CHOICE, CHANGEOVER, AND TRAVEL

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Since foraging in nature can be viewed as instrumental behavior, choice between sources of food, known as "patches," can be viewed as choice between instrumental response alternatives. Whereas the travel required to change alternatives deters changeover in nature, the changeover delay (COD) usually deters changeover in the laboratory. In this experiment, pigeons were exposed to laboratory choice situations, concurrent variable-interval schedules, that were standard except for the introduction of a travel requirement for changeover. As the travel requirement increased, rate of changeover decreased and preference for a favored alternative strengthened. When the travel requirement was small, the relations between choice and relative reinforcement revealed the usual tendencies toward matching and undermatching. When the travel requirement was large, strong overmatching occurred. These results, together with those from experiments in which changeover was deterred by punishment or a fixed-ratio requirement, deviate from the matching law, even when a correction is made for cost of changeover. If one accepted an argument that the COD is analogous to travel, the results suggest that the norm in choice relations would be overmatching. This overmatching, however, might only be the sign of an underlying strategy approximating optimization.

Key words: choice, concurrent VI VI, changeover requirements, optimization, foraging, travel, pigeons

Animals' foraging for food in nature must be controlled by its consequences, particularly the frequency of eating. Although natural selection will have seen to it, experimental evidence, if needed, exists to support this proposition (Krebs, 1978). By definition, it implies that foraging in nature is a type of operant or instrumental behavior (Baum, in press). Choice between sources of food, then, is choice between places to forage—"patches" to behavioral ecologists—and, hence, between operant or instrumental alternatives.

Choice between patches in the wild appears to differ from choice between instrumental response alternatives in the laboratory. In particular, whereas alternatives in laboratory experiments are usually right next to one another, patches are usually separated by considerable distances. As a result, ecological theories of foraging emphasize that the necessity of travel between alternatives ought to deter

changeover from one patch to another (Krebs, 1978).

In laboratory experiments, the commonest deterrent to changeover is the changeover delay (COD): a delay, beginning at changeover, during which no scheduled reinforcers can be delivered. Besides decreasing the frequency of changeover, a COD usually also increases differences in preference between alternatives. This effect appears in a relation commonly observed in the laboratory:

$$\frac{B_1}{B_2} = b \left(\frac{r_1}{r_2} \right)^a \quad (1)$$

Where B_1 and B_2 are the amounts of behavior allocated to Alternatives 1 and 2, r_1 and r_2 are the rates of reinforcement obtained, b represents a constant bias toward one alternative, if different from 1.0, and the exponent a represents the sensitivity of the behavior ratio to the reinforcement ratio (Baum, 1974b, 1979). In practice, the logarithm of Equation 1 is used to estimate a and b :

$$\log \frac{B_1}{B_2} = a \log \frac{r_1}{r_2} + \log b \quad (2)$$

In this linear relation, a is the slope and $\log b$ the intercept. With no COD, choice is usually

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less sensitive—i.e., reveals a lower value of a in Equations 1 and 2. Introducing a COD appears to increase the value of a , which is usually less than 1.0, toward a value of 1.0 (Brownstein & Pliskoff, 1968; Fantino, Squires, Delbrück, & Peterson, 1972; Herrnstein, 1961; Shull & Pliskoff, 1967).

A value of a equal to 1.0 brings Equations 1 and 2 into conformance with the matching relation (Baum, 1974b; Herrnstein, 1974). A survey of experimental results (Baum, 1979) indicates that, besides matching, undermatching ($a < 1.0$) occurs commonly, even with a COD. Overmatching ($a > 1.0$), with or without a COD, occurs only rarely.

Although travel presumably deters changeover, just as does the COD, it appears to differ from the COD in at least one way. Whereas the COD imposes a penalty (timeout from reinforcement) following changeover, travel imposes a penalty (time and effort) during changeover. This apparent difference, however, may be only in manner of thinking. Does changeover end when the COD begins, or is the COD part of changeover?

The experiment reported here was an attempt to introduce travel into the standard laboratory situation. It was a study of the effects of travel on choice and allowed a comparison of travel with the COD.

METHOD

Subjects

Six adult male White Carneaux pigeons served. All had previous experience with a variety of procedures, including concurrent schedules of reinforcement. They were housed individually in an animal colony lighted by natural light through windows and fluorescent lights on from approximately 7:00 in the morning until 7:00 in the evening. They were maintained at 80% of their free-feeding body weights for the duration of the experiment. Water was available in their home cages at all times.

Apparatus

Two identical standard experimental chambers were used. Each was 31 cm high, 33 cm long, and 29.5 cm wide. Two response keys 19 mm in diameter were mounted on the front wall, 22 cm from the floor and 14.5 cm apart. Each was operable by a force of about .20N

and could be transilluminated with white light. The opening of the grain hopper was in the center of the same wall, 9 cm from the floor, which consisted of stainless steel rods, 5 mm in diameter, spaced 2 cm apart. Standard mixed grain was presented in a Gerbrands grain feeder lit with two 7-W lamps. House-lights could illuminate the chamber from the ceiling. The door to the chamber, made of transparent plastic, opened in the rear. Each chamber was enclosed in a sound-attenuating outer box.

The only unusual feature of the chambers was a partition that might be between the two keys, extending toward the rear of the box and forcing a pigeon to go around it to get from one key to the other. The partition was opaque and varied from 1 in. to 8 in. in length. A wooden hurdle could be attached to the 8-in. partition, requiring a pigeon to climb over it to get from one key to the other. A hole in the partition allowed a pigeon to eat from the grain feeder from either side.

A PDP-9T computer (Digital Equipment Corporation) controlled and monitored events in the apparatus.

Procedure

Three of the pigeons had their experimental sessions in one chamber; three in the other. Since the birds were experienced, they were immediately exposed to the first condition of the experiment. Table 1 summarizes the conditions. Initially, there was no partition. Then a 1-in. partition was added, and the partition was lengthened across conditions to a final length of 8 in. for Group 1 and 4 in. for Group 2. The hurdle was then introduced at a height of 1.75 in. for Group 1. It was raised to a final height of 3.25 in. From Condition 8 onwards for Group 1 and from Condition 4 onwards for Group 2, no further changes were made in travel requirements. Comparison between the two groups allowed assessment of the difference between the effects of a smaller and larger requirement. The scheduling of reinforcers varied. During the first series of conditions (1 to 15), the procedure resembled that used by Stubbs and Pliskoff (1969); a single variable-interval program scheduled reinforcers probabilistically for the two keys. Since the program stopped until a scheduled reinforcer had been delivered, requiring the pigeon to changeover between keys to obtain reinforcers scheduled

Table 1

Summary of Conditions:
FCO = Forced Changeover; IND = Two Keys Independent

Condition Order	Groups Exposed	Partition	Programmed $P(S^*)$ left	Schedule Type	Number of Sessions: Gr. 1, Gr. 2
1	1,2	0"	.25	FCO	46-48, 9
2	1,2	1"	.25	FCO	14, 28-29
3	1,2	2"	.25	FCO	14-16, 42-45
4	1,2	4"	.25	FCO	21-29, 23-24
5	1	8"	.25	FCO	51-53
6	1	8" + 1.75" hurdle	.25	FCO	20-24
7	1	8" + 2.25" hurdle	.25	FCO	14-15
8	1	8" + 3.25" hurdle	.25	FCO	18
9	1,2	(no further changes)	.5	FCO	34, 54-55
10	1,2		.75	FCO	21-22, 21-22
11	1,2		.5	FCO	23, 39-40
12	1,2		.25	FCO	35, 21-22
13	1,2		0	1-KEY	11, 24-25
14	1,2		.25	FCO	39, 18
15 ^a	1		.25	FCO	15
16	1,2		.25	IND	32-34, 39
17	1,2		0	1-KEY	9-10, 29-30
18	1,2		.25	IND	17-18, 30-31

^aCOD = FR1 in this condition only.

for both keys, this type of procedure is referred to in Table 1 as "forced changeover" (FCO). In two conditions, 13 and 17, reinforcers were presented only for pecks at the key on the right. The scheduling in Conditions 16 and 18 (IND in Table 1) resembled procedures in which an independent program schedules reinforcers for each alternative in that no changeovers were required. The program continued to operate when a reinforcer was scheduled for one key; it stopped only when reinforcers were scheduled for both keys.

No changeover delay was used, except for Group 1 in Condition 15, in which the changeover response (first peck after traveling around the partition) was never reinforced, with result that at least two pecks were required for reinforcement.

The procedure and results were presented in summary form in a previous article (Baum, 1981). In that presentation, Condition 14 for Group 2 was accidentally omitted; it is now included. A final incomplete condition included in the earlier presentation is omitted here, because the experiment terminated before stable performance was achieved. Conditions were changed when, for all three pigeons in a group, day-to-day plots of relative responses made and relative time spent at the alternatives appeared stable by inspection for

at least five days. The numbers of sessions that conditions lasted appear in the last column in Table 1.

Reinforcers were scheduled on the average every 41 sec for Group 1 and every 20 sec for Group 2. The intervals in the schedules formed an arithmetic series from a shortest interval of .02 sec, each interval longer than the previous one by .02 sec. Intervals were selected randomly and were equiprobable.

For Group 1, each peck at a key produced a feedback click. For Group 2, each peck produced both a click and a momentary flicker of the keylights. The houselights and keylights were on throughout the session, except during reinforcers. Each reinforcer consisted of a 3-sec operation of the grain feeder. All recorded times excluded the durations of feedback (40 msec per peck) and reinforcement. Each session ended when 50 reinforcers had been presented. Sessions were generally conducted six days a week.

RESULTS

Stable performance was estimated by averaging the raw data (times and counts) of each bird over the last five days of each condition.

Figure 1 shows changes in three performance measures during the first series of conditions,

Fig. 1. Single-side measures of performance in the first series of conditions, in which the travel requirement increased. Symbols represent data of different pigeons, as follows: Group 1 (left column): squares, 46YP; circles, 291YP; triangles, 492BP; Group 2 (right column): squares, 47YP; circles, 23GP; triangles, 471BP. Lines connect medians. Note logarithmic vertical axis. See text for further explanation.

in which the travel requirement was increased. The top panels show average travel time or changeover time—the time between an initial peck at one key and the last peck at the other—from left to right and right to left. The different symbols represent the data of different pigeons. For each condition, each pigeon is represented by two points—one for each side (direction of travel). The lines connect the three-bird medians—one for each direction of travel. Group 1 showed no systematic difference in travel time between the two directions; the lines connecting the medians crisscross and cannot be easily distinguished. Although the medians for Group 2 suggest a tendency for travel left to right (upper line) to take longer than travel right to left (lower line), the difference was consistent for only one pigeon (23GP). No systematic differences between directions appeared in the rest of the experiment. With no partition present (Condition 1),

Group 2 tended to take longer to change over. By the time the 4-in. partition was in place (Condition 4), the two groups were both taking about 2 sec to travel from key to key. In keeping with the increasing requirement, travel time for Group 1 continued to increase in Conditions 5 through 8, up to about 5 to 6 sec. No further systematic changes in travel time occurred in the rest of the experiment.

The middle panels of Figure 1 show the average durations of stays at the two sides, measured from first peck at arrival to last peck before changeover; if only one peck was made in a visit to a side, the duration of the stay was counted as zero. In keeping with the difference in the rate of reinforcement, the durations of stays at the right key (upper lines) were almost uniformly longer than those at the left key (lower lines). The only exceptions were for Bird 47YP in Conditions 1 and 2. For the first four conditions, the durations of stay remained approximately stable for both groups. After Condition 4, durations of stay for Group 1 tended to increase at both sides as the travel requirement increased.

The bottom panels of Figure 1 show average numbers of pecks made per stay. As with durations of stay, the preference for the right key is clear; almost uniformly, fewer pecks per stay were made at the left key. The only exceptions were for Birds 47YP and 471BP in Condition 1 and Bird 47YP in Condition 2. Over the first four conditions, pecks per stay remained approximately stable for Group 1. Although median pecks per stay at the right key (upper line in Figure 1) increased for Group 2, this trend was evident only in the data of one pigeon, 47YP. By the time the 4-in. partition was in place (Condition 4), the two groups' data agreed: approximately 1 to 3 pecks per stay at the left (medians of 1.5 and 1.3) and 2 to 6 pecks per stay at the right (medians of 3.5 and 3.4). As the travel requirement increased further for Group 1 (Conditions 5 through 8), pecks per stay at the right increased for all three birds, substantially for 291YP and 492BP. Median pecks per stay at the left increased also but to a much lesser extent.

Comparison of the middle panels of Figure 1 with the bottom panels reveals that the local response rates were generally higher on the left (nonpreferred) side than on the right. Across the first four conditions, this difference remained stable. As the travel requirement in-

creased beyond the 4-in partition for Group 1, however, local response rate on the left fell and eventually approximately equalled that on the right. This is reflected in the approximately ten-fold increase in duration of stay (middle panel, lower line), as compared with the less than two-fold increase in pecks per stay (bottom panel, lower line).

From the middle panels of Figure 1, one can infer that, for the first four conditions, rate of changeover remained approximately constant, and, for Group 1 in Conditions 5 through 8, it fell. Figure 2 verifies that this was generally so. The different symbols represent the data of different pigeons. For two birds, 291YP and 492BP, rate of changeover fell from Condition

Fig. 2. Rate of changeover as travel requirement increased. Symbols represent data of different pigeons, as in Figure 1. Note logarithmic vertical axis.

3 (2-in partition) to Condition 4 (4-in partition). Apart from this, the major drops in rate of changeover occurred from Condition 4 to Condition 8 (8-in partition plus 3.25-in hurdle). The rates of changeover shown were calculated with travel time excluded. Were travel time included, Figure 1 indicates that the decreases in rate of changeover for Group 1 would have been steeper. Although travel time has always been included in calculation of rate of changeover in past research, it was omitted here because observation indicated that the pigeons always completed a changeover once begun. Since this means that travel time was time out from initiating changeovers, it seemed appropriate to omit it when calculating rate of initiating changeovers.

Figure 3 shows the effects of increasing travel requirement on choice. The lines with symbols represent data of different pigeons. The lines without symbols indicate the median ratios of reinforcement, left to right, which were always close to one third in these conditions. The top panels show the ratios of pecks at the left to

Fig. 3. Changes in choice as travel requirement increased. Symbols represent data of different pigeons, as in Figure 1. Lines without symbols connect medians of reinforcement ratios. Note logarithmic vertical axis.

pecks at the right. Although two pigeons in Group 2, 47YP and 471BP, showed initial preferences for the left key, by the time the 4-in partition had been introduced (Condition 4), the six pigeons were largely in agreement; the peck ratios were close to, but generally above, the reinforcement ratio. When the travel requirement was further increased for Group 1, two pigeons, 291YP and 492BP, shifted to preferences clearly stronger than matching—i.e., below the reinforcement ratio.

The ratios of time spent at the left key to time spent at the right key, excluding travel time (middle panels in Figure 3), differed from the peck ratios. In Group 1, with the exception of one bird in one condition, the preference indicated by the time ratios began and ended more extreme than matching. By Condition 4, all three pigeons of Group 2 likewise produced time ratios below the reinforcement ratio.

The bottom panels of Figure 3 show the ratios of time spent left to time spent right, including travel time from one side to the other in the time spent on the former side—the conventional measure of time spent or inter-

changeover time. As with the peck ratios, idiosyncratic performances tended to disappear by Condition 4; all these time ratios including changeover time were near matching, and five out of six indicated preferences weaker than

(i.e., above) matching. When the travel requirement was increased further for Group 1, one bird (492BP) switched to a preference more extreme than matching, and one bird (291YP), already showing a preference more

Fig. 4. Choice as a function of reinforcement ratio, individual pigeons. Left three columns show data of Group 1; right three columns, Group 2. Squares: conditions with forced changeover. Circles, Group 1: condition with one-peck COD. Circles, Group 2, and triangles: conditions resembling independent conc VI VI. Lines without symbols represent the matching relation. Note logarithmic axes.

extreme than matching, showed a still stronger preference.

In the second series of conditions, the travel requirement remained constant, whereas the reinforcement scheduling varied. It began with Condition 8 for Group 1 and with Condition 4 for Group 2. Figure 4 shows choice as a function of reinforcement ratio for these conditions. The data of the three pigeons in Group 1 appear in the left three columns; those for Group 2 appear in the right three columns. The matching relation appears as a straight line with no symbols. The squares represent data from the conditions with forced changeover and no COD (through Condition 14). For Group 1, the circles represent data from Condition 15, with the one-peck COD. The data from Conditions 16 and 18, in which the scheduling resembled that of independent VI programs, appear as triangles for Group 1 and circles for Group 2. The data from Conditions 13 and 17 are omitted, because the reinforcement ratios were zero and the choice ratios equalled or approached zero; they could not be represented on the logarithmic axes of Figure 4.

Hysteresis increased the variability in the performances in Figure 4, particularly for Pigeons 46YP, 291YP, and 23GP. This can be seen in the separation of ordinates with approximately the same abscissa. Where a vertical line connects two points, the separation arises from intervening exposure to a condition in which responses at the left key were extinguished (Condition 13 or 17).

Despite the hysteresis, Figure 4 reveals a clear pattern. Neither the one-peck COD in Condition 15 nor the independent scheduling in Conditions 16 and 18 produced performances inconsistent with the others. For Group 1, all three choice measures reveal a strong tendency toward overmatching—preferences more extreme than the matching relation would predict. Table 2 shows that when straight lines (Equation 2) were fitted to these data, the slopes a for Group 1 all exceeded 1.0. For Group 2, in contrast, only the time ratios excluding travel time revealed a tendency toward overmatching; preference measured as peck ratios or as time ratios including travel time ("with CO" in Figure 4 and Table 2) tended to be less extreme than the matching

Table 2

Straight Lines fitted to the data of Figures 4 and 5 by the Nonparametric Method of Hollander and Wolfe (1973).

Subject	Measure	Slope (a)	Intercept (log b)	Proportion of Variance Accounted For	Median Absolute Deviation
46YP	Pecks	1.86	.005	.8595	.322
291YP	Pecks	2.28	-.112	.9735	.115
492BP	Pecks	1.67	-.355	.9761	.138
Group 1, pooled	Pecks	1.93	-.145	.9337	.216
47YP	Pecks	.539	-.134	.9382	.050
23GP	Pecks	.672	.016	.7414	.132
471BP	Pecks	.390	-.057	.9798	.015
Group 2, pooled	Pecks	.526	-.061	.8562	.125
46YP	Time	2.38	-.069	.8886	.284
291YP	Time	2.70	-.326	.9383	.309
492BP	Time	1.87	-.262	.9620	.145
Group 1, pooled	Time	2.29	-.221	.9017	.191
47YP	Time	.949	-.032	.9506	.074
23GP	Time	1.99	.079	.7678	.269
471BP	Time	2.12	-.019	.9501	.157
Group 2, pooled	Time	1.49	-.037	.8272	.153
46YP	Time with CO	1.34	.008	.8688	.218
291YP	Time with CO	1.61	-.154	.9827	.088
492BP	Time with CO	1.57	-.244	.9605	.103
Group 1, pooled	Time with CO	1.48	-.136	.9404	.184
47YP	Time with CO	.560	.005	.9352	.030
23GP	Time with CO	.851	.108	.8030	.125
471BP	Time with CO	.681	-.021	.9584	.044
Group 2, pooled	Time with CO	.629	.015	.8825	.056

relation would predict. The slopes of the lines fitted to these data (Table 2) for Group 2 were all less than 1.0—the definition of undermatching.

Figure 5 shows lines fitted to the pooled data. In these coordinates, the matching relation (slope = 1.0) would appear as a line forming a 45° angle with the axes. The parameters of the lines shown appear in Table 2. The lines fitted to the time ratios excluding travel time have slopes greater than 1.0, that for Group 1 exceeding that for Group 2. With the peck ratios and time ratios including travel time, not

only does the slope for Group 1 exceed that for Group 2, but the data of Group 1 show overmatching, whereas those of Group 2 show undermatching.

As preference diverges from indifference, the stays at the two sides must change in one or both of two ways: (1) the stays at the preferred side become longer, or (2) the stays at the non-preferred side become shorter. Figure 6 shows how the durations of stay changed as the time ratio excluding travel changed. The data of Group 1 appear in the left column of graphs; those of Group 2 appear in the right column. The squares represent the durations of stay at the preferred side (usually the right side, but sometimes the left). The circles represent the durations of stay at the nonpreferred side (usually the left, but sometimes the right).

Figure 6 indicates that, in general, as preference increased, both possible changes occurred: stays at the preferred side lengthened and stays at the nonpreferred side shortened. Comparable graphs (not shown) for pecks per stay showed qualitatively the same results. For four out of the six birds (492BP and 47YP excluded), however, there was a tendency for the local response rates to diverge as preference grew strong—for rate on the preferred side to decrease and rate on the nonpreferred side to increase. The durations of stay, therefore, tended to diverge more than the numbers of pecks per stay.

Although Figure 6 suggests that stays at both sides tended to level off as preference grew strong, this was more clearly true of the stays at the nonpreferred side, because long stays at the preferred side were often cut short artificially by termination of the session. Since, when preference was strong the reinforcement ratio also was extreme, the fiftieth reinforcer usually occurred at the preferred side and rarely would have been followed by a changeover had the session continued. Greater accuracy might have been achieved if sessions had ended after a changeover and the last, brief, incomplete component been disregarded. Since, however, the procedure used underestimated the longest stays at the preferred side, it seems likely that greater accuracy would show them to continue increasing.

No such artifact can account for the tendency of stays at the nonpreferred side to level off in Figure 6. The short stays could decrease all the way to zero (one peck per stay), and the

Fig. 5. Choice as a function of reinforcement ratio, pooled data. Lines were fitted according to Equation 2. Matching relation would appear as a line of 45° slope. Note logarithmic axes.

Fig. 6. Duration of stay as a function of preference. Squares: stays at preferred side. Circles: stays at nonpreferred side. Note logarithmic axes.

stays of two birds in Group 2 fell well below the shortest stays for Group 1. The tendency for stays at the nonpreferred side to level off at a minimum appeared clearly in the data of all

three birds of Group 1 and possibly in the data of 47YP in Group 2. Bird 46YP, in fact, showed no tendency at all for stays at the nonpreferred side to shorten.

DISCUSSION

Overmatching versus Matching

Introducing a substantial travel requirement produced strong overmatching. For choice measured as peck ratio or time ratio including changeover (travel) time, the shorter partition (Group 2) produced the undermatching that has been typical, or at least common, in previous research (Baum, 1979), whereas the combination of longer partition and hurdle (Group 1) produced overmatching (Figures 4 and 5 and Table 2). For choice measured as time ratio excluding travel time, both travel requirements produced overmatching, but the smaller requirement produced approximate matching in one of the three pigeons (47YP; slope = .949) and relatively weak overmatching in the pooled data of Group 2 (slope = 1.49), whereas the larger requirement produced consistent and unusually strong overmatching (Baum, 1979). Other differences between the two groups, such as idiosyncracies, visual feedback for Group 2, the higher overall rate of reinforcement for Group 2, and the two different experimental chambers, probably played no important role, because, when travel requirements were the same, the two groups came to agree in performance by the fourth condition (4-in partition; Figures 1, 2, and 3). Systematic differences in performance appeared only when the travel requirements differed.

Factors other than travel can be ignored also because the degree of overmatching observed in Group 1 is almost unprecedented. In an earlier review, out of 103 data sets, only three revealed overmatching that was statistically different from matching at the .05 level (test of Hollander & Wolfe, 1973; see Baum, 1979, Figure 5). The experiments reviewed differed in all the ways that the two groups' conditions differed in this experiment, and more; yet those kinds of variations produced overmatching rarely and only in one subject or one measure of choice. The one pigeon that ever before produced overmatching pecking at keys was in Herrnstein's (1961) original report of the matching relation; Pigeon 231, by the same method of fitting used here, produced a slope of 1.42 (Baum, 1979, Table 1). Even this unusually high slope falls short of the slopes for the peck ratios in Group 1 (Table 2). Overmatching in time ratios occurred earlier in one pigeon (490) in Baum and Rachlin's (1969)

study. Since the times measured in that study excluded the COD, because the COD was signaled, the time ratios would be comparable to those in this study that excluded travel time. The slope of 1.33 produced by that pigeon in no way compared to the slopes of Group 1 in Table 2. Even the highest slope reported among these 103 data sets, a slope of 1.56, was similarly based on time ratios that excluded a signaled COD (Baum, 1973, Pigeon 488) and failed to approach the slopes of Group 1 in Table 2. It was also not statistically significant, whereas the slopes for Group 1 in this experiment were all significantly greater than 1.0 beyond the .05 level (test of Hollander & Wolfe, 1973). The third slope from a previous study that was significantly greater than 1.0 came from the time ratios, pooled across subjects, of Stubbs and Pliskoff (1969). It equaled 1.22, considerably less than the comparable 1.48 of Group 1 in Table 2.

Although the overmatching found in this experiment is unusual, it can be compared with some previous results that appear to be similar. Pliskoff, Cicerone, and Nelson (1978) studied the effects of requiring a certain number of responses to be completed on a changeover key before the change of schedules occurred (a fixed-ratio changeover requirement), instead of imposing a COD (see also Pliskoff & Fetterman, 1981). They exposed two groups of three pigeons to various pairs of VI schedules, requiring five responses (FR 5) for changeover of one group and ten responses (FR 10) for changeover of the other. Todorov (1971) studied the effects of punishing changeover: each peck at the changeover key, which changed schedules, was followed by an electric shock. Two pigeons were exposed to various pairs of VI schedules, with no COD, sometimes with changeover punished, sometimes with it not. Table 3 summarizes the results of the two experiments.

Table 3 shows that when the power function (Equation 2) was fitted to the data of Todorov (1971) and Pliskoff et al. (1978), overmatching comparable to that observed in this experiment occurred under certain conditions. The peck ratios revealed strong overmatching when FR 10 was required for changeover ($a = 1.78$) and when changeover was punished ($a = 1.64$). Neither result is quite as extreme as the comparable result in Table 2, but both are more extreme than any results with usual procedures

Table 3

Straight Lines fitted to the data of Pliskoff et al. (1978) and Todorov (1971) by the Nonparametric Method of Hollander and Wolfe (1973).

<i>Experiment, Subjects</i>	<i>Condition</i>	<i>Data</i>	<i>Slope (a)</i>	<i>Intercept</i>	<i>Proportion of Variance Accounted For</i>	<i>Median Absolute Deviation</i>
Pliskoff et al.:	CO-FR 5	Pecks	1.27	.009	.9602	.123
Pigeons A, B, and C, pooled	CO-FR 5	Time	1.08	.019	.9657	.083
Pigeons 1, 2, and 3, pooled	CO-FR 10	Pecks	1.78	-.031	.9430	.093
	CO-FR 10	Time	1.69	-.098	.9131	.112
Todorov:	No shock	Pecks	.562	.072	.9343	.042
Pigeons P-4 & P-10, pooled	No shock	Time	.565	.046	.8965	.113
	CO shock	Pecks	1.64	-.176	.9548	.198
	CO shock	Time	1.11	-.073	.9683	.055

(Baum, 1979). With FR 5 required for changeover, less extreme overmatching occurred ($a = 1.27$). No punishment of changeover led to undermatching ($a = .562$). The time ratios revealed parallel variations in the slope or exponent a , but less extreme overmatching. When FR 10 was required for changeover, strong overmatching occurred ($a = 1.69$), intermediate between that for time including travel ("with CO" in Table 2; $a = 1.48$) and that for time excluding travel ($a = 2.29$). When changeover was punished, overmatching occurred in the time ratios, but it was less extreme ($a = 1.11$) than in this experiment. The difference in degree of overmatching between the peck ratios and the time ratios in Todorov's experiment probably arose from a tendency to pause following the electric shock. The pause would add time to both sides, but no pecks to either side, thereby reducing preference measured in terms of time, but not preference measured in terms of pecks. Consistent with this reasoning, Todorov found the local response rate (pecks on a schedule divided by time on the schedule) lower for the nonpreferred schedule.

Todorov (1971) and, earlier, Silberberg and Fantino (1970), studied the effects of substituting a blackout instead of a COD. (Although Todorov called the intervention a "timeout," his description states that "all lights in the experimental chamber went off," a situation more appropriately called "blackout.") Todorov's results were comparable to those shown in Figure 3: as duration of blackout increased, preference increased and, eventually, exceeded the prediction of the matching relation. Silberberg and Fantino's less complete results were in agreement with Todorov's. Although such results, like those in Figure 3, could represent,

in principle, either overmatching or bias (b different from 1.0 in Equation 1), they are most reasonably viewed as indicating overmatching, because the changeover requirement or penalty applies equally to both alternatives, whereas bias arises from some inequality between alternatives; the symmetrical effect of changeover ought, in particular, to allow indifference when the rates of reinforcement are equal.

What do these four operations—punishing changeover with electric shock, penalizing changeover with blackout, requiring a number of responses for changeover, and requiring travel for changeover—all producing overmatching in choice, have in common? They all impose some kind of cost on changeover. Both electric shock and blackout punish responding (Azrin & Holz, 1966). Travel and a FR requirement take effort, a cost in time and energy.

Following the lead of Farley (1980) and de Villiers (1980), we can modify the matching law to try to take account of cost of changeover. The matching law becomes:

$$\frac{B_1}{B_2} = b \left(\frac{r_1 - qc_1}{r_2 - qc_2} \right)^a \quad (3)$$

where b represents bias, as in Equation 1, q represents cost of changeover, and c_1 and c_2 are rates of changing over to Alternatives 1 and 2. Since c_1 must approximately equal c_2 , Equation 3 amounts to subtracting a constant from each rate of reinforcement in the reinforcement ratio, thereby tending to predict more extreme choice ratios than the unmodified matching law. Whereas Equation 1 accounted for overmatching by allowing a to exceed 1.0, Equation 3 accounts for overmatching both in introducing q and by allowing a

to exceed 1.0. For perfect matching, however, a should equal 1.0.

In comparison with Equation 1, Equation 3 contains one more variable (c_1 and c_2) and one more parameter (q). If a were required to equal 1.0, then Equations 1 and 3 would both have two parameters. In practice, q can take on only a limited range of values, because as q increases, either of the quantities $r_1 - qc_1$ or $r_2 - qc_2$ can become negative. The same non-parametric fitting technique that was used earlier was applied to the logarithm of Equation 3:

$$\log \left(\frac{B_1}{B_2} \right) = a \log \left(\frac{r_1 - qc_1}{r_2 - qc_2} \right) + \log b \tag{4}$$

setting q to various values. The results appear in Table 4.

The columns in Table 4 are the same as in Table 2, except for the last two. For each data set, the cost of changeover q was varied until the fitted slope a was as close to 1.0 as possible ("closest" in the last column of Table 4). For two data sets (46YP, for pecks and time with CO), the closest slope a falls slightly below 1.00, because q was varied only to four decimal places. For five data sets (the three pooled sets and 492BP for pecks and time), the closest slope a exceeds 1.00, because larger values of q caused negative values of $r_1 - qc_1$ or $r_2 - qc_2$ in Equation 4.

Table 4 shows that the data of the individ-

ual birds allowed selection of a value of q that produced a slope a (Equation 4) close to 1.00. Comparison with Table 2 reveals that with one exception out of the nine data sets (492BP, for time with CO), Equation 4 with a close to 1.0 produced substantially poorer fits than Equation 2 with a greater than 1.0. Indeed, only for the three data sets of 492BP did there exist costs q greater than zero that allowed Equation 4 to account for a greater proportion of variance, to three decimal places, than Equation 2 (indicated by "better" in the last column of Table 4). For two of those three sets, these best-fitting slopes a exceeded 1.0 (1.30 for pecks and 1.17 for time), further strengthening the idea, based on Table 2, that the data of Group 1 are best viewed simply as overmatching. A similar analysis, not shown, done on the data of Pliskoff et al. (1978) and Todorov (1971), in comparison with Table 3, led to the same conclusion: that the modified matching law (Equation 3) provides a poor account of the overmatching that arises from a high cost of changeover.

Equation 3, of course, constitutes only one possible modification to the matching law; some other might accommodate the data better. The failure of Equation 3 to fit the data well, therefore, discredits just one plausible and conceptually simple modification. It might be difficult, however, to find another modification to the matching law as plausible or as simple.

Table 4

Results of fitting Equation 4 to the data of Group 1, showing, for each data set, the result with a as close to 1.0 as possible ("closest") and any result better than that in Table 2, with $q = 0$ ("better").

Subject	Measure	Slope (a)	Intercept (log b)	Prop. of Variance	Median Absolute Deviation	Cost of CO (q)	Criterion
46YP	Pecks	.988	-.205	.7920	.474	.0359	closest
291YP	Pecks	1.00	-.234	.8984	.357	.2841	closest
492BP	Pecks	1.02	-.707	.9099	.187	.3022	closest
492BP	Pecks	1.30	-.450	.9896	.153	.2000	better
Group 1, pooled	Pecks	1.38	-.194	.7141	.272	.0800	closest
46YP	Time	1.00	-.361	.7527	.553	.0667	closest
291YP	Time	1.00	-.650	.8675	.732	.2579	closest
492BP	Time	1.05	-.898	.6145	.369	.3043	closest
492BP	Time	1.17	-.491	.9959	.083	.2500	better
Group 1, pooled	Time	1.74	-.177	.5232	.295	.0810	closest
46YP	Time with CO	0.981	-.073	.8365	.269	.0225	closest
291YP	Time with CO	1.00	-.225	.9553	.220	.1966	closest
492BP	Time with CO	1.00	-.425	.9972	.050	.2171	closest
Group 1, pooled	Time with CO	1.01	-.194	.7391	.237	.0800	closest

Choice, Travel and Foraging

If we accept that the present data, as well as those of Todorov (1971) and Pliskoff et al. (1978), stand in nonconformance to the matching law, we need to seek an alternative account. Figure 6 holds out a possibility. It shows that the stronger the preference observed, the more performance tended to conform to a pattern of occasional brief visits to the nonpreferred side. As preference increased away from indifference, the pigeons tended to station themselves on the better side and make brief forays to the poorer side. Watching the pigeons indicated that they generally ran around the partition, made one or two pecks on the poorer alternative, frequently obtained food there—nearly always when the rate of changing over was low—and then ran back again to the better side.

Houston and McNamara (1981), deriving strategies for performance on concurrent VI schedules that maximize overall rate of reinforcement (optimal strategies), found that optimal performance ought to resemble that found here. When the two alternatives are nearly equal, and preference is near indifference, their reasoning predicts that animals should make stays of moderate duration at the two sides. Houston and McNamara called this a "stay-stay" strategy. When the two alternatives become clearly unequal, their reasoning predicts that performance should shift from a "stay-stay" strategy to a "stay-switch" strategy: the organism should optimally make long stays at the better alternative and minimally brief visits to the poorer alternative. One result in Figure 6 appears to contradict their predictions: whereas, according to Houston and McNamara, optimality requires that in the "stay-switch" strategy the visits to the nonpreferred alternative be as brief as possible, and hence constant, in this experiment, for five out of six birds (excluding 46YP), duration of stay at the nonpreferred side decreased. The stays including more than one peck and greater than zero time would be nonoptimal, but the variation in average duration of stay could have arisen from a mixing of "stay-stay" strategy with "stay-switch" strategy. Such mixing, as opposed to an all-or-none shift in strategy, might be expected on the basis that performance depends on finite samples of the environment, samples subject to error. Over a short sampling interval, two VI schedules that differ even by a fac-

tor of three can deliver equal rates of reinforcement. The more different the two schedules, however, the less likely this short-run equality. As a result, one might expect that as the two schedules diverged, and preference increased, performance would shift back and forth between "stay-stay" and "stay-switch," gradually settling on "stay-switch." Such reasoning might derive support from the tendency, in the pigeons of Group 1, for visits to the nonpreferred side to level off at an apparent minimum duration as preference increased.

Houston and McNamara's model makes no formal distinction between the duration of the COD in earlier experiments and the duration of the travel in this one. The difference in results when travel is required and when a COD is imposed might seem to contradict their predictions. Whereas a COD, no matter how long, never seems to produce the overmatching observed here (e.g., Silberberg & Schrot, 1974), Houston and McNamara's model would predict overmatching as a rule.

The apparent conflict could be resolved if time and responses during the COD were excluded from measures of choice. Silberberg and Fantino (1970) and Baum (1974a) found that this leads to overmatching comparable to that in Figure 5.

What justification could there be for excluding time and responses during the COD? Time spent in travel or blackout could be excluded on the basis that they are discriminable periods, out of the time base for responding because no responses can occur during them. Baum and Rachlin (1969) excluded time during the COD on similar grounds: the COD was signaled and hence, presumably, discriminated. Following this line of reasoning, we would exclude time and responses during an unsignaled COD if there were evidence that the COD was discriminated. A discriminated COD could be treated like a fixed-interval (FI) requirement used in place of the FR requirement in the experiment of Pliskoff et al. (1978). It would be functionally equivalent to travel.

Two types of evidence indicate that the COD generally is discriminated. First, in experiments that require key pecking for reinforcement, the rates of pecking during the COD are generally much higher (often by a factor of three or four) than those following the COD (Baum, 1974a; Menlove, 1975; Silberberg & Fantino, 1970). Short FI schedules, followed by

reinforcement only occasionally, produce similarly high response rates (e.g., Neuringer & Chung, 1967). Second, changeovers rarely occur during the COD (Baum, 1974a; Menlove, 1975). That is, pigeons almost always outstay the COD, even though no stimulus change signals its end. The fixed duration of the COD makes such a temporal discrimination possible.

If we accept this evidence and line of reasoning, then we have no reason to treat the unsignaled COD differently from travel, blackout, and FR changeover requirement; all should be excluded from calculations of measures of choice. The norm for results of experiments on choice would then be neither matching nor undermatching, as it is according to customary measures, but rather overmatching (Baum, 1979). Perhaps more important, however, the overmatching might be only the sign of a more fundamental phenomenon: a strategy of behavioral allocation corresponding to optimal foraging in the wild (Krebs, 1978). Such a correspondence between laboratory and nature would open many new avenues of research and theory.

Numerous questions remain unanswered, if such a line is to be pursued. How does the concept of travel apply to discrete-trial experiments on choice (e.g., Nevin, 1969)? If the COD is analogous to travel, why does matching seem to persist when the COD is lengthened (Fantino, Squires, Delbrück, & Peterson, 1972; Shull & Pliskoff, 1967; Silberberg & Fantino, 1970; Silberberg & Schrot, 1974)? Future work will determine whether such questions can be answered.

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