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TIME ALLOCATION IN HUMAN VIGILANCE[1]

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Three human subjects detected unpredictable signals by pressing either of two telegraph keys. The relative frequencies with which detections occurred for the two alternatives were varied. The procedure included a changeover delay and response cost for letting go of a key. All subjects matched the relative time spent holding each key to the relative number of detections for that key, in conformity with the matching law. One subject's performance, which at first deviated from the relation, came into conformity with it when response cost was increased. Another subject's performance approximated matching more closely when the changeover delay was increased. The results confirm and extend the notions that choice consists in time allocation and that all behavior can be measured on the common scale of time.

Experiments on human vigilance suggest that detection of an uncertain signal reinforces the behavior that makes it possible (Holland, 1958; Rosenberger, 1973; Schroeder and Holland, 1968, 1969). Schroeder and Holland (1969) found that, when such detections could be made at two sites, the proportion of responses (eye movements) at each site matched the proportion of detections at the site, just as the proportion of an animal's responses at a choice alternative matches the proportion of reinforcement obtained at the alternative (see Herrnstein, 1970, for overview). In both types of experiment, the matching law appears to hold:

$$\frac{B_1}{B_1 + B_2} = \frac{r_1}{r_1 + r_2} \qquad (1)$$

where B_1 and B_2 are the frequencies of responding at Alternatives 1 and 2, and r_1 and r_2 are the frequencies of reinforcement (or detection) produced by responding at Alternatives 1 and 2.

In the experiment of Schroeder and Holland (1969), and in most experiments with animals, the frequencies B_1 and B_2 have been measured as numbers of brief, discrete responses (lever presses, key pecks) per unit of time. Some experiments, however, have studied continuous activities, such as staying in a location and staying in the presence of a light of a certain color (Baum, 1973; Baum and Rachlin, 1969; Brownstein, 1971; Brownstein and Pliskoff, 1968). In these experiments, the frequencies of the alternative activities were measured as the proportion of time spent in them.

Baum and Rachlin (1969) and Premack (1965; 1971) independently argued that all activities can be measured on the common scale of time. Both arguments point out that counts of discrete responses translate into times spent responding as long as the time required per response remains constant.

To extend the notion of time-based measurement to human vigilance, the present experiment took up a suggestion of Premack and Collier (1966), that the time human subjects spend viewing stimuli can be a sensitive measure of performance. Instead of requiring discrete button pushes or eye movements, the procedure allowed the subjects to watch continuously for uncertain signals at either of two alternatives. The relative frequencies with which the signals occurred for the two alternatives were varied, to see whether the relative times spent at the alternatives conformed to the matching relation.

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METHOD

Subjects

Three undergraduates—two male (Doug and John), one female (Noa)—served. All were approximately 20 yr old.

Apparatus

The subject's seat, a swivelling desk chair, was in front of a table 87 cm high and approximately 2.0 m from a vertical translucent plastic screen 1.9 m square. Three rectangular areas on the screen, 3.5 cm high and 9.5 cm wide, spaced 45 cm apart approximately at the subject's eye level, could be lit either red, green, or white with two 28-V dc lamps. Also approximately at eye level, a 150-W ac floodlamp was located behind the center of the screen. On the table in front of the subject, two telegraph keys were spaced 49 cm apart, and two pushbuttons were spaced 24 cm apart. At the center of the table were two digital counters, one labelled "scores", the other labelled "hits", illuminated by a 7-W ac lamp shaded from the subject's eyes. At the right and left ends of the table, shaded from the subject's eyes, were mounted, respectively, a red and a green 100-W ac floodlamp, either of which could illuminate the screen. Under the table, a 28-V dc tone generator ("Sonalert", P. R. Mallory and Co.) could produce a high-pitched audible signal.

Electromechanical equipment in an adjacent room scheduled and recorded events in the experimental room.

Procedure

Treatment of subjects. At the beginning of the experiment, each subject was handed a set of written instructions that explained the method of payment and described the vigilance task as a game. As the captain of a spaceship under enemy siege, the subject had to defend himself by detecting and destroying two types of enemy missiles: red missiles and green missiles. By pressing the telegraph keys, he could turn on the appropriate sensors, the colored floodlights: green for red missiles (left key), red for green missiles (right key). (Opposite colors so that the missiles would be visible.) The missiles appeared on the screen as red or green (rectangular) lights. As long as the appropriate floodlight was on, a missile remained on until it was destroyed by pushing the button next to the depressed key. (The light on the screen changed from colored to white momentarily, and then disappeared.) The instructions went on to state: "Unfortunately, every time you deactivate one of these sensors you must drop your protective shield, and if the enemy is quick, he can do some damage to your ship." Such a "hit" was signalled by a pulse of tone and a flash of the center white floodlamp. The subject was instructed to destroy as many missiles as possible with as few "hits" as possible. The two events were tallied on the counters in front of him. The difference between "scores" (missiles destroyed) and "hits" constituted the session's score. The "hits" therefore constituted response cost (Azrin and Holz, 1966). Pilot studies indicated that response cost was necessary to keep the subjects from simply alternating as rapidly as possible between the two keys.

Subjects agreed to finish a series of at least forty 45-min sessions. They were paid $1.50 per session, of which $0.50 was withheld, to be paid at the end of the experiment, provided the subject continued to the end. A bonus of $1.50 was paid to the subject who totalled the highest score for each block of five sessions. A "score board" mounted on the wall in the experimental room allowed subjects to compare their performances.

Questions about the procedure either went unanswered or were answered by repeating phrases from the written instructions. Subjects were forbidden to enter the room containing the scheduling apparatus. The contingencies and purpose of the experiment were explained at the end of the series. Although he had been briefed, John was recalled four months later for a second series of sessions, for reasons apparent in the Results section.

Before and after a session, the subject was in the dark. The onset of the counter light signalled the start; its offset signalled the finish. A subject's sessions were usually 24 hr apart. When more than one session was conducted in a day, the subject was required to rest for a minimum of 15 min between sessions.

Several features of the subjects' treatment require explanation. The apparently superfluous stimuli accompanying response cost and key pressing (floodlights and tone) provided extra behavioral feedback. They were in-tended also to help maintain the subjects' interest by enhancing the game-like appearance of the experiment. This reason underlay also the use of three possible locations for the signals and of color rather than location to distinguish the two different types of signals. It prompted also the use of competition for bonuses among the subjects.

Scheduling events. The signals ("missiles") were arranged according to a variable-interval (VI) 30-sec schedule. Fourteen intervals, distributed according to the formula of Fleshler and Hoffman (1962), were repeated 14 times (196 intervals total). An electromechanical stepper determined whether the signal was to be red or green (*cf.* Stubbs and Pliskoff, 1969). Another stepper determined, equiprobably, at which of the three possible locations it would occur. A third stepper arranged that letting go of a key produced response cost (a "hit"), on the average, once out of three times (variable-ratio 3).

Once scheduled, a signal could appear on the screen only when the appropriate key was pressed. Pressing both keys caused neither to operate. A scheduled signal could be "destroyed" with the appropriate pushbutton only if the corresponding telegraph key was depressed. When the appropriate key was depressed, a signal remained on until it was "destroyed". The subjects could hold a key as long as they wished, detecting several signals in a row. Indeed, the response cost ("hits") discouraged them from letting go.

The VI programmer advanced continuously, regardless of whether a key was pressed or not, until a signal was scheduled. The programmer then halted until the signal had been "destroyed" (*i.e.*, until the appropriate button had been pushed). Unless all the lights were of one color, therefore, the subject was forced to switch keys occasionally to detect additional lights. Besides the response cost, a changeover delay (COD) further penalized changing keys. Each changeover started a COD of 2 sec, during which time no signal could appear on the screen.

The experimental conditions are summarized in Table 1. Each condition held for two consecutive sessions. Subjects began with condition *d*, and were then exposed to conditions *c* through *a*, in that order. They were then exposed to conditions *b* through *g*, in order, and finally *f* through *b*, in order. At this point, Doug only was exposed additionally to conditions *a* through *e*, in order, with a COD of 10 sec.

Table 1

The Experimental Conditions

Condition	*Ratio of Lights, Green: Red Left: Right*	*Programmed Proportion of Detections, Left Key*
a	0:1	0.00
b	4:29	0.12
c	10:23	0.30
d	16:17	0.48
e	2:1	0.67
f	10:1	0.91
g	1:0	1.00

John's second series of conditions, four months later, is summarized in Table 2. He began with condition *c* with the COD increased to 10 sec. He was exposed to condition *b*, and then to *a* through *d*, in order. The COD was then changed back to 2 sec, and, instead of response cost being scheduled on VR 3 (probability of hit = 0.33), it was arranged that response cost occurred every time a key was released (probability of hit = 1.0). With these changes, John was exposed to the conditions *d* through *g*, *f* through *a*, and *b* through *d*, in order.

RESULTS

The data from the first three conditions (*d*, *c*, and *b*; see Table 1) were discarded, because they produced performances that tended to be unrepresentative of later performance. The data from the second session of each condition's pair were used in the analysis.[2]

The subjects spent virtually all of the session time holding the keys. As a result, the number of presses on the left key tended to equal the number on the right, and their sum

Table 2

John's Second Series of Experimental Conditions

Conditions	*COD (sec)*	*P(hit)*
c, b, a-d	10	0.33
d-g, f-a, b-d	2	1.00

[2]A table of the data may be obtained from the author.

to equal the number of changeovers, except for the most extreme distributions of time.

The Matching Relation

Figure 1 shows the ratio of time holding the left key (T_1) to time holding the right key (T_2) as a function of the ratio of the number of signals detected with the left key (N_1) to the number of signals detected with the right key (N_2), in logarithmic coordinates. The matching relation appears as a broken line of slope 1.0, passing through the point (1,1). The solid lines were fitted by the method of least squares to the points from the first series (circles) and John's second complete series (squares). The equation of each line appears beside it. The variable *e*, the proportion of variance unaccounted for, estimates goodness of fit. In no graph was less than 90% of the variance accounted for.

If the fitted line fails to pass through the point (1,1), its intercept differs from zero, and the preferences were biased in favor of one side or the other. The generalized matching relation predicts that bias should take this form (Baum, 1974*b*). It produces a value of *w* different from 1.0 in the equation:

$$\frac{T_1}{T_2} = w\,\frac{N_1}{N_2} \qquad (2).$$

The value of *w*, the antilogarithm of the intercept, appears in each graph. Noa and John showed virtually no bias in the first series. Doug showed a small bias in favor of the right key, primarily due to the unusually low point in the lower-left corner of the graph. In the additional conditions with a 10-sec COD (triangles), Doug showed no such bias. John showed a definite bias in favor of the left key in his second series of conditions (triangles and squares). When asked at the end whether he enjoyed one colored floodlight more than the other, he replied that he preferred the red, the right key's light. This preference would lead to a bias opposite to that observed. The anomaly might be explained, however, if the color preference extended to the red signals.

If the slope of the fitted line failed to equal 1.0, then preferences were either stronger than matching (overmatching; slope greater than 1.0) or weaker than matching (undermatching; slope less than 1.0). (See Baum, 1974*b*, for a fuller discussion.) Noa produced a slope close to 1.0. Doug produced a slope slightly greater than 1.0, due primarily, as with the bias, to the aberrant point in the lower-left corner of the graph. The additional conditions with a 10-sec COD (triangles) produced preferences closely conforming to the matching relation. In the first series (circles), John's preferences showed definite undermatching (fitted slope = 0.67). Lengthening the COD to 10 sec (triangles) failed to correct the tendency. When the probability of response cost [p(hit)] for releasing a key was increased to 1.0 (squares), however, John's preference conformed to a line with a slope close to 1.0.

Comparing the sequences of increasing and decreasing preference for the left key revealed little evidence of hysteresis ("lagging behind"; Stevens, 1957; Baum, 1974*a*). Indeed, Doug and Noa show the opposite tendency, which might be called "running ahead". The aberrant point in Doug's graph resulted from this tendency.

Changing Over

Experiments in which the duration of the COD has been varied have shown that increasing the COD produces preferences closer to the matching relation (Brownstein and Pliskoff, 1968; Fantino, Squires, Delbrück, and Peterson, 1972; Herrnstein, 1961; Schroeder and Holland, 1969; Shull and Pliskoff, 1967). Figure 1 confirms this relation for Doug, but not for John (compare triangles and circles). Previous research has revealed another effect of increasing the COD: decreasing the frequency of changeover (Brownstein and Pliskoff, 1968; Herrnstein, 1961; Pliskoff, 1971; Schroeder and Holland, 1969; Shull and Pliskoff, 1967; Silberberg and Fantino, 1970; Stubbs and Pliskoff, 1969). Besides the duration of the COD, frequency of changeover depends also on the degree of preference between the alternatives: the greater the preference, the lower the frequency of changeover (Baum, 1973, 1974*a*).

Figure 2 shows rate of changeover as a function of preference, the ordinate of Figure 1. For Noa, John, and, to a lesser extent, Doug, the expected inverted U-shaped relation is apparent. The greatest rates of changeover generally occurred near indifference, and rate of changeover declined as preference for either alternative increased.

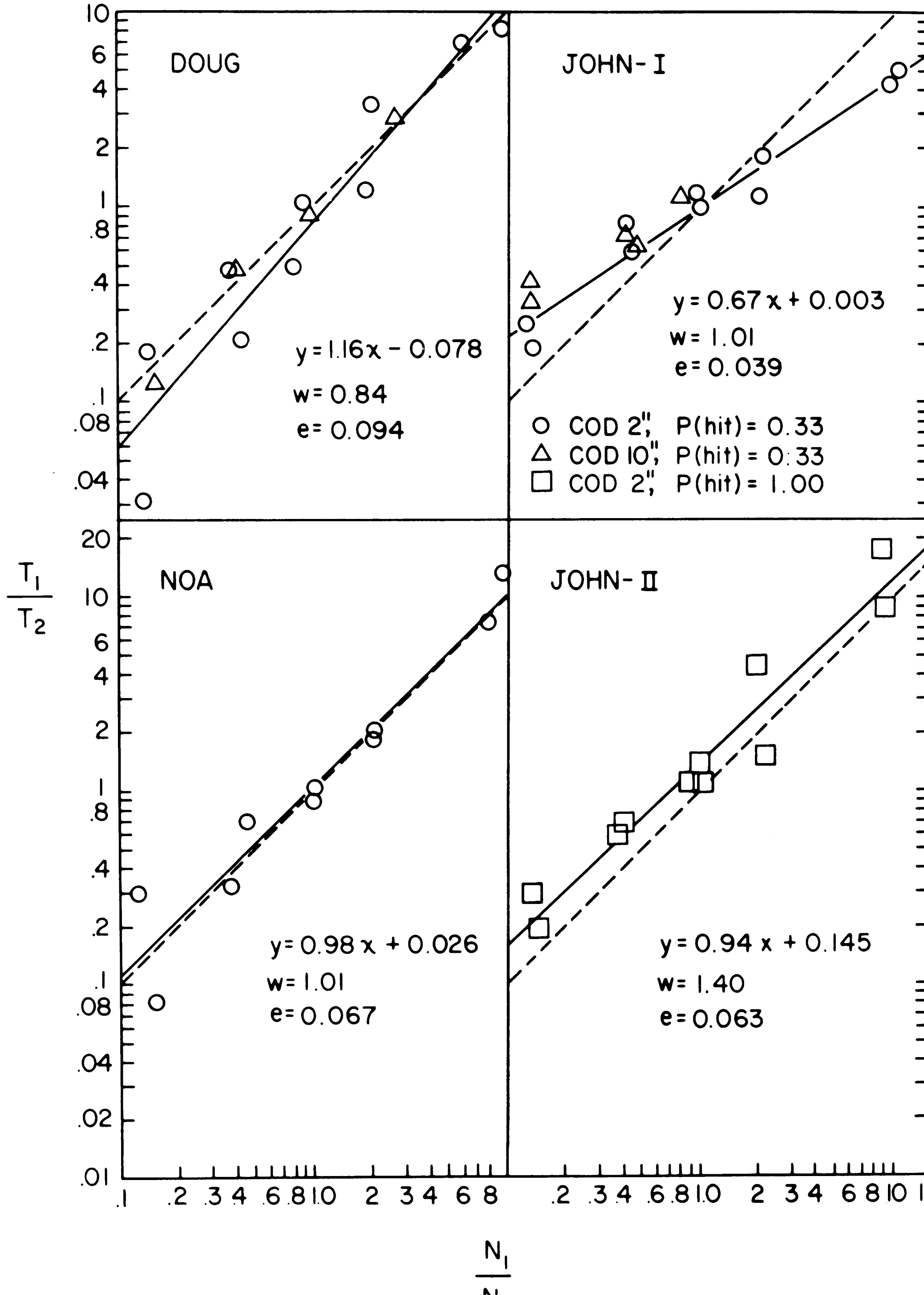

Fig. 1. Ratio of time spent holding the left key (T_1) to time spent holding the right key (T_2) as a function of the ratio of detections with the left key (N_1) to detections with the right key (N_2), in logarithmic coordinates. Broken lines represent the matching relation. Solid lines were fitted either to circles or squares by the method of least squares. The equation of the fitted line appears in each graph. See text for further explanation.

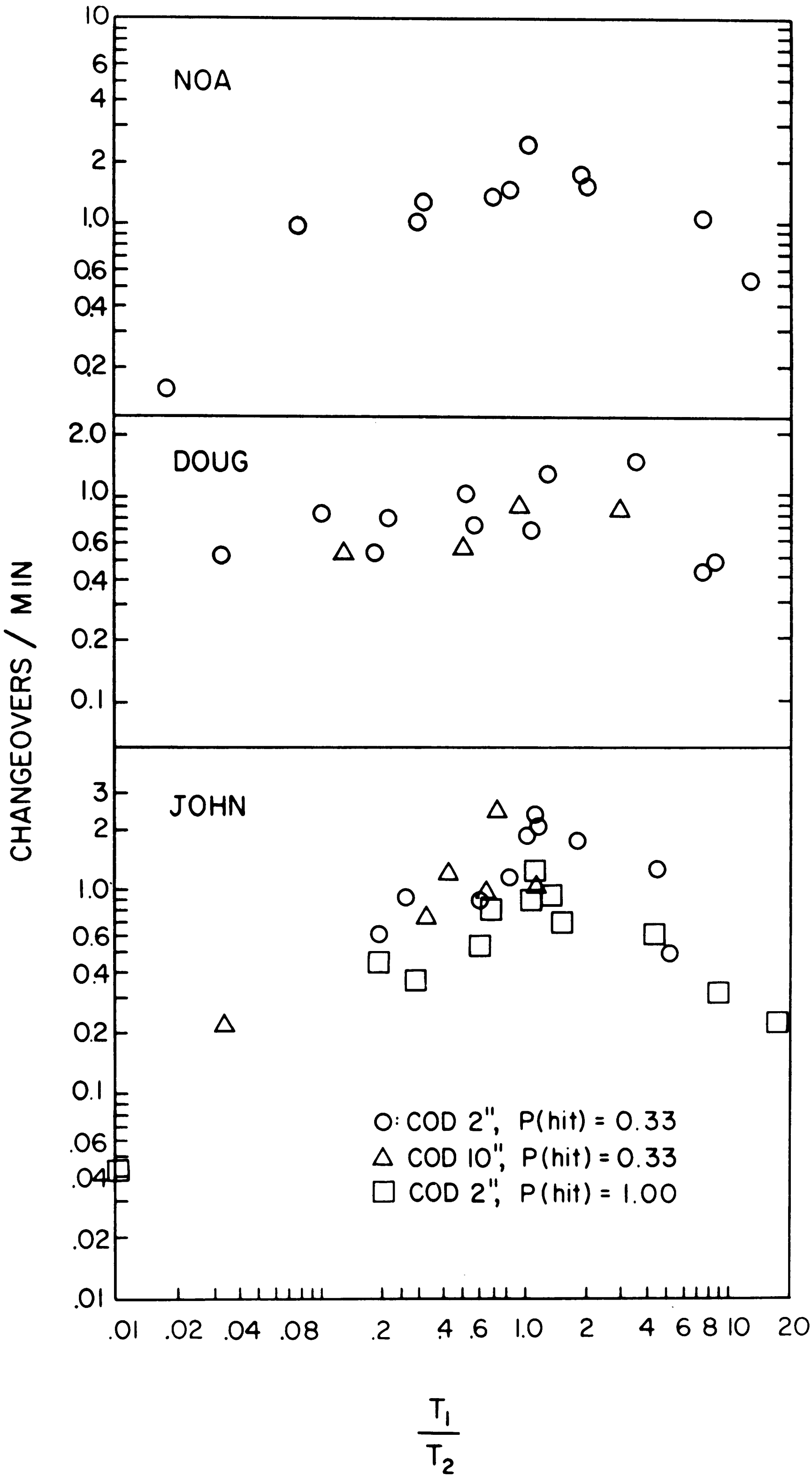

Fig. 2. Rate of changeover as a function of preference (ordinate of Figure 1), in logarithmic coordinates.

Increasing the COD from 2 sec (circles) to 10 sec (triangles) appears to have slightly decreased Doug's rate of changeover, but had no noticeable effect on John's. In contrast, increasing the probability of response cost from 0.33 (circles) to 1.0 (squares), which brought John's preferences into conformity with the matching relation (Figure 1), noticeably decreased his rate of changeover as well.

Subjects' Reports

The subjects all reported finding the task boring. The procedure appeared to lose its game-like quality after the first few sessions. The competition for bonuses, however, appeared to retain interest throughout.

Despite the absence of overt explanation during the experiment, Noa and Doug revealed in the briefing at the end of the first series that they had guessed several of the contingencies—notably, the time-based scheduling of signals and the COD. John reported no awareness of the contingencies at the end of the first series, but was able to recall the substance of the briefing at the end of the second series, nearly five months later.

DISCUSSION

The results support and extend the notion that choice can be viewed as distribution of time between alternatives. Since all behavior involves choice, in the sense that an organism engaging in one activity is omitting another (Herrnstein, 1970; 1974), it may be that the most basic measure of the frequency of any activity is the time spent in that activity.

Herrnstein (1974) has pointed out that generalization of the matching law requires that the various activities occurring in a situation be commensurate. Considerable evidence suggests that the common behavioral scale need be nothing more complicated than time (Baum and Rachlin, 1969; Brownstein, 1971; Brownstein and Pliskoff, 1968; Premack, 1965). I know of no data that contradict this notion.

The one set of data that has been taken to contradict it was gathered by LaBounty and Reynolds (1973), studying pigeons key pecking for food on a concurrent fixed-interval fixed-ratio schedule. These experimenters both counted the number of pecks at each alternative and measured for each alternative the time from changing over to the alternative until a changeover to the other alternative —*i.e.,* the cumulated interchangeover time. Graphing the proportion of responses and proportion of time as a function of the proportion of reinforcement, they found that the response counts seemed to produce a closer approximation to the matching relation. Replotting their data, however, in the coordinates of Figure 1 reveals that the distribution of time closely paralleled the distribution of responses (Baum, 1974*b*). The two functions differed systematically only in that the time ratios were biased in favor of the fixed-interval schedule. The pigeons tended to pause more after pecking the key associated with the fixed-interval schedule than the one associated with the fixed-ratio schedule. The bias took the form predicted by the generalized matching law (Equation 2).

In contrast, an experiment by Hollard and Davison (1971) failed to confirm matching with responses while obtaining matching with interchangeover times. They studied pigeons choosing between food and electrical stimulation of the brain, arranged according to concurrent variable-interval schedules. Their experiment may constitute the only published confirmation of the notion that choice consists in allocation of time *rather than* response counts.

Since the subjects in the present experiment spent virtually all of the session holding the keys, no possibility arose of distinguishing response allocation from time allocation. Unless there are periods in which the subject engages in neither alternative activity, the response counts remain trivial. Only when the times and counts can vary independently can the superiority of one of the other measure be established. Even when the two can vary independently, they may covary nonetheless. One subject, in a pilot experiment without response cost, produced such results when allowed to read a newspaper during the experiment; his responses tended to be of brief, constant duration. Accordingly, his distributions of time and responses both approximately matched the distribution of signals detected. If such covariance proved typical, it would imply that continuous activities are interrupted according to characteristic cycles. Further research might explore this possibility.

The variations in rate of changeover with COD and response cost observed in this experiment (Figure 2) may shed some light on the role of the COD. For Doug, the increase in COD both lowered the rate of changeover (Figure 2) and improved approximation to matching (Figure 1). The increase in COD may have failed to affect John's performance because it was too small. Afterwards, he reported having noticed only the shortening of the COD back to its original length. In contrast, he reported having noticed the increase in response cost almost at once. An increase in COD long enough to be reported might have affected John as the change to a 10-sec COD affected Doug. On the other hand, the absence of an effect on John's performance and the smallness of the effect on Doug's suggest the possibility that response cost alone might have been sufficient to produce the results observed.

The use of response cost here may be compared with Todorov's (1971) use of electric shock to punish pigeons' changeovers. Todorov found that punishment decreased the rate of changeover, and, for some intensities, produced better approximation to matching. Both in the present experiment and Todorov's, better matching seems to have depended on lowering the rate of changeover.

Killeen (1972) likened a concurrent schedule to a multiple schedule in which the animal changes the components. In such a view, the COD, by decreasing the rate of changeover, would function to increase the durations of the components. In this way, the COD may achieve a temporal separation of the components that allows them to be treated independently. Without this separation, discrimination between them fails, resulting in undermatching (Baum, 1974*b*), as in John's initial data (Figure 1, "JOHN-I").

In research with humans, the experimenter inevitably faces the problem of choosing the correct method of instructing the subjects. Should one simply explain all the contingencies? This approach may liken the experiment to many real-life situations. Often, however, possibly much more often, people find themselves faced with contingencies they can discover only through experience. This and a desire to make the procedure as nearly comparable as possible to procedures used with animals lead most researchers to minimize instruction of human subjects. The instructions of the present experiment were designed to bring the subjects to a level of performance comparable to a pigeon's after preliminary training to eat from a grain hopper and peck a key for grain.

The question remains, however, whether explanation of the procedure and purposes of the experiment influences the performance of human subjects. In this experiment, it seems to have made little difference. Although Doug was able to describe all the main features of the procedure by the end, still his approximation to matching improved when the COD was lengthened. This suggests that his matching depended on more than verbalization of the necessity of changing keys and the time-based schedule of the signals. Likewise, John began his second series with no better approximation to matching, even though not only the procedure, but the purpose of the experiment had been explained to him at the end of the first series. Neither this nor the lengthened COD appeared to affect his performance.

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