Chapter 5
The Time Courses

So FAR ALL THE INDICES of performance we have examined were derived from entire sessions of 300, 350, or 700 responses. We differentiated among the performances in different games and under different conditions, but did not inquire into the dynamics of the process, that is, into the changes exhibited by performances during the course of a session. We shall now examine these changes. Consistent trends in changes of behavior are attributed to learning; or, to put it another way, learning is usually defined by experimental psychologists as consistent discernible trends in behavior change, especially when manifested in changed responses to presumably similar stimuli. Accordingly, we can attribute any consistent trends in performance in repeated plays of Prisoner's Dilemma to learning.

The first question which naturally occurs is whether the subjects learn to cooperate or, on the contrary, learn to defect. Neither answer can be supported on a priori grounds, or, perhaps, both answers can be supported by argument. On the one hand, the structure of Prisoner's Dilemma is such that the defecting response, when it is positively reinforced, is reinforced more strongly (assuming reinforcements measured by the payoffs) than the positively reinforced cooperative response. Also, the cooperative response, when it is punished, is punished more strongly than the punished defecting response. On these grounds learning ought to go in the direction of decreasing cooperation. This argument is even more compelling when one keeps in mind that a decrease in cooperation of one player can be expected to induce more

defection in the other, and so a vicious cycle operates which ought to drive both players to defection.

On the other hand, one can argue that since the double-defecting state is punishing to both players, while the double-cooperative state is rewarding, the latter ought to be fixated, rather than the former. This argument attains even greater plausibility when one remembers that once the *CC* state is established, defecting from it is not likely to "pay" because of the likelihood of retaliation. "Learning" may well be a realization by both players that they are in the same boat, as it were, and hence may lead to the persistence of the *CC* response.

At any rate the problem is a complex one, as we shall see when we extend the stochastic model of rote learning applied to the interaction situation represented by Prisoner's Dilemma. Analysis of data shows that it will be useful to distinguish two phases of the process, namely a short range phase and a long range phase. The trends in the two phases are different.

First we shall examine the values of *C* in the first two responses. Since the gross time trend is our object of attention, we shall not differentiate between games but only between the two conditions, where the matrix is displayed and where it is not. We do this in the interest of having a larger sample, especially since a cursory examination reveals that at this early state the games are not well differentiated by the subjects.

Table 19 shows the comparison of the four categories of responses on the first and second plays observed in groups of ten pairs in the Matrix Conditions (Pure, Block, and Mixed). The first seven relate to the seven games in the Pure Condition, the second seven to the same seven games in the Block Condition, and the last to the group of ten pairs of the Mixed Condition. It is apparent that the tendency on the second move is to

cooperate less than on the first move. We might ask whether this tendency is a reaction to betrayed trust or the result of yielding to temptation. Evidence for the second conjecture would be a decrease of *CC* responses on the second play compared with the first. Evidence for the first conjecture would be an increase of *DD* responses at the expense of the unilateral responses on the second play. Table 19 shows that both conjectures are corroborated.

TABLE 19

	1st Move					2nd Move					Change From 1st to 2nd Move
Game	*CC*	*CD*	*DC*	*DD*	%*C*	*CC*	*CD*	*DC*	*DD*	%*C*	*Sgn* Δ
Pure											
I	4	4	2	0	70	5	1	2	2	65	—
II	1	6	1	2	45	2	5	2	1	45	0
III	2	4	1	3	45	2	2	3	3	45	0
IV	1	4	3	2	45	1	3	3	3	40	—
V		2	2	3	50	2	2	1	5	35	—
XI	3	1	3	3	50	2	5	1	2	50	0
XII	3	3	2	2	55	4	1	1	4	50	—
Block											
I	5	3	0	2	65	4	4	0	2	65	0
II	3	3	4	0	65	3	3	1	3	50	—
III	1	5	3	1	50	1	4	1	4	35	—
IV	5	1	2	2	65	3	1	4	2	55	—
V	4	0	2	4	50	0	2	3	5	25	—
XI	2	2	4	2	50	3	2	2	3	50	0
XII	1	3	3	3	40	0	2	1	7	15	—
Mixed	4	1	2	3	65	2	3	3	2	50	—
Total	42	42	34	32	53	34	40	28	48	45	—

As control, we can use the No Matrix Condition. Since the first response gives no information to the subjects about the relative advantages or disadvantages of choosing Right or Left, we would expect that in the No Matrix Condition there would be no discernible difference between the cooperative frequencies on the

first and second plays. From Table 20 we see that this is indeed the case.

TABLE 20

	1st Move					2nd Move					Change From 1st to 2nd Move
Game	*CC*	*CD*	*DC*	*DD*	%*C*	*CC*	*CD*	*DC*	*DD*	%*C*	*Sgn* Δ
I	2	4	0	4	40	0	3	5	2	40	0
II	4	3	0	3	55	5	4	0	1	70	+
III	3	5	1	1	60	6	3	1	0	80	+
IV	5	2	3	0	75	3	3	2	2	45	−
V	3	2	2	3	50	3	2	1	4	55	+
XI	4	1	2	3	45	2	4	3	1	55	+
XII	2	4	0	4	40	1	4	1	4	35	−
Mixed	1	2	4	3	40	2	4	0	4	40	0
Total	24	23	12	21	52	22	27	13	18	52	0

Looking with a "smaller resolving power" at grosser effects, we observe the "running average" of *C* in the Pure Matrix and No Matrix Conditions. These are shown in Figures 7-11. The running average represents

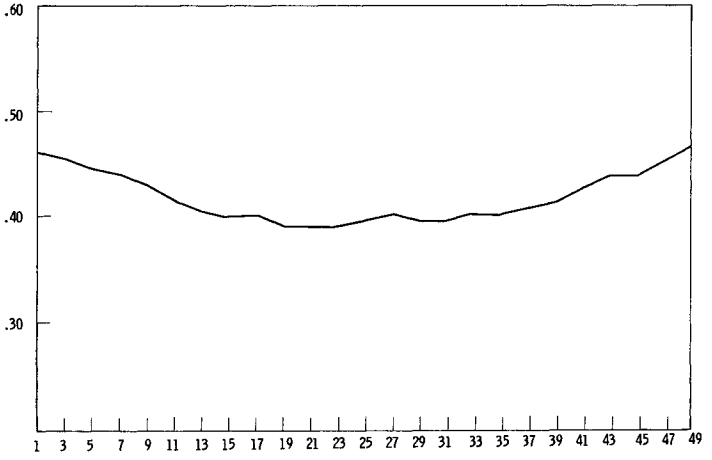

Figure 7. Pure Matrix Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequency of *C* Responses.

an average of 15 responses by each pair of players. Accordingly, the point "1" on the horizontal axis represents the average of responses 1–15, point "3" the average of responses 3–17, etc. We see that in the Matrix Conditions (Figures 7, 8, and 9) the first total effect is

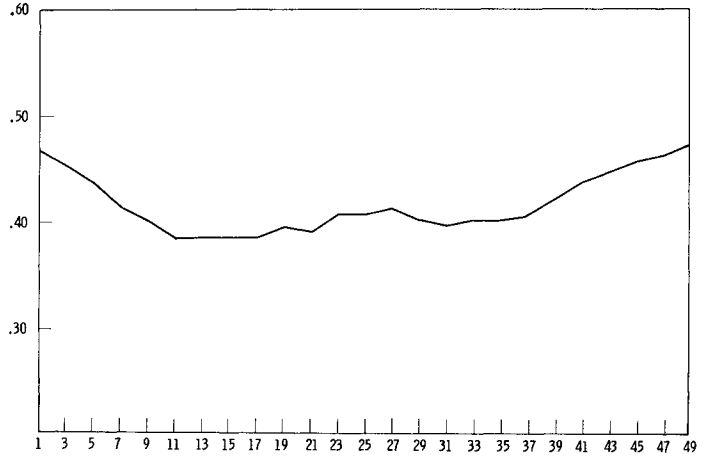

Figure 8. Block Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequency of *C* Responses.

that of continuing decrease of cooperative choices. Somewhere between the twentieth and the thirtieth responses a recovery appears to set in. The downward trend is observed also in the No Matrix Conditions, but no recovery (Figures 10 and 11).

We now separate the responses into three classes, *CC*, *DD*, and the combined class *CD* + *DC* (the unilaterals) in order to see what changes are responsible for the observed initial downward trend and for the subsequent recovery where it occurs (Figures 12–16). We observe that *DD* initially increases in all the conditions. The trend is reversed after about the thirtieth response in the Matrix Conditions but apparently not in the No Matrix Conditions. The trend in *CC* is at first slightly

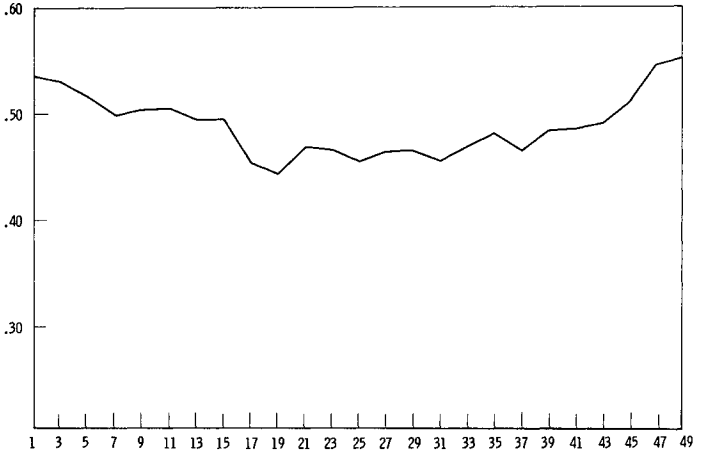

Figure 9. Mixed Matrix Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequency of *C* Responses.

downward in the Matrix Conditions but is reversed quite soon. In the No Matrix Conditions, there is no such recovery of *CC*. As for the unilateral responses, they continue to decrease in both conditions.

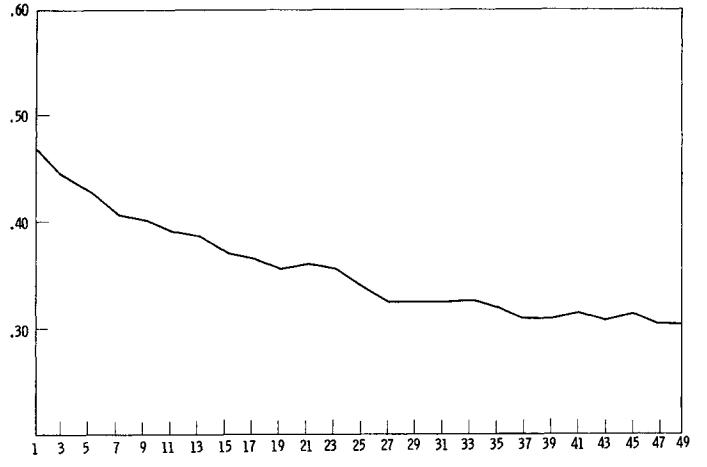

Figure 10. Pure No Matrix Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequency of *C* Responses.

Figure 11. Mixed No Matrix Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequency of *C* Responses.

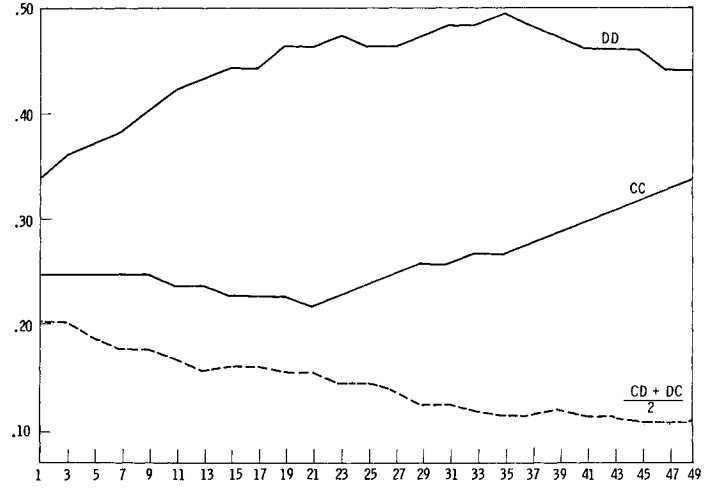

Figure 12. Pure Matrix Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

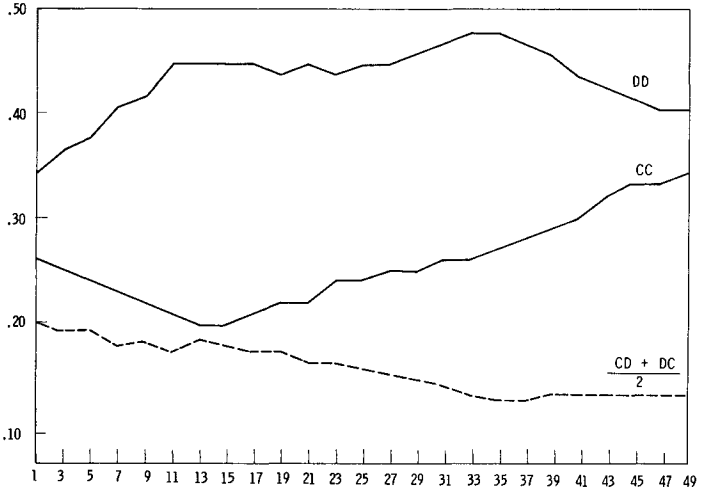

Figure 13. Block Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

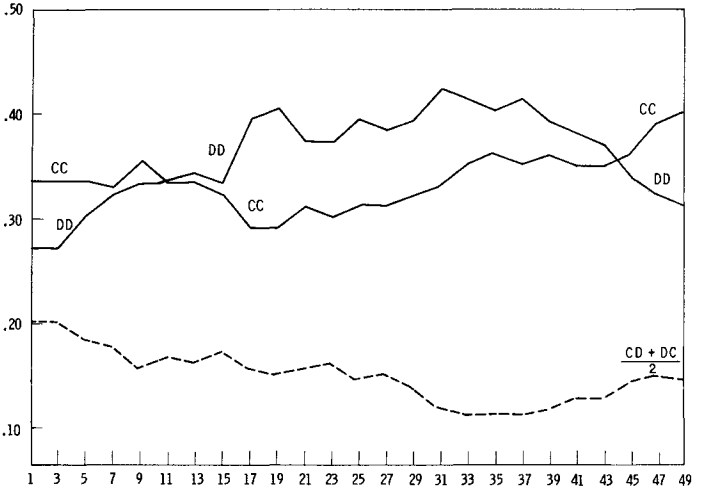

Figure 14. Mixed Matrix Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

In short, the trends in the first fifty plays are the following. The unilateral responses tend to disappear. Initially they become predominantly *DD* responses both when the matrix is displayed and when it is not. Eventu-

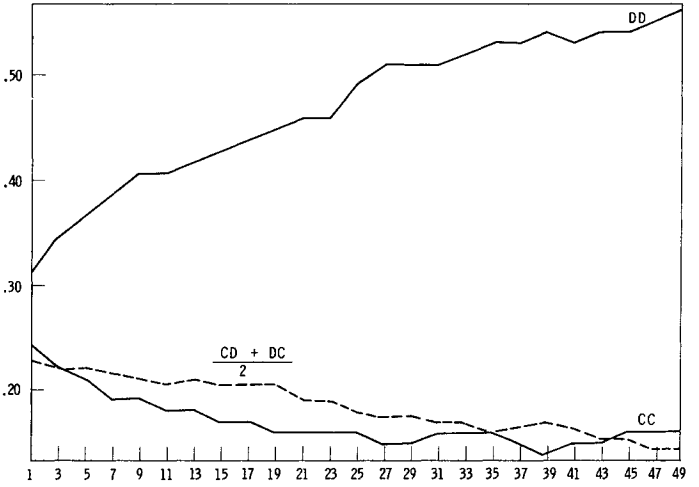

Figure 15. Pure No Matrix Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

ally, however, if the matrix is displayed, the unilateral responses tend increasingly to become *CC* responses (i.e., attempts to initiate cooperation become more successful). If the matrix is not displayed, on the other hand, this does not occur; the unilateral responses continue to be absorbed into *DD* responses. It appears that we have pinned down the role of the displayed matrix as a reminder to the subjects that a tacit collusion is possible. Evidently on the whole they tend to attain this tacit collusion in an increasing measure after about the thirtieth response, if the matrix is displayed, but not in the absence of the matrix.

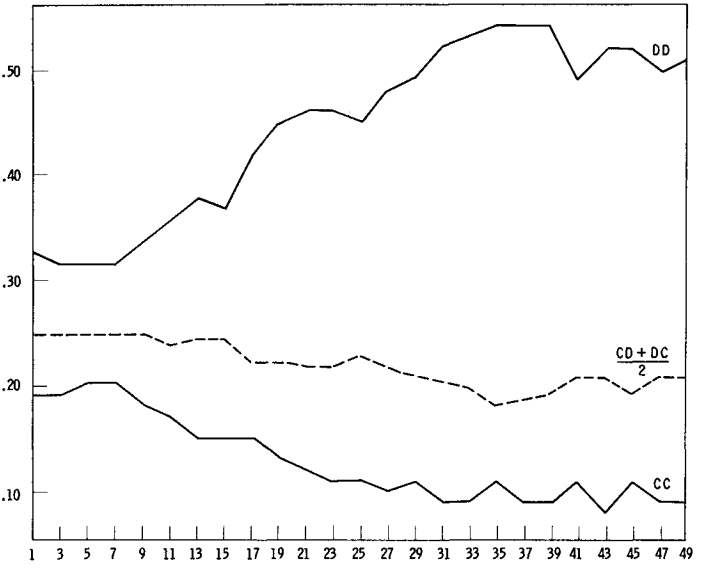

Figure 16. Mixed No Matrix Condition. Horizontal: Responses 1–15, 3–17, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

To see what happens after the fiftieth play, we examine successive fifteen play averages to the end. The comparison of *C* in the successive fifteen play blocks is shown in Figures 17–21. The comparison of state time courses is shown in Figures 22–26.

The trend in the Pure and the Block Matrix Conditions is clear. After the initial drop (shown "blown up" in Figures 7 and 8), *C* increases, appearing to reach an asymptotic value of about .65–.70 on about the 150th play in the Pure Condition and on about the 200th play in the Block Condition. In Figures 22 and 23 we see the breakdown, namely a steady increase of *CC* and decrease of *DD* after the initial trend is reversed. Note that the reversal of *DD* comes somewhat after the reversal of *CC* in both conditions.

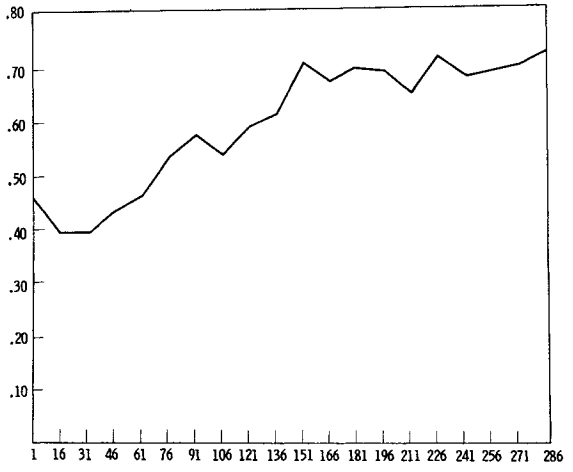

Figure 17. Pure Matrix Condition. Horizontal: Responses 1–15, 16–30, etc. Vertical: Frequencies of *C* Responses.

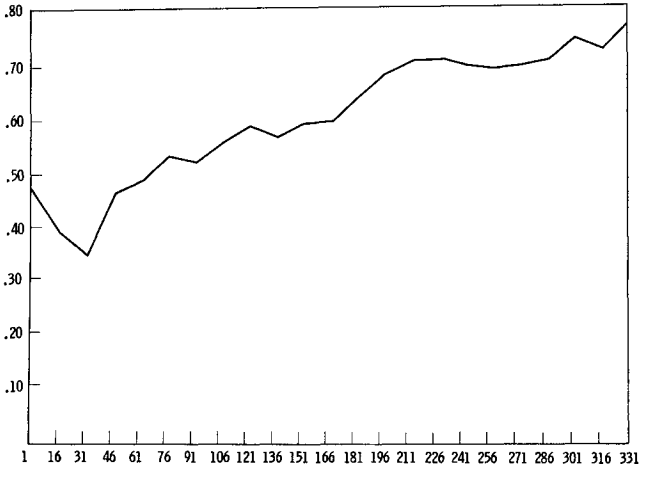

Figure 18. Block Condition. Horizontal: Responses 1–15, 16–30, etc. Vertical: Frequencies of *C* Responses.

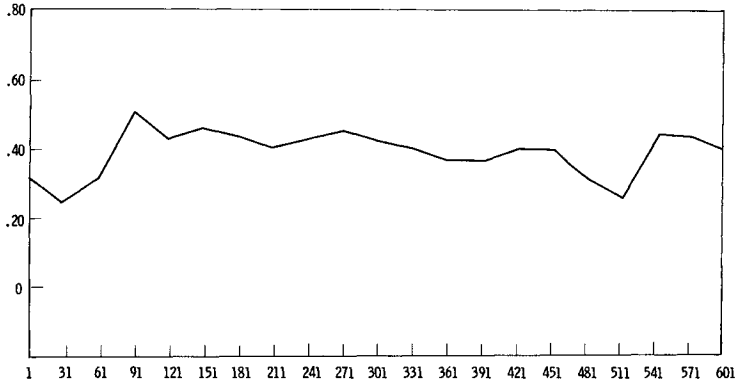

Figure 19. Mixed Matrix Condition. Horizontal: Responses 1–15, 31–45, etc. Vertical: Frequencies of *C* Responses.

In the Pure No Matrix Condition the upward trend of *C* and *CC* comes much later (Figures 20 and 25), on about the 180th play and is very weak.

The picture in the Mixed Conditions is not clear (Figures 24 and 26). This is doubtless due to the fact that only ten protocols are averaged in each of the Mixed Conditions, so that the statistical fluctuations are not smoothed out and tend to mask the gross trends. Still the data support the conjecture that a steady state

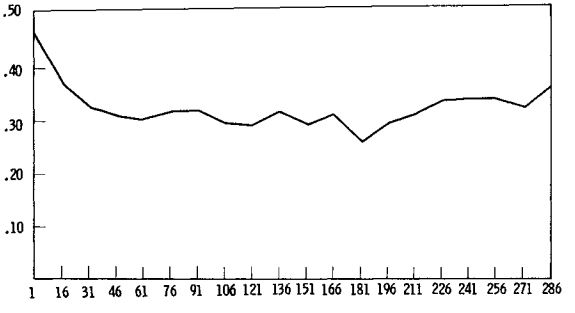

Figure 20. Pure No Matrix Condition. Horizontal: Responses 1–15, 16–30, etc. Vertical: Frequencies of *C* Responses.

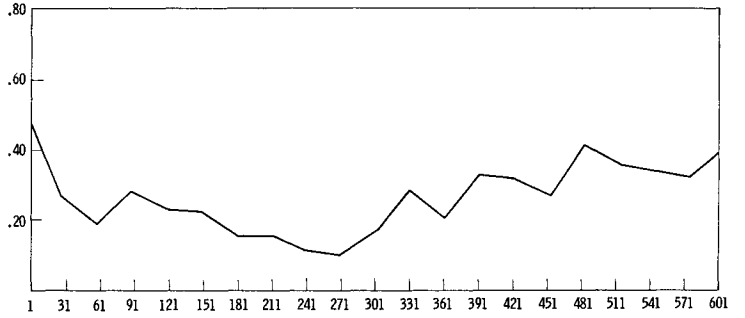

Figure 21. Mixed No Matrix Condition. Horizontal: Responses 1–15, 31–45, etc. Vertical: Frequencies of *C* Responses.

is reached on about the ninetieth play in the Mixed Matrix Condition (Figure 24), that is considerably earlier than in either the Pure or the Block Conditions. Our conjecture is that the Mixed Condition inhibits differentiation between the games and so drives the

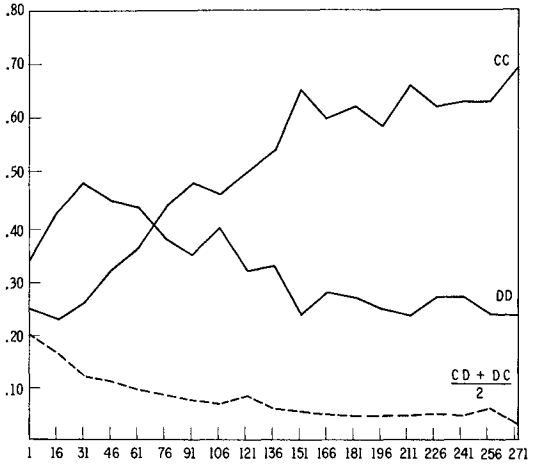

Figure 22. Pure Matrix Condition. Horizontal: Responses 1–15, 16–30, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

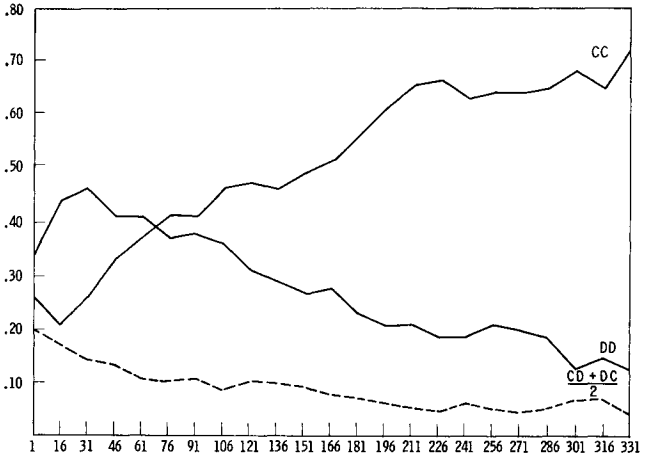

Figure 23. Block Condition. Horizontal: Responses 1–15, 16–30, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

players earlier to a decision as to whether or not to cooperate. The steady state, we recall, represents largely an average of extremes—the pairs who have practically locked-in on *CC* and those who have locked-in on *DD*.

In the Mixed No Matrix Condition the characteristic

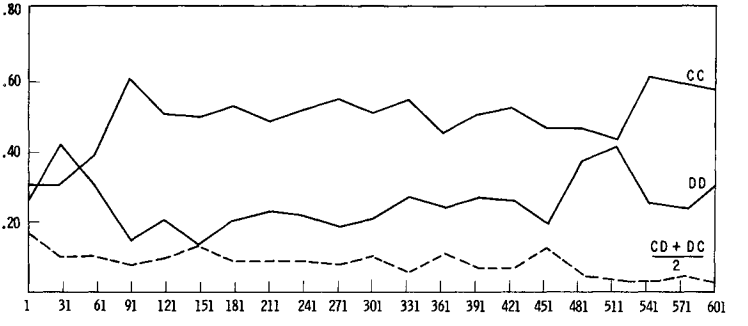

Figure 24. Mixed Matrix Condition. Horizontal: Responses 1–15, 31–45, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

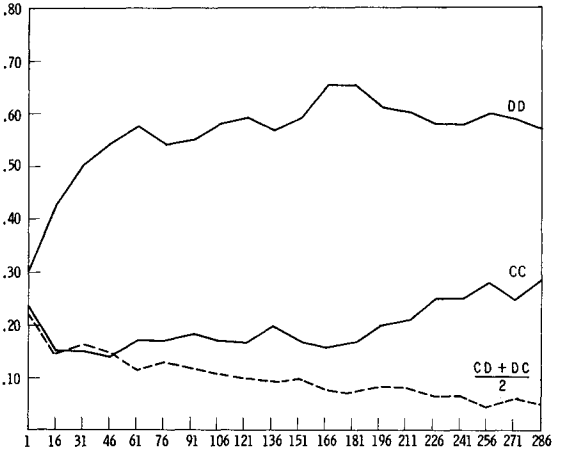

Figure 25. Pure No Matrix Condition. Horizontal: Responses 1–15, 16–30, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

long decline, seen in the Pure No Matrix Condition, is also observed, as well as the eventual slow recovery. The latter seems to start on about the 200th play in the Pure No Matrix Condition (Figure 20) but only on about the

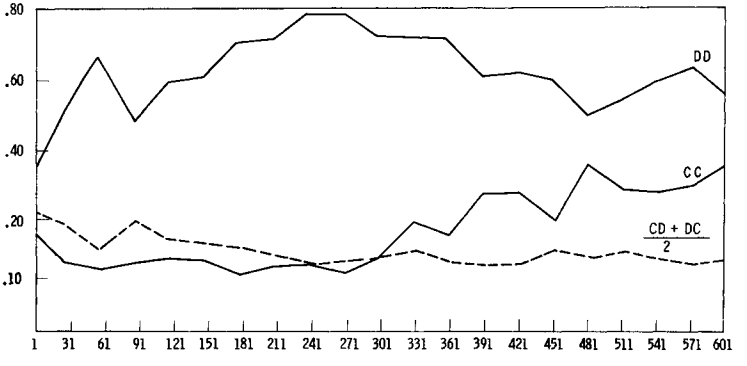

Figure 26. Mixed No Matrix Condition. Horizontal: Responses 1–15, 31–45, etc. Vertical: Frequencies of *CC*, *DD*, and Unilateral Responses.

270th play in the Mixed No Matrix Condition (Figure 21).

As for the unilateral states, these decline slowly but steadily in all conditions.

Summary of Chapter 5

The initial gross trend in repeated plays of Prisoner's Dilemma is toward more defection. After a while "recovery" sets in, and the frequency of cooperative responses increases. This recovery is relatively quick and pronounced when the matrix is displayed but comes much later and is relatively weak when the matrix is not displayed. The steady decline of the unilateral states, i.e., the increasing predominance of *CC* and *DD* states, is evidently responsible for the fact that paired players become more and more like each other in repeated plays of Prisoner's Dilemma.