When the ambiguity is minimal, the situation is analogous to that of Asch. When the ambiguity is complete, that is, when the lights extinguish at the same time, the situation resembles the perceptual phenomena used by Sherif. An important aspect of the perceptual stimulus used is that subjects seem to be able to retain the impression that an objective discrimination is always possible. A typical comment of a subject in the situation when there was no objective difference in the extinction time of the two lights was the following: "C'était quasiment impossible à juger, sauf pour quelques essais où la différence était claire." The principal difference between this situation and that of Sherif is in the type of judgment demanded of subjects.

We preferred to consider the problem of discrimination at the moment of extinction of the lights rather than at the onset of the signal because the simultaneous illumination of the lights signalled the beginning of each

trial. To avoid any possible side effects from one light being illuminated first, the simultaneous illumination of both lights at the same instant was carefully controlled. The order of extinction of the lights was programmed in advance. Each light had the same probability of extinguishing first: $P(S_1) = P(S_2) = .5$ where S_1 is the event occurring on a trial when the light designated "1" extinguishes first and S_2 is defined in a similar manner. The designation S_1 was applied to the light located on the left for half the subjects in each experimental group and to the light located on the right for the other half. For half of those sessions in which the stimulus S_1 was on the left the position of subject A was fixed as left, and similarly for half of the sessions when S_1 was on the right. The same 19 programs were used for all four experimental groups.

In the condition $\delta = .5$, the extinction of the lights was simultaneous and the designation of the stimuli as S_1 and S_2 was purely conventional. The other experimental condition, in which the psychophysical judgment without social influence would be correct approximately .9 of the time, was determined in the following manner. An approximation of δ between .90 and .95 was obtained with four subjects. An interval of .06 sec seemed a good approximation. A psychophysical study was then run with this time interval with 15 subjects for a total of 4,170 trials. The mean estimate for the group was .933; that is, the perceptually correct judgment was made on the average with that probability.

2.3 Social Stimulus. As already indicated, subjects were selected from a population relatively homogeneous as to sex, age, and education. We also tried to avoid effects from the existence of close personal relations between the members of a subject pair. Three kinds of pairs occurred in each experimental group: pairs with members from different schools, pairs with members from the same school but from different classes, and pairs with members from the same class. The number of pairs in each of these three categories (respectively 10, 18, 10) was exactly the same in the two conditions $\delta = .9$ and $\delta = .5$. This was the sole restriction on placing subjects randomly in one of the four experimental conditions. To minimize extensive discussion of the experiment by the subjects, all experimental sessions were completed in three weeks.

The response information that subjects were told they were communicating to each other was transmitted by small lights on the tables of their apparatus. This manner of communication reduced to a minimum possible variations in the manner in which they informed each other of their perceptual judgments. However, two sources of information could not be eliminated with our apparatus. First, the duration of illumination of the light indicating the response made by the other subject was determined solely by the duration of the time the other subject held down his response key. Second, the latency of the information received, whether before or after the subject's own response, depended upon the regularity of his response rhythms and of the other member of his pair.

As already indicated, the programming of the social stimuli was done completely in advance of the experiment and in no way depended upon the actual responses of the subject. Let σ_1 be the event of a subject's being shown that the other member of his pair predicted that the S_1 light extinguished first and let σ_2 be defined similarly. The experimentally controlled conditional probabilities of this information being correct were as follows:

$$P(\sigma_1 \mid S_1) = .2 \qquad \text{and} \qquad P(\sigma_2 \mid S_2) = .6 .$$

Of course, when $\delta = .5$, the designation of S_1 and S_2 events was made on an arbitrary random basis.

2.4 Experimental Equipment. The two subjects forming a pair were placed in a small nearly cubical room (2.5 m wide, 3 m long, and 2.5 m high). The walls of this room were of compressed wood of different density on each panel in order to avoid resonance. When the door was closed, the room was relatively insulated. An electric ventilator functioned continually in order to renew the air in the room; it also had the effect of creating a background of moderate but constant noise. A diagram of the room and the positions of the subjects are shown in figure 1.

The two subjects were seated and instructions were read while they were in position. They were not able to see each other because of a panel of 1.25 m which ran from the floor to the ceiling of the room. In front of

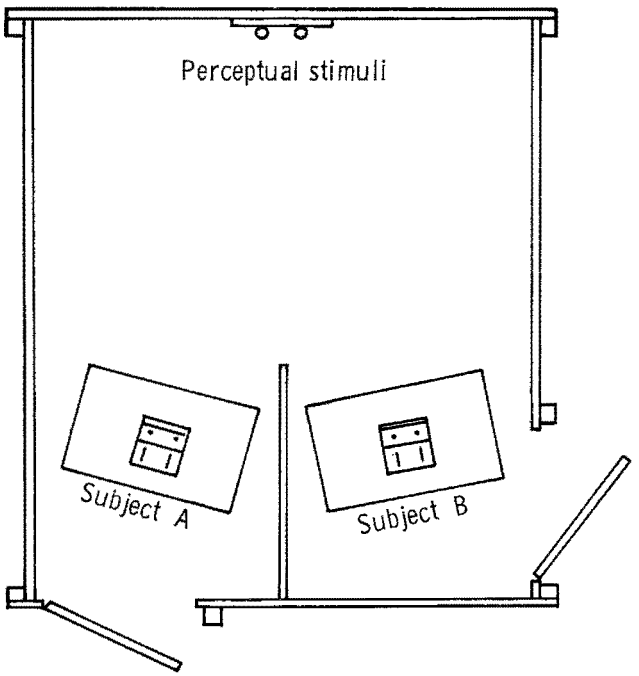

FIG. 1. Plan of the experimental room.

each subject was a table on which there was a small metallic apparatus painted gray-blue. The general shape of the apparatus resembled a portable typewriter. On the oblique plane of the apparatus were the two keys, each 7 cm in length and 1.6 cm in width, which subjects pressed to indicate their responses. The keys were painted black. They were separated from one another by a distance of 14 cm. Just beyond the keys was a small vertical panel on which there was a small neon light exactly above each key. These lights were used to inform the subject of the responses given by his neighbor. An electric light of 25 w, activated by a reduced current, was situated 1.4 m above each apparatus and served to illuminate the apparatus itself. The remainder of the room, except for the stimulus lights, was in darkness.

Two stimulus lights at the same horizontal level were on the wall of the room facing the subjects. They were two neon lights 3 cm in diameter separated from each other by 21 cm and 1.25 m from the floor, which placed them slightly below the level of the eyes of the subjects. In order to soften the image of these lights, they were covered with paper. The mean distance between the subjects and the stimulus lights was approximately 2.2 m. Because there were two subjects it was impossible to place each so that he was exactly the same distance from both lights. However, the design of the equipment as shown in figure 1 was such that there was no more than 6 cm difference in the total length of 2.2 m in the distance of each light to any subject.

The mechanical and electrical equipment containing the program of reinforcements and the record of responses was housed outside the experimental room itself.

2.5 Instructions to Subjects. The following instructions were read in French to all subjects.

Cette expérience est en réalité individuelle. Chacun de vous doit accomplir sa tâche indépendamment de l'autre et ne pas communiquer avec lui. Si l'expérience se déroule pour deux volontaires en même temps, c'est parce que le fonctionnement de l'appareil est très coûteux; en le faisant marcher pour deux personnes à la fois, nous réalisons une grande économie.

L'expérience consiste, pour chacun de vous, en une série d'épreuves successives. Au début de chaque épreuve, vous voyez les deux lampes de ce panneau central s'allumer en même temps. Ensuite, elles s'éteignent mais, chaque fois, l'une d'elles s'éteint avant l'autre. Votre tâche consiste à dire laquelle s'est éteinte la première. Pour le dire, il faut vous servir d'une des deux touches de la boîte placée devant vous: vous appuyez sur la touche gauche si c'est la lampe gauche qui s'éteint la première, sur la touche droite si c'est la lampe droite qui s'éteint la première. N'appuyez pas trop fort pour ne pas caler les touches, mais appuyez suffisamment longtemps pour que votre réponse soit bien indiquée.

(At this point the experimenter shows how to press the buttons and the subject practices pressing them.)

Pour ne pas embrouiller l'enregistrement de vos réponses, il faut que vous évitiez de répondre en même temps. Les deux petites lampes qui sont placées sur votre cadran vous permettent de savoir quand votre voisin est en train de répondre; en effet, les touches de votre voisin sont reliées à ces lampes, et l'une d'elles s'allume chaque fois que votre voisin répond. Pour ne pas embrouiller l'enregistrement, il importe aussi que vous répondiez toujours dans le même ordre. Vous qui êtes assis à gauche, vous répondrez toujours le premier. Aussi, dès que vous voyez s'éteindre une des lampes du panneau central, appuyez sur la touche correspondante, puis relâchez-la. Vous qui êtes assis à droite, dès que vous voyez sur votre écran que votre voisin a répondu, indiquez immédiatement votre propre réponse en appuyant sur la touche correspondant à la lampe que vous avez vu s'éteindre la première, ensuite relâchez-la.

Ne vous découragez pas s'il vous paraît parfois impossible de distinguer laquelle des deux lampes s'éteint la première. Certaines perceptions peuvent être correctement effectuées sans que l'on en ait conscience. C'est pourquoi vous devez donner une réponse de toute façon à chaque épreuve, même si vous n'êtes pas sûr du tout qu'elle est bonne.

Pour éviter de fatiguer votre vue, ne fixez pas tout le temps les lampes du panneau central.

Enfin, si quelque chose ne fonctionne pas bien, par exemple si les petites lampes au-dessus des touches ne s'allument pas, cessez de répondre.

3. Results

We have organized the presentation of results in the following manner. The mean learning curve and some general statistical results that do not depend on the consideration of a particular model are given first. The results of applying the one-element θ model are next indicated, and the usual difficulties of applying this model to the fine structure of the data are commented upon. We then turn to the class of models central to this paper, the generalized conditioning models of both the positional and relational sort. After defining these models, we proceed to apply them *seriatim* to each of the four experimental groups.

3.1 Mean Learning Curves. The proportions of A_1 and A_2 responses given the perceptual stimulus event S_1 or S_2 are plotted in figure 2. (The A_1 response is the prediction that stimulus event S_1 occurred.) The mean conditional proportions $P(A_2 \mid S_1)$ and $P(A_1 \mid S_2)$ are plotted in figure 2 in blocks of 40 trials. Note that these are the probabilities of incorrect responses, i.e., the probabilities of making an error in perceptual judgment. For the $\delta = .5$ groups this designation is conventional. Because $P(\sigma_2 \mid S_1) - P(\sigma_1 \mid S_2) = .4$, the spread between $P(A_2 \mid S_1)$ and $P(A_1 \mid S_2)$ is directly indicative of the mean conformity effect for each experimental group. It is quite apparent from figure 2 that this effect is most pronounced for Group B.5, the group which receives the social stimulus before making their own responses and for which an objective perceptual discrimination is impossible.

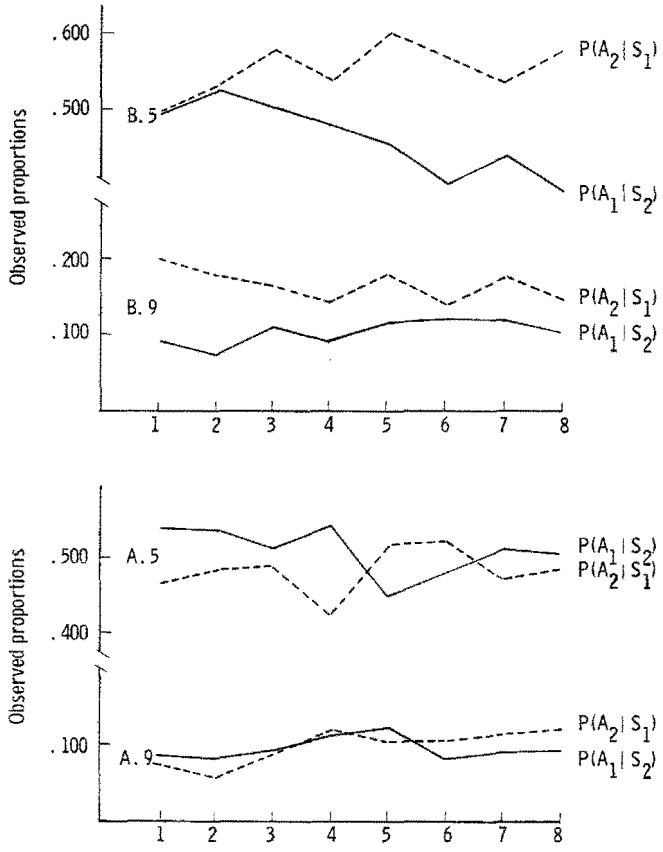

FIG. 2. Conditional proportions of A_1 and A_2 responses for all four experimental groups in blocks of 40 trials.

By comparing B.5 with A.5, and B.9 with A.9, it is also apparent from figure 2 that, independent of the difficulty of discrimination, the conformity effect is greater for the B than for the A subjects. Put another way, it is clear from figure 2 that the temporal position of the social stimulus in relation to the subjects' responses is a critical variable.

3.2 Response Dependencies. Before analyzing sequential dependencies in some detail with different models, we report at this point a rather striking difference in the $\delta = .5$ and the $\delta = .9$ groups in simple response dependency. Using the standard χ^2 test for zero-order vs. first-order Markov process in the sequence of response random variables (see [12], ch. 2), we obtained the following results. For the two $\delta = .5$ groups the zero-order vs. first-order results are highly significant. For A.5 in the test of first-order vs. second-order dependency, $\chi^2 = 9.88$, which with $2(2-1)^2 = 2$ df approaches significance at the .01 level. For B.5, we even approach significance at the .01 level in testing second-order vs. third-order ($\chi^2 = 13.41$, df $= 4(2-1)^2 = 4$).

TABLE 1

ABSOLUTE AND RELATIVE FREQUENCIES OF A_1 RESPONSES IN THE LAST 160 TRIALS FOR EACH SUBJECT AND FOR FOUR SUBSEQUENCES, GROUPS B.9 AND B.5

Subjects	$S_1\sigma_1$				$S_1\sigma_2$				$S_2\sigma_1$				$S_2\sigma_2$			
	.9		.5		.9		.5		.9		.5		.9		.5	
1	11	1.000	4	.364	62	1.000	15	.203	-	.000	7	.241	-	.000	7	.152
2	14	1.000	12	.667	53	.855	21	.284	4	.108	15	.577	5	.106	11	.262
3	9	.643	6	.462	52	.788	13	.200	13	.371	10	.385	18	.400	6	.107
4	14	.824	6	.333	51	.750	10	.154	13	.448	11	.306	4	.087	9	.220
5	8	.444	5	.455	26	.400	32	.500	9	.250	22	.611	5	.122	17	.347
6	14	1.000	4	.308	61	1.000	60	.800	-	.000	12	.462	-	.000	40	.870
7	13	.813	10	.714	57	.750	33	.508	4	.160	27	.730	10	.233	24	.545
8	9	.819	8	.571	45	.692	16	.246	14	.424	22	.647	18	.353	14	.298
9	12	1.000	7	.700	55	.753	32	.516	10	.345	26	.722	-	.000	21	.404
10	13	.867	9	.600	50	.862	23	.390	6	.143	22	.489	2	.044	15	.366
11	21	1.000	3	.130	60	1.000	28	.483	-	.000	5	.185	1	.019	12	.231
12	13	1.000	7	.538	48	.960	27	.587	1	.026	29	.674	-	.000	23	.397
13	11	1.000	7	.583	66	.930	31	.477	-	.000	19	.633	1	.018	29	.547
14	19	1.000	10	.476	59	.908	15	.221	1	.032	18	.621	-	.000	7	.167
15	11	.611	6	.375	48	.787	46	.767	4	.167	4	.160	4	.070	40	.678
16	24	.857	13	.591	57	.950	43	.652	-	.000	13	.464	1	.023	18	.322
17	10	1.000	2	.250	47	.758	15	.231	15	.455	9	.281	4	.073	14	.255
18	11	.786	13	.929	72	.900	33	.413	1	.034	23	.793	-	.000	13	.351
19	18	.947	20	1.000	54	.885	4	.066	-	.000	26	.929	1	.019	7	.137
$\bar{X}$		.874		.528		.838		.405		.156		.522		.082		.350
S^2		.0249		.0455		.0196		.0415		.0280		.0447		.0135		.0362

On the other hand, the results of the test of zero-order vs. first-order are not significant for either Group A.9 or B.9. For A.9, $\chi^2 = .217$, df $= 1$, $P > .50$; for B.9, $\chi^2 = .096$, df $= 1$, $P > .70$. However, if we look at the sequence of correct or incorrect responses (correct with respect to the perceptual stimulus), rather than at the sequence of A_1 or A_2 responses, dependencies are evident. The test of zero-order vs. first-order is highly significant for both groups. For A.9, $\chi^2 = 63.05$, df $= 1$, $P < .001$; for B.9, $\chi^2 = 111.50$, df $= 1$, $P < .001$. The consistency of these significance levels with the results described later for the models tested on these two groups will be evident.

3.3 Response Variance. Because, as indicated by figure 2, the effects of conformity were greater for the two B groups, we have tabulated the response variances for each subsequence $S_i\sigma_j$ in the last 160 trials. Restriction to a given subsequence $S_i\sigma_j$ entails uniformity of stimulation for the subject for that subsequence.

Another reason for selecting these subsequences is that the one-element θ model may be easily applied separately to the four subsequences. If we apply it in the form used by Suppes and Krasne [13] as described above, the two parameters of perceptual and social reinforcement, θ_I and θ_G, must be estimated from the data and thus there remain no degrees of freedom in the 2×2 response transition matrix. However, these estimates can be used to predict the variances shown in table 1. The results are given in table 2. Evidently, as shown in the third row for each group, the predicted variances are always too small. This result is of some interest because

TABLE 2

PREDICTED AND OBSERVED VARIANCES OF RESPONSES IN THE SUBSEQUENCES $S_i\sigma_j$, LAST 160 TRIALS, GROUPS B.9 AND B.5

Quantity	Subsequence			
	$S_1\sigma_1$	$S_1\sigma_2$	$S_2\sigma_1$	$S_2\sigma_2$
B.9				
$\theta_I + \theta_G$	.793	.831	.872	.825
Predicted Variance	.0113	.0030	.0057	.0021
Observed Variance	.0249	.0196	.0280	.0135
Obs. Var./Pred. Var.	2.20	6.53	4.91	6.43
Mean No. of Trials	15.47	64.47	30.89	49.10
B.5				
$\theta_I + \theta_G$	.800	.839	.858	.866
Predicted Variance	.0241	.0051	.0104	.0062
Observed Variance	.0455	.0415	.0447	.0362
Obs. Var./Pred. Var.	1.89	8.14	4.30	5.84
Mean No. of Trials	15.05	65.11	31.68	48.16

for most of the cases reported in [12], the variance predicted by the one-element model is greater than the observed variance. We are not prepared to offer an explanation of this reversal of the usual ratio.

3.4 Definition of Generalized Conditioning Models. We now turn to the models of most direct concern in this article. These models also assume only one stimulus element but they generalize the conditioning assumptions in several directions. Their *raison d'être* is in fact the detailed study of which past events are most effective in predicting responses. The *positional* models, as we shall call them, were first introduced by Suppes and Atkinson [12], the *relational* models were introduced by us in an earlier paper [14]. Roughly speaking, in the positional models the conditioning parameters are defined in terms of positional variables like an S_1 stimulus or an S_1A_2 stimulus-response pair. (Admittedly this use of "positional" is still abstract, for the subscript 1 or 2 refers to the left lights or keys for half the subjects and right for the other half.) In the relational models, on the other hand, the conditioning parameters are defined in terms of relations between pairs or triples of perceptual or social stimuli and responses; for instance, a single parameter for the pairs $S_1\sigma_1$ and $S_2\sigma_2$, and a single parameter for the pairs $S_1\sigma_2$ and $S_2\sigma_1$.

Because of the relative complexity of the experimental situation, the notation for the various generalized conditioning models becomes somewhat cumbersome. The reader should keep in mind the central idea that in every case conditioning parameters of a certain sort are being used. We shall explicitly state the intuitive idea behind each model. We define at this point only the eight models tested on Group B.9.

The first positional model has four parameters defined as follows:

$$c(i', j') = P(A_{1,n+1} \mid \sigma_{j',n+1}S_{i',n+1}) . \tag{1}$$

Since i' and j' each take on the value 1 or 2, we have the four parameters $c(1, 1)$, $c(1, 2)$, $c(2, 1)$, and $c(2, 2)$. If this model were to fit perfectly, it would mean that responses would be conditioned completely, even though probabilistically, to the perceptual and social stimuli on the same trial and no knowledge of earlier events such as the nature of the perceptual or social stimulus on the preceding trial (trial n) would improve prediction of response probabilities.

The other model with four parameters is a relational one. To define the parameters it is desirable to use the familiar Kronecker delta symbol:

$$\delta_{ij} = \begin{cases} 1 & \text{if } i = j , \\ 0 & \text{otherwise} . \end{cases}$$

We then define

$$c(\delta_{ik}, \delta_{i'j'}) = \delta(A_{i',n+1} \mid \sigma_{j',n+1}S_{i',n+1}A_{k,n}S_{i,n}) . \tag{2}$$

The most interesting thing about the parameters defined by (2) is that they take into account the response on trial n and also the perceptual stimulus

on that trial, as well as the perceptual and social stimuli on trial $n+1$, and yet there are only four parameters. It is pertinent to consider the difference between these four parameters and the four of model (1). The parameters of the second model depend on the relation between the perceptual and social stimuli on trial $n+1$, that is, the $\delta_{i'j'}$, and the relation between the perceptual stimulus and response on trial n, that is, δ_{ik}. Should this model fit perfectly it would mean that these two relationships fully determined (in a probabilistic fashion) the conditioning of responses.

It should be noticed in the tables given below that although both models (1) and (2) depend on exactly four parameters (namely, the conditional probabilities indicated), eight different predicted values of the response probability for A_1 occur for model (2) because the parameters are defined for A_i $(i = 1, 2)$, whereas the parameters for model (1) are defined in terms of A_1. In the tables to follow observed data and predictions are all given for A_1.

The third model is a positional one depending on eight parameters, the perceptual stimuli on trials n and $n+1$ and the response on trial n. If the social stimuli are important, this model should not predict responses very well.

$$c(i, k, i') = P(A_{1,n+1} \mid S_{i',n+1}A_{k,n}S_{i,n}) . \tag{3}$$

For the fourth model, a relational one also with eight parameters, we need to generalize the delta notation to possible agreement or disagreement among the perceptual and social stimuli and response on a trial.

$$\gamma_{ijk} = \begin{cases} 1 & \text{if } i = j = k , \\ 2 & \text{if } i = j \text{ and } i \neq k , \\ 3 & \text{if } i = k \text{ and } i \neq j , \\ 4 & \text{if } j = k \text{ and } i \neq j . \end{cases}$$

We then define

$$c(\gamma_{ijk}, \delta_{i'j'}) = P(A_{i',n+1} \mid \sigma_{j',n+1}S_{i',n+1}A_{k,n}\sigma_{j,n}S_{i,n}) . \tag{4}$$

It is clear from this definition that model (4) is defined in terms of the relation between the two stimuli on trial $n+1$ and the relation between the two stimuli and response on trial n.

Model (5) is a mixed positional and relational model having eight parameters. It is positional with respect to trial $n+1$ and relational with respect to trial n.

$$c(\delta_{ik}, i', j') = P(A_{1,n+1} \mid \sigma_{j',n+1}S_{i',n+1}A_{k,n}S_{i,n}) . \tag{5}$$

Each of the three remaining models tested on Group B.9 involves sixteen parameters. Model (6) is purely positional, and the other two are mixed. We comment on their significance later.

$$c(i, k, i', j') = P(A_{1,n+1} \mid \sigma_{j',n+1}S_{i',n+1}A_{k,n}S_{i,n}) , \tag{6}$$

TABLE 3

GROUP B.9—CONDITIONING PARAMETERS, TRANSITION PROBABILITIES, GOODNESS OF FIT OF EIGHT GENERALIZED CONDITIONING MODELS

n	$n+1$	A_1 obs.	(1) $c(i', j')$	(2) $c(\delta_{ik}, \delta_{i'j'})$	(3) $c(i, k, i')$	(4) $c(\gamma_{ijk}, \delta_{i'j'})$	(5) $c(\delta_{ik}, i', j')$	(6) $c(i, k, i', j')$	(7) $c(\delta_{ik}, j, i', j')$	(8) $c(\gamma_{ijk}, i', j')$	N
$S_1\sigma_1A_1$	$S_1\sigma_1$	.843	.874	.931	.867	.934	.897	.902	.880	.879	51
	$S_1\sigma_2$	.821	.826	.855	.867	.844	.842	.859	.824	.825	218
	$S_2\sigma_1$	.094	.140	.145	.078	.156	.118	.121	.101	.115	96
	$S_2\sigma_2$	.032	.075	.069	.078	.066	.058	.052	.065	.047	157
$S_1\sigma_1A_2$	$S_1\sigma_1$	.667	.874	.793	.717	.765	.742	.738	.742	.667	15
	$S_1\sigma_2$	.741	.826	.718	.717	.722	.727	.710	.757	.739	27
	$S_2\sigma_1$	.353	.140	.282	.227	.278	.303	.290	.368	.316	17
	$S_2\sigma_2$	.118	.075	.207	.227	.235	.188	.184	.159	.190	17
$S_1\sigma_2A_1$	$S_1\sigma_1$	.918	.874	.931	.867	.929	.897	.902	.905	.911	184
	$S_1\sigma_2$	.869	.826	.855	.867	.863	.842	.859	.849	.855	809
	$S_2\sigma_1$	.128	.140	.145	.078	.137	.118	.121	.125	.120	391
	$S_2\sigma_2$	.057	.075	.069	.078	.071	.058	.052	.055	.065	648
$S_1\sigma_2A_2$	$S_1\sigma_1$	.761	.874	.793	.717	.803	.742	.738	.741	.774	46
	$S_1\sigma_2$	.705	.826	.718	.717	.717	.727	.710	.714	.723	166
	$S_2\sigma_1$	.277	.140	.282	.227	.283	.303	.290	.279	.298	83
	$S_2\sigma_2$	.192	.075	.207	.227	.197	.188	.184	.199	.187	130
$S_2\sigma_1A_1$	$S_1\sigma_1$	.812	.874	.793	.752	.803	.742	.750	.742	.774	16
	$S_1\sigma_2$	.763	.826	.718	.752	.717	.727	.752	.757	.723	76
	$S_2\sigma_1$	.381	.140	.282	.237	.283	.303	.333	.368	.298	21
	$S_2\sigma_2$	.173	.075	.207	.237	.197	.188	.194	.159	.187	52
$S_2\sigma_1A_2$	$S_1\sigma_1$	.897	.874	.931	.839	.929	.897	.893	.880	.911	107
	$S_1\sigma_2$	.825	.826	.855	.839	.863	.842	.825	.824	.855	394
	$S_2\sigma_1$	.104	.140	.145	.085	.137	.118	.115	.101	.120	202
	$S_2\sigma_2$	.081	.075	.069	.085	.071	.058	.064	.065	.065	308
$S_2\sigma_2A_1$	$S_1\sigma_1$	.667	.874	.793	.752	.765	.742	.750	.741	.667	12
	$S_1\sigma_2$	.738	.826	.718	.752	.722	.727	.752	.714	.739	61
	$S_2\sigma_1$	.286	.140	.282	.237	.278	.303	.333	.279	.316	21
	$S_2\sigma_2$	.220	.075	.207	.237	.235	.188	.194	.199	.190	41
$S_2\sigma_2A_2$	$S_1\sigma_1$	.890	.874	.931	.839	.934	.897	.893	.905	.879	164
	$S_1\sigma_2$	.826	.826	.855	.839	.844	.842	.825	.849	.825	706
	$S_2\sigma_1$	.121	.140	.145	.085	.156	.118	.115	.125	.115	346
	$S_2\sigma_2$	.052	.075	.069	.085	.066	.058	.064	.055	.047	478
	χ^2		150.38	45.60	62.11	42.73	20.78	18.37	13.66	12.00	
	n		28	28	24	24	24	16	16	16	
	P		$P < .001$	$P > .01$	$P < .001$	$P > .01$	$P > .60$	$P > .30$	$P > .60$	$P > .70$	

$$(7) \qquad c(\delta_{ik}, j, i', j') = P(A_{1,n+1} \mid \sigma_{j',n+1} S_{i',n+1} A_{k,n} \sigma_{j,n} S_{i,n}) ,$$

$$(8) \qquad c(\gamma_{ijk}, i', j') = P(A_{1,n+1} \mid \sigma_{j',n+1} S_{i',n+1} A_{k,n} \sigma_{j,n} S_{i,n}) .$$

We now apply these eight models to the data for Group B.9.

3.5 Generalized Conditioning Models for Group B.9. The conditional observed proportions of A_1 responses and the predictions for the eight models are given in table 3. (The maximum likelihood estimates of the conditioning parameters for each model are easily derived by the methods given in [12, ch. 2].) The conditional proportions are given for the full sequence of events on trial n and $n+1$ preceding the response on trial $n+1$, and they are computed on the entire 320 trials of the experiment. Thus with 19 subjects in each group the tables are based on 6061 observations (these remarks apply as well to the tables given below for the other experimental groups). It would have been desirable to conditionalize the proportions of A_1 responses on trial $n-1$ as well, but this would have yielded a matrix with 256 rows, which would have required an incredibly large number of observations for reliable analysis. The absolute frequencies of each row are shown in the last column of table 3 and it is apparent that some of them, with only 32 rows, are too small for the χ^2 tests we apply. However, collapsing those rows together with theoretical cell frequencies less than 10 does not appreciably affect any of our conclusions. It should also be emphasized that the goodness of fit of the models we consider is relative to the limited sequence of events given in the tables. The order tests reported above tend to support this cut-off point, but undoubtedly somewhat worse results would be obtained if data for still another trial back were included.

The three general questions we may ask for each experimental group are the following: (a) Is there a nontrivial model that accounts for the data (by "nontrivial" we mean a model that has less parameters than the number of degrees of freedom in the data)? (b) What is the minimum number of parameters needed to define such a model? (c) What kind of information is most effective in predicting responses—knowledge of the perceptual stimulus, the social stimulus, relations between these two stimuli, etc.?

The answer to the first question is provided by model (5). As shown at the bottom of table 3, the goodness-of-fit test yields a χ^2 of 20.78 with 24 df, which with $P > .60$ suggests acceptance of the null hypothesis. (For discussion of this χ^2 test, see [12, ch. 2].) Correspondingly, the answer to the second question is also provided by model (5); among the models we tested 8 is the minimum number of parameters needed to define a satisfactory model. However, there is one important methodological reservation to this conclusion (and this applies to later remarks about the other experimental groups as well). For a test based on over 6,000 observations it is unrealistic to hold Type I errors at the conventional significance level of .01 or .05. When this is done there is a strong asymmetry between Type I and Type II errors, for, with a large number of observations, the Type II error

rapidly approaches zero. We have not made the detailed computations for this paper, but it may be shown that if a noncentral χ^2 test is used with model (2) as the null hypothesis, model (1) as the simple alternative and Type I and Type II errors equated, then model (2), with only 4 parameters, yields acceptable results. We shall not pursue this point in further detail, but the extreme sensitivity of χ^2 goodness-of-fit tests with 6,000 observations must be kept in mind.

We now turn to some detailed remarks about the comparison of relational and positional models for Group B.9. We note first that the poor fit of model (1) with parameters $c(i', j')$ eliminates the hypothesis of independence of the previous trial, which is a strikingly different result from that obtained by looking only at the sequence of response random variables. Secondly, of the two four-parameter models, model (2), the relational model, is very much better than model (1), a positional model, as has already been noted in the preceding paragraph. Also, model (3), which has 8 parameters and is a purely positional model, does not fit as well as model (2).

Model (4), a purely relational model with 8 parameters, has a χ^2 value that is not appreciably lower than that of model (2) with 4 parameters. The difference between the two models is that (4) takes account of the social stimulus on trial n (both take account of it on trial $n + 1$). Apparently this is not an important factor in conditioning for this experimental group.

The comparison of positional and relational models among these first four is unequivocally favorable to the relational models, which is consonant with the comparison we have reported in our earlier double-contingent study [14]. On the other hand, model (5), a mixed positional and relational model with 8 parameters, has a decisively smaller χ^2 than any of the four pure models. This model may be most directly compared with model (2). It improves on (2) by considering the actual perceptual and social stimuli on trial $n + 1$, rather than simply their agreement or disagreement.

We have delayed consideration of the third question raised above. We may begin by examining the influence of social information. In the first place we may infer from the poor fit of model (3) with parameters $c(i, k, i')$, which do not depend on the social stimulus, that the social information is important in determining the conditioning of subjects in this group.

On the other hand, there is some evidence from model (2) that social information is not as directly important in conditioning as response perseveration. The evidence is that $c(1, 0) > c(0, 1)$; i.e., the probability $c(1, 0) = .855$ of making a perceptually correct response on trial $n + 1$ when the social stimulus on trial $n + 1$ contradicted the perceptual one, is slightly greater than the probability $c(0, 1) = .793$ of making such a response when a perceptually incorrect response was made on trial n. The evidence of a similar effect in our earlier double-contingent study suggests that past responses play an important mediating role in conditioning. More detailed analysis of this role will depend on a deeper sequential analysis than we have been able to make here.

From the conditioning parameters of model (4) we may infer the perseveration of a similar conformity effect. If we examine pairs of parameters in model (4) defined for identical i, k, i', and j', and varying only on $\sigma_{j,n}$, we find that the probability of a conforming response's following a conforming response is always higher than the probability of its following a nonconforming response. Of course, these 16 inequalities for the pairs are not independent, but are determined by the 8 parameters. What is surprising is that when we ask the same question of the observed proportions in column 1 of table 3, the results are not all significant; 8 of the pairs have the inequality in one direction and the remaining 8 in the other.

Models (6)–(8) of table 3, each with 16 parameters, support a similar conclusion that the effects of the social stimulus are detectable, but are not large. Model (6), which does not take account of the social stimulus on trial n, has the worst fit of the three, but this is only comparatively, for in absolute terms its fit is quite good ($P > .30$). It may also be noted that models (7) and (8) are mixed positional and relational models, whereas model (6) is a pure positional model.

Models (5)–(8) indicate that there is no simple answer, on the basis of our data, to the third general question we posed at the beginning of this discussion of Group B.9. The structure of the information to which subjects are conditioned in making their responses may be described in several ways. Model (5), which uses the relation between perceptual stimulus and response on trial n, and the actual perceptual and social stimuli on trial $n + 1$, gives one reasonably satisfactory answer ($P > .60$). The relatively small net reduction of χ^2 value for model (6) over that for model (5), in spite of the addition of 8 parameters, indicates that the relational aspects on trial n are the essential thing rather than the actual perceptual stimulus and response. Models (7) and (8) show that if we add to the information of model (5) either the actual social stimulus on trial n or its relations to the perceptual stimulus and response, some gain in goodness of fit can be made.

More general comments we reserve until after analysis of the other three experimental groups.

3.6 Generalized Conditioning Models for Group A.9. The conditional observed proportions of A_1 responses and the predictions for the eight models tested for this group are given in table 4. It may be noticed immediately that the table for Group A.9 has 16 rows instead of the 32 in table 3. This is because the social stimulus occurred after rather than before the subject's response on trial $n + 1$, and consequently this event is deleted from the possible events occurring on trial $n + 1$ prior to the subject's response.

The eight models whose conditioning parameters and goodness of fit are tabulated in table 4 are defined in a manner similar to that used for defining the eight models tested on Group B.9. These definitions need not be repeated if two observations are made. First, i always refers to the perceptual stimulus on trial n and i' to the perceptual stimulus on trial $n + 1$; j refers to the social stimulus on trial n; and k to the response on trial n.

TABLE 4

GROUP A.9—EIGHT GENERALIZED CONDITIONING MODELS

n	$n+1$	A_1 obs.	(1) $c(i')$	(2) $d(\delta_{ik})$	(3) $d(\gamma_{ijk})$	(4) $d(i,k)$	(5) $c(\gamma_{ikt'})$	(6) $c(\gamma_{ijkt'})$	(7) $c(i,k,i')$	(8) $c(\gamma_{ikt'},j)$	N
$S_1\sigma_1A_1$	S_1	.916	.901	.912	.911	.915	.914	.911	.917	.916	275
	S_2	.083	.097	.088	.089	.085	.091	.088	.086	.097	264
	S_1	.806	.901	.810	.818	.798	.784	.802	.780	.785	31
	S_2	.125	.097	.190	.182	.202	.164	.167	.182	.103	24
$S_1\sigma_2A_1$	S_1	.917	.901	.912	.912	.915	.914	.916	.917	.914	1079
	S_2	.087	.097	.088	.088	.085	.091	.092	.086	.088	1132
	S_1	.773	.901	.810	.804	.798	.784	.774	.780	.784	128
	S_2	.193	.097	.190	.196	.202	.164	.162	.182	.186	119
$S_2\sigma_1A_1$	S_1	.907	.901	.810	.804	.822	.836	.838	.853	.897	54
	S_2	.226	.097	.190	.196	.178	.216	.226	.211	.215	62
	S_1	.896	.901	.912	.912	.908	.909	.908	.905	.903	541
	S_2	.084	.097	.088	.088	.192	.086	.084	.088	.084	523
$S_2\sigma_2A_1$	S_1	.823	.901	.810	.818	.822	.836	.833	.853	.814	96
	S_2	.200	.097	.190	.182	.178	.216	.198	.211	.216	80
	S_1	.910	.901	.912	.911	.908	.909	.912	.905	.912	846
	S_2	.090	.097	.088	.089	.092	.086	.089	.088	.086	807
	χ^2		64.29	8.19	7.92	6.90	5.30	4.62	3.82	1.85	
	n		14	14	12	12	12	8	8	8	
	P		$P < .001$	$P > .80$	$P > .70$	$P > .80$	$P > .90$	$P > .70$	$P > .80$	$P > .98$	

Secondly, the parameter $d(\ldots)$ used in models (2), (3) and (4) is defined as follows.

$$d = c\delta_{i'1} + (1 - c)(1 - \delta_{i'1}) .$$

The effect of this definition of d is to make the conditional probabilities in these three models depend on the perceptual stimulus on trial $n + 1$. We mean by this that if an S_1 occurs on trial $n + 1$ in the case, for instance, of model (2) then the conditional probability of an A_1 response is .912. If an S_2 occurs on trial $n + 1$ the conditional probability of an A_1 response is 1 -- .912 = .088.

Concerning the general questions raised at the beginning of the discussion of Group B.9, we may immediately answer the first two by referring to model (2) in table 4. We find that a model requiring only two parameters fits extremely well. What is surprising is that this relational model does not directly use any social information whatsoever, that is, the conditioning parameters of the model do not depend in any direct way on the preceding occurrence of a particular social stimulus σ_1 or σ_2.

From the comparison of model (1) and model (2) we may infer several significant facts. In the first place from the poor fit of model (1) it is clear that knowledge simply of the perceptual stimulus on trial $n + 1$ does not yield adequate predictions of responses on that trial. Secondly, model (1) is probably the simplest positional model with two parameters and model (2) the simplest relational model with two parameters. The relative comparison of fit for the two is completely favorable to the relational model.

Because of the excellent fit of model (2), which does not explicitly include the social stimulus, there is little hope of making a case for the explicit consideration of this stimulus. Model (3), which adds two additional parameters in taking account of the social stimulus on trial n, does have a slightly smaller χ^2 value than does model (2), but because of the increase in the number of parameters the actual significance level is lower, although the significance level of both models is too high to draw anything significant from this fact. In this respect the results for Group A.9 differ from those for Group B.9. As we saw in the above discussion of B.9, the direct inclusion of the social stimulus did improve the prediction of response on trial $n + 1$.

As would be expected from the excellent results shown in table 5 the consideration of additional parameters in models (6)–(8) given in table 4 is even better. The fit of the last of the three, model (8), is almost unbelievably good when one considers that the χ^2 of 1.85 is based on more than 6,000 observations. One can only conclude from results of this kind that the eight parameters of the model take account of *all* information of significance to the subjects in conditioning their responses. The detailed comparison of the conditioning parameters of this model and the observed proportions shown in the first column suggest that one can scarcely expect a model to fit data any better than does this one.

The relatively good fit of model (2) with only two parameters suggests

that the answer to our third general question is that it is sufficient for Group A.9 to know the relation between the perceptual stimulus and response on trial n in order successfully to predict responses on trial $n+1$, given that one adjusts the prediction to the occurrence of perceptual stimulus S_1 or S_2 on trial $n+1$. This conclusion rules out any direct role for the social stimulus shown to the subject after his response on trial n.

Somewhat subtler conclusions can be obtained by moving from consideration of the goodness of fit of the models to the relative order of magnitude of the various conditioning parameters. The necessity for even these effects to be very small may be seen by comparing the observed proportions in A_1 for the pairs in which the only thing varied is the social stimulus on trial n. A very slight variation of response proportions on the members of these pairs is evident. For the two pairs having the largest number of observations, namely, the pair consisting of row 1 and row 5, the difference in observed proportions is .001 and for the other pair consisting of row 2 and row 6 the difference in observed proportions is .004. Clearly for these pairs change in the social information had no significant effect whatsoever.

This same conclusion about the relatively complete ineffectiveness of the social stimulus on trial n determining responses on trial $n+1$ may be seen by examining the four conditioning parameters of model (3). The maximum likelihood estimates of these four parameters involve the entire 6061 observations and not simply the rows with the largest number of observations. The interesting thing to note about the four parameters of model (3) is that if the social stimulus has no effect whatsoever, then the model reduces effectively to the model with two parameters, and this is in fact very close to being the situation. When the social stimulus agrees with the perceptual stimulus and the response, the value of the parameter is .911; when the social stimulus disagrees with these two the value of the parameter is .912, a difference of only .001. When the perceptual stimulus and response disagree, if the social stimulus agrees with the perceptual stimulus, the value of the parameter is .818; when the social stimulus agrees with the response, on the other hand, the value of the parameter is .804, which is a larger difference than in the previous case but still only a matter of .014.

3.7 Generalized Conditioning Models for Group B.5. The conditional observed proportions of A_1 responses and the predictions for four models are given in table 5. The conditional proportions are given for the same sequence of events as for Group B.9 in table 3. However, only four models have been tested because the distinction between perceptual stimulus S_1 and S_2 is wholly arbitrary for group B.5. It will be recalled that experimentally this group corresponds to the condition of Sherif, since an objective perceptual discrimination is impossible.

We may begin by observing that because perceptual stimuli have no significance for this group, we would expect model (5) for B.9 to fit very poorly here although this model did very well on the data for B.9. That this is the case is evident from the data for the goodness of fit results for model (4) in table 5. The value of χ^2 is significant at the .001 level. The

TABLE 5

GROUP B.5—FOUR GENERALIZED CONDITIONING MODELS

n	$n+1$	A_1 obs.	(1) $c(k, j')$	(2) $c(\gamma_{jkj'})$	(3) $c(j, k, j')$	(4) $c(\delta_{ik}, i', j')$	N
$S_1\sigma_1A_1$	$S_1\sigma_1$	.562	.639	.630	.642	.563	32
	$S_1\sigma_2$	.353	.446	.442	.396	.399	119
	$S_2\sigma_1$	.627	.639	.630	.642	.549	67
	$S_2\sigma_2$	.336	.446	.442	.396	.400	113
$S_1\sigma_1A_2$	$S_1\sigma_1$	.517	.508	.519	.487	.577	29
	$S_1\sigma_2$	.490	.371	.364	.366	.425	96
	$S_2\sigma_1$	.389	.508	.519	.487	.576	54
	$S_2\sigma_2$	.391	.371	.364	.366	.393	69
$S_1\sigma_2A_1$	$S_1\sigma_1$	.663	.639	.636	.637	.563	92
	$S_1\sigma_2$	.490	.446	.481	.475	.399	406
	$S_2\sigma_1$	.576	.639	.636	.637	.549	184
	$S_2\sigma_2$	.462	.446	.481	.475	.400	331
$S_1\sigma_2A_2$	$S_1\sigma_1$	.507	.508	.558	.514	.577	136
	$S_1\sigma_2$	.378	.371	.370	.372	.425	596
	$S_2\sigma_1$	.520	.508	.558	.514	.576	296
	$S_2\sigma_2$	.360	.371	.370	.372	.393	417
$S_2\sigma_1A_1$	$S_1\sigma_1$	.709	.639	.630	.642	.577	55
	$S_1\sigma_2$	.431	.446	.442	.396	.425	267
	$S_2\sigma_1$	.641	.639	.630	.642	.576	128
	$S_2\sigma_2$	.408	.446	.442	.396	.393	218
$S_2\sigma_1A_2$	$S_1\sigma_1$	.462	.508	.519	.487	.563	52
	$S_1\sigma_2$	.327	.371	.364	.366	.399	217
	$S_2\sigma_1$	.544	.508	.519	.487	.549	103
	$S_2\sigma_2$	.331	.371	.364	.366	.400	145
$S_2\sigma_2A_1$	$S_1\sigma_1$	.630	.639	.636	.637	.577	73
	$S_1\sigma_2$	.492	.446	.481	.475	.425	303
	$S_2\sigma_1$	.704	.639	.636	.637	.576	142
	$S_2\sigma_2$	.443	.446	.481	.475	.393	210
$S_2\sigma_2A_2$	$S_1\sigma_1$	.527	.508	.558	.514	.563	110
	$S_1\sigma_2$	.364	.371	.370	.372	.399	453
	$S_2\sigma_1$	.502	.508	.558	.514	.549	209
	$S_2\sigma_2$	.389	.371	.370	.372	.400	339
	χ^2		33.77	35.89	27.50	91.05	
	n		28	28	24	24	
	P		$P > .20$	$P > .10$	$P > .20$	$P < .001$	

parameters of model (4) depend on both i and i', that is, on the two perceptual stimuli. The arbitrary assignment of values 1 or 2 to the same stimulus does not have any empirical significance, and this fact is reflected in the bad fit of the model for Group B.5.

Our second observation for this group is contrary to one we just made for group A.9. It is that model (2), a purely relational model, is somewhat inferior to model (1), a purely positional model. Both models have four parameters. The parameters of model (1) depend on the social stimulus on trial $n+1$ and the response on trial n. The parameters of model (2) depend upon the agreement or disagreement among the social stimuli on trial n and $n+1$, and the response on trial n. The slight difference in goodness of fit between models (1) and (2) is not interpreted as of great significance. The fact, however, that the difference is slightly in favor of the positional model is in contrast to the very sharp differential results in favor of the relational model in the case of Group A.9.

It may also be noted that model (3) yields a slight improvement over model (1), and this is indicative of the usefulness for predictive purposes of incorporating into the positional model the actual social stimulus on trial n as well as that on trial $n+1$, which is the additional feature of model (3). In general, model (1) would seem to provide a satisfactory answer to the first two general questions we have been asking of each experimental group, namely, that it is a model with only four parameters which provides an adequate fit to the data of this experimental group.

We turn now to more detailed consideration of the role of social information for this experimental group, with particular emphasis on its relative importance. Prior to any detailed comments we would certainly expect the social stimuli to have a more important influence on responses of subjects for this group than in the two previous cases, because of the impossibility of any real perceptual discrimination for the $\delta = .5$ condition.

First, we may observe from the conditioning parameters of model (1) that the social stimulus on trial $n+1$ is more important to the subject than the response he made on trial n, contrary to the evidence for Groups B.9 and A.9. In particular, we may note that when $k = 2$ and $j' = 1$ then the probability of an A_1 response on trial $n+1$ is .508. In the contrary case, when $k = 1$ and $j' = 2$, that is, when response 1 is made on trial n and social stimulus 2 occurs on trial $n+1$, then the probability of an A_1 response is .446.

The direct importance of the social stimulus on trial $n+1$ immediately preceding the subject's response is also attested to by model (3). Examination of the conditioning parameters of this model shows that when we consider the two extreme cases of $\sigma_{1,n}A_{1,n}\sigma_{2,n+1}$ and $\sigma_{2,n}A_{2,n}\sigma_{1,n+1}$, in the first case the probability of an A_1 response is .396 and in the second case, the probability is .514. This would seem to show the clear dominance of the social stimulus on trial $n+1$ over the preceding response or preceding social stimulus. This same fact is reflected in the relationally defined

parameters of model (2). In the first place, there is small difference between the probability of an A_1 response in model (2) when, on the one hand, the social stimulus on trial $n+1$ and the response on trial n agree with the social stimulus on trial n and when, on the other hand, these first two events disagree with the social stimulus on trial n. In the first case, the probability of an A_1 response is .630 and in the second case, .636. The difference of .006 leaves little room for the effect of the social stimulus on trial n to be evident. The other two parameters also reflect the importance of the social stimulus on trial $n+1$. When the response and social stimulus on trial n are both 1 but the social stimulus is 2 on trial $n+1$, the probability of an A_1 response is then .442. When the two social stimuli are 1 on both trial n and $n+1$ and the response on trial n is 2 the probability of an A_1 response is .519, indicating again that the social stimulus on $n+1$ is more important than the response on trial n.

To summarize, the analysis of conditioning parameters for the three models that fit reasonably well, that is, models (1)–(3), indicates that the order of importance of information is as follows. The most important information is the social stimulus on trial $n+1$; the next most important is the actual response made on trial n; and least important of the three is the social stimulus on trial n. Secondly, the relative goodness of fit of the three models indicates that in this case the positional information is more important than the relational information (in using the phrase "more important" we mean, of course, important for predicting correctly the probability of an A_1 response).

It should be remarked of model (3) that it actually tests only the goodness of our experimental design, for it takes account of all objectively observable events occurring on trials n and $n+1$ prior to a response on trial $n+1$. This observation does not invalidate the importance of this model for the analysis of the relative significance of social information for the subjects, as reflected in its parameters.

3.8 Generalized Conditioning Models for Group A.5. The conditional observed proportions of A_1 responses and the predictions for five models are given in table 6. The conditional proportions are given for the same sequence of events as for Group A.9 in table 4. But as in the case of Group B.5, the first four models tested have not utilized the artificial distinction between perceptual stimuli S_1 and S_2. Model (5), which does utilize this distinction, has been included only for direct comparison with the results for Group A.9.

As in the case of Group A.9 it is clear that the social stimulus' coming *after* the subject's response does not have the importance that it has for the two groups in which it comes prior to that response. This is clearly indicated by comparison of models (1) and (2) in table 6, both of which are positional models. Each has two parameters. Model (1) takes account of the social stimulus on trial n, and model (2) takes account of the response on trial n. Once again, we find the mediating role of the

TABLE 6

GROUP A.5—FIVE GENERALIZED CONDITIONING MODELS

n	$n+1$	A_1 obs.	(1) $c(j)$	(2) $c(k)$	(3) $c(\delta_{jk})$	(4) $c(j,k)$	(5) $c(\gamma_{ijkt'})$	N
$S_1\sigma_1A_1$	S_1	.523	.491	.552	.522	.527	.541	149
	S_2	.470	.491	.552	.522	.527	.515	151
	S_1	.419	.491	.472	.441	.451	.437	124
	S_2	.461	.491	.472	.441	.451	.469	154
$S_1\sigma_2A_1$	S_1	.555	.522	.552	.559	.562	.544	607
	S_2	.559	.522	.552	.559	.562	.550	662
	S_1	.509	.522	.472	.478	.480	.479	625
	S_2	.472	.522	.472	.478	.480	.450	566
$S_2\sigma_1A_1$	S_1	.527	.491	.552	.522	.527	.531	315
	S_2	.556	.491	.552	.522	.527	.563	315
	S_1	.461	.491	.472	.441	.451	.485	280
	S_2	.450	.491	.472	.441	.451	.459	278
$S_2\sigma_2A_1$	S_1	.576	.522	.552	.559	.562	.550	460
	S_2	.563	.522	.552	.559	.562	.521	453
	S_1	.462	.522	.472	.478	.480	.450	478
	S_2	.471	.522	.472	.478	.480	.456	444
	χ^2		46.49	12.65	7.84	7.26	11.45	
	n		14	14	14	12	8	
	P		$P < .001$	$P > .50$	$P > .85$	$P > .80$	$P > .10$	

previous response to be an important and an excellent predictor of the next response. Model (1) is significant at beyond the .001 level, whereas the fit of model (2) is excellent ($P > .50$).

The fit of the positional model (2), however, is improved upon in a still significant manner by the purely relational model (3), which takes account of the agreement or disagreement between the social stimulus and response on trial n. The goodness of fit of model (3) could hardly be better ($P > .85$). In fact, model (4), which takes account of the actual social stimulus and response on trial n, and therefore has four parameters, does not fit any better. The actual value of the χ^2 shows only a very slight difference between models (3) and (4), and the addition of two more parameters to model (4) renders its significance level slightly worse than that of model (3). It may be noted that model (4), like model (3) in table 5, actually tests only the experimental design, for it takes account of all observable events occurring on trials n and $n+1$.

Model (5) has been included because it fits the data of Group A.9 extremely well (it is model (6) in table 4). It is evident that it does not do

nearly as well in the present case, for which the distinction between the perceptual stimuli is wholly artificial ($P > .10$ in comparison to $P > .70$ in the former case).

Model (2) with only two parameters provides an adequate answer to the two general questions raised at the beginning of our discussion of the experimental groups. Concerning the third question regarding the most important information, the remarks that have just been made about the various models outline the situation. Because of the importance of this question, we may describe our conclusions as follows. In the first place, knowledge of the social stimulus by itself does not provide adequate information to predict responses, even though the perceptual stimuli are actually wholly neutral. This is shown by the poor fit of model (1). Secondly, the social stimulus is decidedly less important in predicting responses than the actual preceding response. This is shown by the good fit of model (2). Thirdly, the social stimulus does have some effect when considered in relation with the actual response. This is shown by the excellent fit of model (3) and a consideration of the actual parameter values of this model. We note that when the past response and social stimulus both agree (and σ_1 occurred) the probability of an A_1 response is .522 whereas when they disagreed and σ_2 occurred the probability of an A_1 response is .559. The paradoxical thing, of course, about this result is that the probability of an A_1 response goes up when the preceding response was an A_1 and the preceding social stimulus was different, namely, σ_2. A difference of .037 in these two parameter values provides some evidence for a kind of negative recency effect for this experimental group. It would be interesting to know if this kind of negative recency effect could be shown to increase with consideration of longer sequences of past information. We have not analyzed our own data from this standpoint. The present effect does show that social conformity in the direct sense is not playing a major role at all in the responses of the subjects in this group. It can be claimed in terms of the conditioning parameters of model (3) that there is a slight tendency of the subjects to "anticonform."

3.9 General Conclusions. From the many detailed remarks about the four experimental groups, we extract four conclusions that we believe are of general importance. First, the information provided by the social stimulus is relevant for three of the groups, and is essentially irrelevant for one of the groups, namely, A.9. Second, the temporal position of the social stimulus is of crucial importance. The effect of the social stimulus is much greater when it precedes than when it follows a response. When the social stimulus follows the response its effect on the next trial's response is not as great as in those situations when it immediately precedes the response on the same trial. As far as we know, the present experiment is the first to establish this conclusion with a uniform treatment of both kinds of experimental groups. As we noted in the introduction, previous studies of social conformity have been made under one of these two conditions

regarding the position of the social stimulus. Third, the difficulty of the perceptual judgment crucially affects the use of the social information. For the B Groups, this is shown for instance by the good fit for B.9 of the model with parameters $c(\delta_{ik}, i', j')$ and the bad fit of the same model for B.5. In the case of the A Groups, this is shown by the good fit for A.9 and bad fit for A.5 of the model with parameters $c(\delta_{ijkl'})$. Fourth, the temporal position of the social stimulus is more important than the difficulty of the perceptual judgment in evaluating the role of social information. Perhaps the best evidence of this conclusion is the relatively unimportant role of the social stimulus for both of the A Groups as compared with the B Groups. The detailed analysis above of the efficacy of using the social information to predict responses substantiates this conclusion.

There is a meta-conclusion we want to mention as a postscript. Neither much of the detailed analysis for the various experimental groups nor the general conclusions given above follow from a consideration of the mean learning curves. Almost everything of significance we have inferred from the data has been obtained by use of detailed sequential analysis in terms of the generalized conditioning models. Because of their ability to identify the events affecting behavior, we believe that these models have a useful role to play in further studies of social interaction. Their application to more complicated conformity situations is reasonably straightforward. It would be particularly interesting to extend the present studies to conformity studies involving more than two persons with particular attention to the elaboration of various combinations of positions for the social information passing from one participant to another.

REFERENCES

[1] ASCH, S. E., Effects of group pressure upon the modification and distortion of judgments, chap. 12 in *Group Dynamics*, D. Cartwright and A. Zander, eds., London: Tavistock, 1953.

[2] ASCH, S. E., Studies of independence and conformity. I. A minority of one against a unanimous majority, *Psychol. Monog.*, 1956, No. 9.

[3] ATKINSON, R. C., and P. SUPPES, An analysis of two-person game situations in terms of statistical learning theory, *J. Exptl. Psychol.*, 1958, **55**, 369-78.

[4] COHEN, B. P., A probability model for conformity, *Sociometry*, 1958, **21**, 69-81.

[5] DEUTSCH, M., and H. B. GERARD, A study of normative and informational social influences upon individual judgment, *J. Abnorm. Soc. Psychol.*, 1955, **51**, 629-36.

[6] DI VESTA, F. J., Effects of confidence and motivation on susceptibility to informational social influence, *J. Abnorm. Soc. Psychol.*, 1959, **59**(2), 204-9.

[7] ESTES, W. K., Component and pattern models with Markovian interpretations, chap. 1 in *Studies in Mathematical Learning Theory*, R. R. Bush and W. K. Estes, eds., Stanford, Calif.: Stanford Univ. Press, 1959.

[8] FLAMENT, C., Ambiguité du stimulus, incertitude de la réponse et processus d'influence sociale, *Année Psychol.*, 1959, **1**, 73-92.

[9] FLAMENT, C., Modèle stratégique des processus d'influence sociale sur les jugements perceptifs, *Psychol. Française*, 1959, **2**, 91-101.

[10] JANIS, I. L., G. I. HOVLAND, and H. H. KELLEY, *Communication and Persuasion*, New Haven: Yale Univ. Press, 1953.

[11] SHERIF, M., A study of some social factors in perception, *Arch. Psychol.*, 1935, No. 187.

[12] SUPPES, P., and R. C. ATKINSON, *Markov Learning Models for Multiperson Interactions*, Stanford, Calif.: Stanford Univ. Press, 1960.

[13] SUPPES, P., and F. KRASNE, Application of stimulus sampling theory to situations involving social pressure, *Psychol. Rev.*, 1961, **68**(1), 46-49.

[14] SUPPES, P., and M. SCHLAG-REY, Test of some learning models for double contingent reinforcement, *Psychol. Reports*, 1962, **10**, 259-68.