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An Alternative to the Stay/Switch Equation Assessed When Using a Changeover-Delay

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Abstract

An alternative to the generalized matching equation for understanding concurrent performances is the stay/switch model. For the stay/switch model, the important events are the contingencies and behaviors at each alternative. The current experiment compares the descriptions by two stay/switch equations, the original, empirically derived stay/switch equation and a more theoretically derived equation based on ratios of stay to switch responses matching ratios of stay to switch reinforcers. The present experiment compared descriptions by the original stay/switch equation when using and not using a changeover delay. It also compared descriptions by the more theoretical equation with and without a changeover delay. Finally, it compared descriptions of the concurrent performances by these two equations. Rats were trained in 15 conditions on identical concurrent random-interval schedules in each component of a multiple schedule. A COD operated in only one component. There were no consistent differences in the variance accounted for by each equation of concurrent performances whether or not a COD was used. The simpler equation found greater sensitivity to stay than to switch reinforcers. It also found a COD eliminated the influence of switch reinforcers. Because estimates of parameters were more meaningful when using the more theoretical stay/switch equation it is preferred.

Keywords

concurrent choice; stay/switch model; changeover delay; lever press; rats

1. INTRODUCTION

Choice is fundamental to understanding behavior (Herrnstein, 1970). Consider a student with the choice of reading assigned material or engaging with social media (Facebook™, or the like). The student may read for a while, then go onto social media, then return to reading, and so on. The standard view is the choices occur when the student changes their activity. The generalized matching equation (Baum, 1974), the most established model of choice, implicitly uses this approach (Sugrue, Corrado & Newsome, 2004). On closer examination

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we see, however, the student is continually faced with the choice of reading or socializing. As they continue reading the choice is between reading and switching to socializing (Shull & Pliskoff, 1967); as they continue socializing the choice is between socializing and switching to reading. In fact, how could they choose to switch activities unless they were frequently evaluating their choices? This later view is the basis of the stay/switch model of choice (MacDonall, 2009). It views a 'simple' choice between two alternatives, such as reading or socializing, as consisting of two sets of choices, each set is a choice between staying and responding at the current activity or switching to the other activity.

According to the stay/switch model, choice can be modeled by examining the contingencies as a subject experiences them while engaged at a given alternative (MacDonall, 1999, 2000). In the laboratory choice is frequently examined using concurrent schedules of reinforcement. Consider a concurrent random interval (RI) 120 s RI 30 s schedule. While the subject visits the alternative associated with the RI 30 s schedule, that schedule arranges reinforcers for staying and responding there while the RI 120 s arranges reinforcers for switching to the RI 120 s. Switching alternatives exchanges the functions of the two schedules. Thus, after a switch to the RI 120 s schedule, the RI 120 s schedule now arranges reinforcers for staying and responding there while the RI 30 s arranges reinforcers for switching to the RI 30 s. The same two RI schedules operate continuously (except when reinforcers are arranged) but their functions, arranging reinforcers for staying or for switching, exchange as the subject switches alternatives. Switch responses are the first response at an alternative. Stay responses are all responses at an alternative after the switch response until switching to the other alternative.

In concurrent schedules, stay reinforcers are arranged by the stay schedule associated with the current alternative and must be obtained by a response there; they only reinforce stay responses. Switch reinforcers are arranged by the switch schedule associated with the other alternative and must be obtained by a response at the *other* alternative; they only reinforce switch responses. Although the important factor is where reinforcers are arranged, make no mistake, we are only considering arranged reinforcers that were in fact obtained at either alternative. That is, first a reinforcer needs to be obtained, and then we consider the where it was arranged for assigning it as a stay or switch reinforcer.

Although standard concurrent procedures use two schedules, they can be implemented by using separate schedules for arranging stay and switch reinforcers at each alternative, resulting in four schedules (MacDonall, 2005, 2008, 2009). In this case, there are two independent *pairs* of schedules whose values are *symmetrical*, that is, the value of the stay schedule in each pair equals the value of the switch schedule in the other pair. Continuing the previous example, one pair of schedules is RI 30 s for staying and RI 120 s for switching; the other pair of schedules is RI 120 s for staying and RI 30s for switching. From this point of view, standard concurrent schedules are a special case of the four schedule arrangement. This symmetrical arrangement is common, but other arrangements are possible and examining the behavioral effects of different arrangements may inform us about the behavioral processes involved in choice (MacDonall, 2005, 2008, 2009).

The stay/switch model focuses on the behavior at an alternative and the choice between staying and switching. Thus, the independent variables are the numbers of stay and switch reinforcers arranged during visits. The dependent measures are the number of responses during a visit, called run length, and the durations of visits, called visit duration (MacDonall, 2003, 2005). MacDonall (1999, 2000) trained rats on a variety of arrangements of stay and switch schedules and found the following equation, the stay/switch model, described behavior and reinforcers at one alternative:

$$\left(\frac{Bst}{Bsw}\right) = k' \left(\frac{Rst/Bsw}{Rsw/Bsw}\right)^{l'} \left(\frac{Rst+Rsw}{Bsw}\right)^{m'}, \quad (1)$$

where Bst is stay responses (or time) at the alternative, Bsw is switches from the alternative, Rst is reinforcers arranged for staying at the alternative and Rsw is reinforcers arranged for switching from the alternative. Because Bsw is in the denominators of both stay reinforcers per visit (Rst/Bsw) and switch reinforcers per visit (Rsw/Bsw), it cancels leaving the ratio of stay to switch reinforcers (Rst/Rsw). The three fitted parameters are k' , the tendency to respond at the alternative not accounted for by the ratio of stay to switch reinforcers or the sum of the stay and switch reinforcers per visit, l' , sensitivity to the ratio of stay to switch reinforcers, and m' , sensitivity to the sum of the stay and switch reinforcers per visit. This equation says that run lengths or visit durations are a joint function of the ratio of stay to switch reinforcers and the sum of the stay and switch reinforcers arranged at an alternative. Expressing this equation in logarithmic form, which allows fitting the equation to the data using least-squares linear regression, produces,

$$\log\left(\frac{Bst}{Bsw}\right) = l' \log\left(\frac{Rst}{Rsw}\right) + m' \log\left(\frac{Rst+Rsw}{Bsw}\right) + \log k'. \quad (2)$$

Equation 1 was extended to concurrent performance by taking the equation with subscripts for Alternative 1 and dividing it by the equation with subscripts for Alternative 2. Assume the sensitivities to the ratio of the reinforcers per visit were equal at the two alternatives and substitute l . Assume the sensitivity to the ratio of the sums of reinforcers per visit are the same at the two alternatives and substitute m . Finally, let the ratio of the k' equal k . Because the number of switches from each alternative are normally within one of each other and are usually very large ($>> 100$) they cancel from the ratio of run lengths, the ratio of visit durations and the ratio of the sum of reinforcers. The resulting equation, expressed in logarithmic form, plots as a plane and can be fitted using least-squares linear regression,

$$\log\left(\frac{Bst_1}{Bst_2}\right) = l \log\left(\frac{Rst_1/Rsw_1}{Rst_2/Rsw_2}\right) + m \log\left(\frac{Rst_1+Rsw_1}{Rst_2+Rsw_2}\right) + \log k. \quad (3)$$

The symbols are as in previous equations with subscripts denoting the alternative where reinforcers were arranged. Equation 2 says the ratio of run lengths and of visit durations are a joint function of the ratio of the ratio of stay to switch reinforcers and the ratio of the sum of the stay and switch reinforcers.

1.1 Generalized Matching

Descriptions by the generalized matching equation (Baum, 1974), which has been supported in numerous experiments (for reviews see Baum, 1979; Wearden & Burgess, 1984), were compared to those by the original stay/switch equation in six experiments. The generalized matching equation may be expressed, in terms of stay and switch responses and stay and switch reinforcers, as,

$$\log \left(\frac{Bst_1 + Bsw_2}{Bst_2 + Bsw_1} \right) = s_1 \log \left(\frac{Rst_1 / Rsw_2}{Rst_2 / Rsw_1} \right) + \log s_2, \quad (4)$$

where s_1 and s_2 are sensitivity to reinforcer allocation and bias, response allocation unrelated to reinforcer allocation, respectively. The other symbols are as in previous equations. This equation says the ratio of responding or time at the alternatives is a function of the ratio of the reinforcers obtained at the alternatives. Experiments that used two pairs of schedules and a variety of combinations of schedule values in the pairs found the generalized matching equation described the results only when the four separate schedules were arranged symmetrically, mimicking the standard arrangement where two schedules operate continuously (MacDonall, 2005, 2008, 2009; MacDonall, Goodell & Juliano, 2006). However, it did not describe the results from symmetrical arrangements pooled with nonsymmetrical arrangements (MacDonall, 2005, 2008, 2009; MacDonall, et al., 2006). The stay/switch equation did describe these combined results, and therefore appears to have greater generality. In addition, comparing selected conditions showed that response and time allocation could be manipulated independently of the ratio of obtained reinforcers in the generalized matching equation (MacDonall, 2008, 2009). That is, the changing the reinforcer ratio was neither necessary nor sufficient for changing the behavior ratio. This suggests the generalized matching equation has not identified the independent variable(s) controlling for choice.

1.2 Simpler Stay/Switch Equation

While Equations 1 and its derivatives described the data, the equation was developed empirically, there was no theoretical justification for it. Rats were exposed to one pair of stay and switch schedules using various RI values. The resulting data were fitted by various equations and Equation 2 fitted the data best and was published as MacDonall (1999). Especially problematic is the ratio of the sums of the reinforcers, it does not appear to have, even after the fact, any theoretical rationale.

A theoretically driven equation may result if we start with the basic notion of matching. The behavior at one alternative, that is, behavior ratios, the ratio of stay responding to switch responding matching reinforcer ratios, reinforcers for staying divided by reinforcers for switching. Because switching requires greater effort than staying, sensitivity to switch reinforcers may be different than sensitivity to stay reinforcers (MacDonall, 2003). The resulting equation with different sensitivities for stay and switch reinforcers per visit is,

$$\frac{Bst_1}{Bsw_1} = c' \frac{(Rst_1 / Bsw_1)^{a'}}{(Rsw_1 / Bsw_1)^{b'}}, \quad (5)$$

where a' is the sensitivity to the stay reinforcers per visit, b' is the sensitivity to the switch reinforcers per visit and c' is the tendency to behave not accounted for by the stay or switch reinforcers per visit. The other symbols are as in previous equations.

Equation 5 is consistent with our intuition. As the number of stay reinforcers increase behavior at that alternative increases, that is, run lengths and visit durations increase. As the number of switch reinforcers increase behavior at the alternative decreases, that is, run lengths and visit durations decrease. Data are fitted to the log form of this equation, which plots as a plane,

$$\log\left(\frac{Bst_1}{Bsw_1}\right) = a' \log\left(\frac{Rst_1}{Bsw_1}\right) - b' \log\left(\frac{Rsw_1}{Bsw_1}\right) + \log c'. \quad (6)$$

An equation of concurrent performance is developed from Equation 5 by dividing the equation with subscripts for one alternative by the equation with subscripts for the other alternative. As noted previously, because the number of switch responses is large, they cancel. Assume the sensitivity, a' , to stay reinforcers are equal at both alternatives and substitute a . Assume the sensitivity, b' , to switch reinforcers are equal at both alternatives and substitute b . Finally, c is the ratio of the c s. Data are fitted to the log form of this equation, which plots as a plane,

$$\log\left(\frac{Bst_1}{Bst_2}\right) = a \log\left(\frac{Rst_1}{Rst_2}\right) + b \log\left(\frac{Rsw_2}{Rsw_1}\right) + \log c. \quad (7)$$

The symbols are as in previous equations. This equation says the ratio of run lengths or visit durations are a joint function of the ratio of stay reinforcers and the ratio of switch reinforcers.

1.3 Changeover delay

A changeover delay (COD) changes how schedules interact with switch responses (MacDonall, 2003). Reinforcers arranged for switching are not obtained following a switch response but instead, are obtained following a sequence consisting of 1) a switch response followed by 2) an unspecified number, including zero, stay responses on the newly selected lever (made during the COD) and finally, 3) the first stay response after the COD elapses (MacDonall, 2003; Shahan & Lattal, 2000). Consider a rat at the left lever. When it switches alternatives it 1) presses the right lever, 2) this is followed by an unknown number of presses at the right lever during the COD, and finally 3) a press at the right lever after the COD that obtains the switch reinforcer. Thus, obtaining switch reinforcers is contingent on *both* a switch response and stay responses, and is delayed relative to the switch response.

There is an additional way a COD changes the contingencies. A stay response following the COD may also obtain a reinforcer arranged by the stay schedule that operated during the COD (MacDonall, 2003). For example, assume no switch reinforcer is arranged and a rat changes to the right lever and starts a COD. While the COD operates, a reinforcer for staying at the right lever may be arranged, but is not delivered because the COD is operating. When the COD elapses, this reinforcer is obtained by the next response at the right lever. These changes in contingencies for obtaining reinforcers occur even when

concurrent schedules are programmed in the standard manner, with two schedules operating simultaneously throughout the session. Because of how a COD changes the stay and switch contingencies it is possible the stay/switch model, equations derived from Equations 1 or 5 may not apply when using a COD or that the sensitivity to the sums of reinforcers (Equation 3) or the sensitivity to the ratios of switch reinforcers (Equation 7) changes when using a COD.

One experiment has assessed the stay/switch equation for describing behavior when using a COD, but only when rats were presented with a choice between just one pair of stay and switch schedules. Equation 2 described the run lengths ($r^2 > .91$) and visit durations ($r^2 > .83$) (MacDonall, 2003). There is no research using a COD in the full analogue of concurrent VI VI, where *two* pairs of stay and switch schedules are used. Consequently, the applicability of the stay/switch model to choice procedures using a COD is unknown.

The first purpose of the present experiment, then, was to see whether Equations 2 and 3 described the results of procedures that used two pairs of stay and switch schedules when using a COD and when not using a COD. The second purpose was to see whether the simpler Equations 6 and 7, described the same results. The third purpose was to compare descriptions of the concurrent performances by these two sets equations.

The basic design consisted of a multiple schedule with identical pairs of stay and switch schedules in each component, and a COD operating in only one. Rats were trained on three symmetrical and 12 nonsymmetrical arrangements. The programmed number of stay and switch reinforcers at each alternative was varied so as to produce the ratios of ratios and ratios of the sums shown in Figure 1. The programmed values were wider than in previous work; for the ratio of ratios the programmed values spanned almost 4 log units and for the ratio of sums the programmed values spanned almost 2 log units.

2. METHOD

2.1 Subjects

The subjects were 5 naïve male Sprague-Dawley rats obtained from Hilltop Lab Animals (Scottsdale, PA) and deprived to 85% of their just determined free-feeding weights. Generally rats were trained twice daily, once starting at about 7:00 am and then again starting at about 5:00 pm. To maintain them at their 85% weights, following the afternoon session rats were fed 5 to 10 grams of food, based on their weight before the morning session. They were approximately 100 days old when the experiment began and were housed individually in a temperature-controlled colony room with lights turned on at 5 am and turned off at 7 pm. They had free access to water in their home cages.

2.2 Apparatus

Five operant conditioning chambers were used. Three chambers were approximately 225 mm wide and 195 mm high; two of these chambers were 235 mm in length, whereas the third was 350 mm in length. Each chamber was located in a light- and sound-controlled box. The 50-mm square opening for the food cup was centered horizontally on one 225- x 195-mm wall, 20 mm above the floor. Two retractable response levers (Model ENV-116RM,

MED Associates), 45 mm long by 13 mm thick, protruded 15 mm into the chamber. The centers of the levers were 60 mm to the left or right of the center of the food cup and 50 mm above the floor. Each lever required a force of approximately 0.3 N to operate. A feeder (Model G5120, R. Gerbrands Co. or Model ENV-293, MED Assoc.) was located behind the wall containing the food cup. The other two chambers were 305 mm wide, 270 mm high and 250 mm long. On one 305- x 270-mm wall were three retractable response levers (Model ENV-116RM) 95 mm above the floor. One lever was centered on the wall and the other two were 90 mm to either side. Only the two outside levers were used in this experiment. Centered horizontally on the opposite wall, 35 mm above the floor, was a 50-mm square opening to the food cup. A Gerbrands feeder was located behind the food cup. The feeders in all boxes dispensed 45-mg food pellets (Formula A/1, P. J. Noyes Co.), which were 85% Purina rodent chow. In all chambers a 24-VDC stimulus light was centered approximately 75 mm above each lever. All chambers were illuminated during sessions by a pair of houselights mounted on the top center of the chamber. White noise was presented through a speaker centered between the houselights. An IBM-compatible computer and MED-PC software and hardware (MED Associates Inc.) controlled the experimental events and recorded responses.

2.3 Procedure

Initially, naïve rats were placed in the operant conditioning chambers and any press at either lever was reinforced. Once a rat emitted at least 100 lever presses the next session began with the multiple schedule in effect (see below). RI 10 s was used for the stay and switch schedules in each pair in each component and this remained in effect for up to three sessions. Then RI 60 s schedules were used. When a rat was changing alternatives at least 30 times per session the COD was increased from 0.1 s to 0.4 s, 1.0 s and finally 4.0 s, which was in effect for the remainder of the experiment. Then for the remainder of the experiment rats were exposed to a two-component multiple schedule with two identical concurrent schedules, one in each component. A COD operated in only one component. Table 1 shows the sequence of conditions.

Whether the session began with a no COD component or a COD component was randomly determined; subsequently, the components strictly alternated. The COD or no COD components were accompanied by either stimulus lights or white noise that were, so far as possible, counterbalanced across rats. To minimize interactions between the components, they were separated by a 60-s blackout, during which the levers were retracted and the stimulus lights or white noise were removed. Except for three conditions, each component ended after the first changeover response after 600 s in the component. For conditions 4, 6, and 13, components ended after 240 s, 360 s and 360 s, respectively. Components in these conditions were shortened to prevent satiation, which might have occurred because the value of the stay RI schedule at one alternative provided a very high rate of reinforcement (in excess of three reinforcers per minute). Sessions ended after each component was presented three times.

At the start of each component neither pair of schedules operated; the first lever press started the pair of schedules associated with that lever. After the pair of schedules started, the first

response at the other lever stopped the pair of schedules that were operating and started the stay and switch schedules associated with that lever. In the no COD component, when either stay schedule arranged a reinforcer that schedule stopped; the next stay response at that lever delivered the reinforcer. When either switch schedule arranged a reinforcer that schedule stopped; the first response at the other lever, a switch response, delivered that reinforcer. If the no COD component ended before an arranged stay or switch reinforcer was obtained that reinforcer was held. During the next visit to the no COD component that session, the first stay response in the appropriate alternative delivered a held reinforcer arranged by the stay schedule and the first switch response in the appropriate alternative delivered a held reinforcer arranged by the switch schedule.

In the COD component, the contingencies were identical, with the following exceptions. After one or more presses at a lever the next response at the other lever started the COD. Arranged stay and switch reinforcers could not be obtained during the COD. Stay reinforcers were held and obtained by the first response at that lever after the COD. Switch reinforcers, arranged at the previous alternative, were delivered by the first response following the COD. If both a stay reinforcer and switch reinforcer were held, the first response following the COD delivered the held switch reinforcer and the next response delivered the held stay reinforcer. If the COD component ended before an arranged stay or switch reinforcer was delivered then during the next COD component that session the corresponding stay or switch response following the COD delivered the held reinforcer.

Rats were first exposed to three symmetrical conditions. Then they were exposed to twelve nonsymmetrical conditions. As is common in the literature (see, for example, Baum, Schwendiman & Bell, 1999) the conditions were sequenced so that the anticipated left or right preference produced by each condition alternated. All rats were exposed to the same sequence of conditions so that the procedure for each rat replicates the procedure for other rats. This eliminates the possibility that different sequences might produce minor differences in results.

All RI schedules were arranged by probing a probability generator every 0.5 s. When an output occurred, the associated reinforcer was arranged. Rats were randomly assigned to chambers. Rat 826 was trained in the chamber that was 350 mm long; Rats 827 and 828 were trained in the chambers that were 235 mm long; Rats 830 and 831 were trained in the chambers with three levers. Conditions remained in effect for at least 15 sessions and until session plots of the logs of the response, time and reinforcer ratios and the logs of the run lengths and visit durations at each alternative in the no COD and COD components showed no upward or downward trend for seven consecutive sessions.

2.4 Data Analyses

All analyses are based on the sums over the last seven sessions of stay responses, switch responses, and times at each lever, and stay and switch reinforcers arranged at each lever, which are shown in the Appendix. Across rats, zero stay or switch reinforcers were delivered in six conditions in the COD component and five conditions in the no COD component. These conditions cannot be used in regressions using Equations 2, 3, 6 and 7 because the log of zero is indeterminate or the quotient is indeterminate when dividing by

zero; therefore, one was added to the total of each reinforcer type for each condition for each rat shown in the Appendix (Hogg, Ruberg & Yuh, 1990). All analyses were based on these sums. All comparisons are within the same subject. To see whether adding one to each reinforcer changed the results of the analysis, the data in the Appendix, without one add to each sum, were fitted to Equations 2 and 3. The estimated parameters and r^2 for both equations generally were unchanged. When the results were different the r^2 were within .02 and parameter values within 0.02, except for one case where they were within 0.04. Only when parameter estimates differ by more than 2 SE will the difference be noted.

The reliability of estimates of parameter values based on regression analyses depend on three assumptions. First, the data are normally distributed, which was assessed by the Kolmogorov-Smirnoff test (SigmaPlot, 2006) using $\alpha = .05$, with the Bonferroni correction (Miller, 1991). Second, the residuals are independent of each other, which was assessed using the Durbin-Watson test (SigmaPlot, 2006); when the statistic was > 2.73 or < 1.27 for fits of concurrent data (Equations 3 and 7) or when the statistic was > 2.602 or < 1.398 for fits of behavior at one alternative data (Equations 2 and 6) the residuals were independent of each other. The critical values include a Bonferroni correction. Third, the variances are constant across different values of the dependent variable, which was assessed using a Spearman rank-order correlation (SigmaPlot, 2006) using $\alpha = .05$ with the Bonferroni correction. Unless otherwise indicated each data set passed all tests.

3. RESULTS

3.1 Changeover responding

The rate of changing from each alternative was lower when using a COD (Figure 2). The rate of changing from each alternative, the reciprocal of visit duration, was the changes from an alternative divided by the sum of the times at that alternative. These rates were calculated separately for the no COD and COD components. Despite the variability across conditions, generally the rates of changing from an alternative decreased as the programmed sum of the log of the ratios of ratios and of the ratios of sums increased. The same pattern is evident for each rat at each alternative. In 141 of the 150 comparisons the rate of changing from an alternative was higher when not using a COD. The lower rate of switching alternatives when using a COD supports the idea that the COD reduces the effectiveness of switch reinforcers.

Because the levers were further apart in the chambers used by Rats 830 and 831 their rates of changing over were compared to the rates for the other rats. Careful inspection of Figure 2 suggests that, generally, the rate of changing alternatives was lower for Rats 830 and 831.

3.2 Analyses using original equations

Because only one of the twenty plot of residuals failed the Durbin-Watson test, regressions were performed. The results of the twenty least-squares linear regressions (Table 2) show that Equation 3 described the stay-response and time ratios from the all conditions in the COD and no COD components each rat ($R^2 > .75$; 18 $R^2 > .90$). Inspection of the figures, available as a supplementary download, shows the residuals do not appear systematically distributed.

There were no systematic differences in goodness-of fit (R^2) for COD and no COD components. There were no systematic differences in goodness-of-fit for stay-response and time ratios. There were no systematic biases.

Next we see how much sensitivity to the ratio of ratios and the ratio of sums, in Equation 3 influenced behavior. Greater sensitivity to a ratio means the more that ratio changes behavior. Sensitivity to the ratio of ratios, l , in the COD component were smaller than in the no COD component when using stay-response ratios for Rats 826, 827, 828 and 830. There was no difference in sensitivity when using time ratios. Sensitivity to the ratios of sums, m , in the COD component were larger than in the no COD component using stay-response ratios for Rats 826, 827, 828 and 830. They were smaller in the no COD component when using visit durations only for Rat 827. For stay-response ratios, sensitivity to ratio of ratios were less than sensitivity to ratios of sums for each rat, except Rat 828 in the COD component. For visit duration ratios, sensitivity to ratios of ratios were less than sensitivity to ratios of sums for Rats 826, 830 and 831 in the no COD component and in the COD component (Table 2).

It was possible for rats to switch into an alternative and immediately switch into the other alternative before making a stay response. When this occurred the number of switch response from an alternative is greater than the number of stay responses at that alternative. If this occurred these data might not be described by Equation 3. The number of switch responses from an alternative was more than the number of stay responses at the alternative, in fewer than 5% of the conditions. When this did occur, however, Equation 3 described the data.

Finally, in developing Equation 3, we assumed the sensitivities at each alternative using Equation 2 did not differ. Showing that 1) the stay/switch equation, Equation 2, describes performances at each alternative, 2) the estimated values of l' are not different at the two alternatives and 3) the estimated values of m' are not different at the two alternatives provides additional support of the stay/switch model. Although ten of the forty plots of residuals failed the Durbin-Watson test, regressions were performed. Table 3 shows the results of least-squares linear regressions of run lengths and visit durations at the left and right alternatives in the COD and no COD components using Equation 2. The goodness-of-fit (R^2) for the forty regressions were good (36 $R^2 \geq .80$). Inspecting individual plots showed that the residuals do not appear to be systematically distributed.

The sensitivities to the ratio of reinforcers, l' , at the Left and Right Alternative were not different in 19 of the 20 comparisons. The sensitivities to the sums of the reinforcers, m' , at the two alternatives were not different in 19 of the 20 comparisons. The tendencies to respond, $\log k$, at the two alternatives were not different in 18 of the 20 comparisons.

3.3 Analyses using simpler equations

Now we turn to the simpler stay/switch equations. Because only one of the twenty plots failed the Durbin-Watson test, the regressions were conducted. The results of twenty least-squares linear regressions (Table 4) show that Equation 7 described stay-response ratios and

visit duration ratios from the COD and no COD components for each rat ($R^2 > .72$; 17 $R^2 > .90$). Inspection of the figures shows the residuals do not appear systematically distributed.

There were no systematic differences in goodness-of fit for COD and no COD components. There were no systematic differences in goodness-of-fit for stay-response and visit duration ratios. There were no systematic biases.

Next we see how sensitivity to ratio of stay reinforcer and ratio of switch reinforcers in Equation 7 contribute to changes in behavior. Sensitivity to ratio of stay reinforcers, a , were all greater than zero. Generally sensitivity to the ratio of switch reinforcers, b , were greater than zero only in the no COD component for stay-response ratios. There were no differences between sensitivity to stay reinforcer ratios and to switch reinforcer ratios in the COD and no COD components except sensitivity when using run lengths were greater in the no COD component than the COD component. Sensitivity to ratio of stay reinforcer were greater than sensitivity to ratios of switch reinforcer for both stay-response ratios and visit duration ratios in both the COD and no COD components (Table 4).

Finally, in developing Equation 7, we assumed the sensitivities at each alternative using Equation 5 did not differ. Showing that 1) the simpler stay/switch equation describes performances at each alternative, 2) the estimated values of a' are not different at the two alternatives and 3) the estimated values of b' are not different at the two alternatives provide further support for this equation. Table 5 shows the results of least-squares linear regressions of run lengths and visit durations at the left and right alternatives in the COD and no COD components using Equation 6. The goodness-of-fit for the forty regressions were good (32 $R^2 \geq .80$). Inspecting individual plots showed that the residuals do not appear to be systematically distributed. The residuals in one plot did not have constant variances and the residuals in 14 plots were not independent of each other. Linear regression were conducted even though 26 of the 40 plots suggested the residuals were not independent of each other.

The sensitivities to the ratio of stay reinforcers per visit, a' , at the Left and Right Alternative were not different in 19 of the 20 comparisons. The sensitivities to the switch reinforcers per visit, b' , at the two alternatives were not different in any of the 20 comparisons. The tendencies to respond, $\log c'$, at the two alternatives were not different in 18 of the 20 comparisons.

3.4 Assessing obtained values of independent variables

The obtained values of the independent variables were close to the programmed values. In the COD component the values of the ratios of ratios and the ratios of sums were generally close to their values in the no COD component (Figure 3). Figure 3 also shows the obtained ranges of the two independent variables were larger than the programmed ranges. To see how the ranges of the obtained ratios compare to the ranges of the programmed ratios the number of data points with an extreme value were calculated. Knowing the obtained values rarely equal the programmed values, a value that exceeded the programmed value by less than 0.2 was considered within the programmed range. Consequently, only data falling outside the range ± 2.1 for the ratio of ratios and outside the range ± 1.1 for ratios of sums were considered extreme. In 58 of the 150 conditions the value of at least one of the

independent variable was extreme. The values of the logs of the ratios of ratios were extreme in 15 conditions and in 13 of these conditions the value of the log ratio of sums also was extreme. The values of the logs of the ratios of sums were extreme in 57 conditions and in 14 of these the value of the logs of the ratios of ratios also was extreme. All the extreme conditions were in the extreme upper right or lower left quadrants of the plots (Figure 3).

4. DISCUSSION

The purposes of this experiment were first, to evaluate the stay/switch model, Equations 2 and 3 when using a COD and not using a COD; second, evaluate the simpler model, Equations, 6 and 7, using the same data; third, to compare the descriptions by the two models. Both Equations 3 and 7 described the choice data equally well when using a COD and when not using a COD (Tables 2 and 4); there were no consistent differences in goodnesses-of-fit among rats or dependent measures (Tables 2 and 4). Both Equation 2 and 6 also described the performances at each alternative whether or not a COD was used (Table 3 and 5).

Both equations describe a plane. The present experiment used a wide range of schedule values to present combinations that would vary widely over the plane. Both equations describe the data well indicating that a plane is the best description of these data. Examining the figures, in the supplementary download, does not indicate any systematic failure of either equation to describe the data as the data approaches the outer edges of any of the quadrants in the figures.

4.1 Comparing equation parameters

Because both equations described the data equally well, goodness-of-fit does not provide a basis for choosing among the equations. Now we turn to a comparison of the parameter estimates and what these estimates tell us about variables influencing choice. For Equation 3 sensitivity to the ratio of ratios was less when using a COD only when estimated using ratios of run lengths. The sensitivity to the ratio of sums, however, was greater when using a COD when estimated using ratios of run lengths. Finally, the sensitivities to the ratio of sums were greater than to the ratio of ratios only when using a COD. There does not appear to be an explanation for a COD decreasing sensitivity to ratio of ratios but increasing sensitivity to ratios of sums, or for the other differences. This is not surprising given that Equation 1 has not theoretical basis.

For Equation 7, there are two important differences in sensitivities. First, estimates of sensitivity to ratio of stay reinforcers were greater than sensitivity to ratios of switch reinforcers. Second, sensitivity to the ratio of switch reinforcers were less in the COD component when using run lengths.

Equations 6 and 7 shed light on the variables controlling concurrent performances and how CODs influence control by those variables. Put briefly, behavior is controlled by the stay and switch reinforcers and stay reinforcers have more influence than switch reinforcers. Furthermore, a COD eliminates the influence of the switch reinforcers. First, sensitivity to stay reinforcers was greater than sensitivity to switch reinforcer. The delay between a stay

response and that reinforcer is very short, the time to move to the feeder and obtain the reinforcer. The delay between a switch response and that reinforcer is longer. Recall, switching requires the rat to 1) move down from the current (stay) lever, 2) move to the other (switch) lever, 3) reach up and press that lever. Without a COD the delay is the sum of the time to emit these responses. Certainly, this delay is longer than the delay to the stay reinforcer. This longer delay reduces sensitivity to switch reinforcers.

Second, the COD reduces the influence of switch reinforcers. As previously discussed, a COD introduces a delay between the switch response and its reinforcer. This increases the delay to switch reinforcers compared to the delay without a COD by the duration of the COD. In this experiment the delay increased by 4 s. We found a reduced sensitivity to switch reinforcers when using a COD. These results, along with those of MacDonall (2005, 2008, 2009; MacDonall, Goodell & Juliano, 2006) suggest the independent variables controlling concurrent performances are the stay reinforcers per visit and the switch reinforcers per visit. The reason for insensitivity of visit durations to switch reinforcers, whether or a COD was used is not clear.

Overall, equations based on Equation 5 described the performances at each alternative and the concurrent performances. Importantly, the sensitivities and changes in sensitivities when using a COD were sensible. While equations based on Equation 1 described performances at the alternatives and concurrent performances the estimates of the parameter values are not sensible. Consequently, it appears Equation 5 and its derivatives is the preferred model. There are many other possible models based on some form of concatenated generalized matching. It is beyond the scope of this paper to examine all of them.

4.2 Contingencies for arranging and obtaining reinforcers

The results of the present experiment show, once again, the importance of understanding the difference between the contingency for arranging reinforcers and the contingency for obtaining reinforcers (MacDonall, 2005, 2008, 2009); it is contingency for arranging reinforcers that produces different patterns of responding. A reinforcer is arranged when the contingency for arranging reinforcers is satisfied. These arranged reinforcers are obtained by a response, that is, they are delivered when the contingency for obtaining them is satisfied (Rachlin, Green, Tormey, 1988). To be clear, the arranged reinforcers also are obtained, but the important feature of those reinforcers is the contingency for arranging them, not the contingency for obtaining them.

Because models of choice almost always use obtained reinforcers, it may seem strange to develop a model based on arranged reinforcers. The following illustrates the significance of contingencies for arranging reinforcers in understanding behavior maintained by a variety of contingencies. Consider a differential-reinforcement-of-low-rate schedule. The contingency for arranging reinforcers is a period of time of no responding. After not responding for this period a reinforcer is arranged. The contingency for obtaining the arranged reinforcers is the emitting the response. The low rate of responding produced by such schedules is a function of the contingency for arranging the reinforcer not the contingency for obtaining the reinforcer. To be sure, the reinforcer must be obtained, but the contingency that produces the low rate is the contingency that arranges reinforcers. Similarly, fixed-interval, variable-

interval, fixed-ratio and variable-ratio schedules have the same contingency for obtaining reinforcers, usually a lever press or a key peck, but the pattern of responding maintained by each schedule is different (Ferster & Skinner, 1957). The patterns are different because the contingency for arranging reinforcers are different. Because of the significance of the contingencies for arranging reinforcers many schedules of reinforcement are named for them.

In an example closer to concurrent schedules, and that partly inspired the present approach, pressing one lever eight times arranged reinforcers and the next press at a second lever obtained those reinforcers (Mechner, 1958). Rats ended up pressing the first lever about eight times and then switched and pressed the second lever. The pattern of eight responses on the first lever is a function of the contingency for arranging reinforcers and not the contingency for obtaining reinforcers. The significance of the contingency for arranging reinforcers was overlooked in the concurrent literature, except for Rachlin, et al. (1988).

Rachlin et al. (1988) provided empirical support for classifying reinforcers according to where they were arranged. They found that reinforcers arranged at one alternative, but obtained by a response at the other alternative after a COD, influence staying and responding at the alternative where reinforcers are arranged, but not obtained. Given that the contingency for obtaining reinforcers is essential for producing the effects of reinforcement, the viability of the generalized matching equation, which is based on where reinforcers were obtained not on where they were arranged, is seriously questioned.

4.3 Implications for the generalized matching equation

These results also suggest that the generalized matching equation does not reflect a fundamental behavioral process, or law. In fact, it is an artifact of how concurrent schedules are commonly arranged. When two variable interval schedules operate continuously, except when a reinforcer was arranged, the values of the stay and switch schedules at the two alternatives are symmetrical. The generalized matching equation described data obtained from these procedures (MacDonall, 2005, 2008, 2009). But, behavior in concurrent choice procedures is driven by the stay and switch reinforcers arranged per visit, not by the total reinforcer obtained at each alternative (MacDonall, 2005, 2008, 2009; MacDonall, et al. 2006). This conclusion results from the stay/switch model, regardless of whether this model is quantified as Equation 1 or Equation 5. Given the limited applicability of the generalized matching equation, it is unclear whether matching, as typically conceived (Herrnstein, 1961) is a general behavioral process.

4.4 Conclusion

The stay/switch model provides a framework for understanding behavior in concurrent choice procedures. Two equations, each based on the stay/switch model, fitted the data equally well when not using a COD and when using a COD. The simpler equation, Equation 5, is the better instantiation of the stay/switch model because the values of the fitted parameters inform us how a COD changes the influence of switch reinforcers. Whether or not a COD was used behavior was more sensitive to stay than to switch reinforcers. Using a COD reduces behavioral sensitivity to switch reinforcers to zero.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Abbreviations

COD	Changeover delay
RI	Random interval
VI	Variable interval

References

- Baum WM. On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*. 1974; 22:231–242. [PubMed: 16811782]
- Baum WM. Matching, Undermatching and Overmatching in Studies of Choice. *Journal of the Experimental Analysis of Behavior*. 1979; 32:269–281. [PubMed: 501274]
- Baum WM, Schwendiman, Bell. Choice, contingency discrimination, and foraging theory. *Journal of the Experimental Analysis of Behavior*. 1999; 71:355–373. [PubMed: 16812900]
- Ferster CB, Skinner BF. *Schedules of Reinforcement*. Appleton-Century-Crofts. 1957
- Herrnstein R. On the Law of Effect. *Journal of the Experimental Analysis of Behavior*. 1970; 13:243–266. [PubMed: 16811440]
- Hogg, RV.; Ruberg, SJ.; Yuh, L. Robust Data Analyses. In: Berry, DA., editor. *Statistical Methodology in the Pharmaceutical Sciences*. CRC Press; 1990. p. 376
- MacDonall JS. A local model of concurrent performance. *Journal of the Experimental Analysis of Behavior*. 1999; 71:57–74. [PubMed: 16812892]
- MacDonall JS. Synthesizing concurrent interval performance. *Journal of the Experimental Analysis of Behavior*. 2000; 74:189–206. [PubMed: 11029022]
- MacDonall JS. Reinforcing staying and switching while using a changeover delay. *Journal of the Experimental Analysis of Behavior*. 2003; 79:219–232. [PubMed: 12822688]
- MacDonall JS. Earning and obtaining reinforcers under concurrent interval scheduling. *Journal of the Experimental Analysis of Behavior*. 2005; 84:167–183. [PubMed: 16262185]
- MacDonall JS. The stay/switch model describes choice among magnitudes of reinforcers. *Behavioural Processes*. 2008; 78:173–184. [PubMed: 18406545]
- MacDonall JS. The stay/switch model of concurrent choice. *Journal of the Experimental Analysis of Behavior*. 2009; 91:21–39. [PubMed: 19230510]
- MacDonall JS, Goodell J, Juliano A. Momentary maximizing and optimal foraging theories of performances on concurrent VR schedules. *Behavioural Processes*. 2006; 72:283–299. [PubMed: 16631321]
- Mechner F. Sequential Dependencies of the Lengths Sequential Response Runs. *Journal of the Experimental Analysis of Behavior*. 1958; 1:229–233. [PubMed: 16811223]
- Miller, RG, Jr. *Simultaneous Statistical Inference*. Springer-Verlag; 1991.
- Rachlin H, Green L, Tormey B. Is There a Decisive Test Between Matching and Maximizing? *Journal of the Experimental Analysis of Behavior*. 1988; 50:113–123. [PubMed: 16812553]
- Shahan TA, Lattal KA. Choice, Changing Over, and Reinforcement Delays. *Journal of the Experimental Analysis of Behavior*. 2000; 74:311–330. [PubMed: 11218228]
- Shull RL, Pliskoff SS. Changeover Delay and Concurrent Schedules: Some Effects on Relative Performance Measures. *Journal of the Experimental Analysis of Behavior*. 1967; 10:517–527. [PubMed: 6080829]
- SigmaPlot. *SigmaPlot for Windows Version 10, Build 10.0.0.54*. 2006
- Sugrue LP, Corrado GS, Newsome WT. Matching Behavior and the Representation of Value in the Parietal Cortex. *Science*. 2004; 304:1782. [PubMed: 15205529]

Wearden JH, Burgess IS. Matching Since Baum (1979) . Journal of the Experimental Analysis of Behavior. 1982; 38:339–348. [PubMed: 7175431]

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Highlights

We compared two equations, based on the stay/switch model.

Rats trained on concurrent schedules using a changeover delay, or not using one.

Both equations described results from both changeover delay conditions.

The simpler equation's parameters found behavior more sensitive to stay reinforcers.

Using a changeover delay eliminated the influence of switch reinforcers.

Fig. 1.

This plot shows the combinations of values for symmetrical and nonsymmetrical arrangements in this experiment. The ellipse shows the approximate locus of most data points in previous experiments.

Fig. 2.

For each rat in the no COD and COD components, the left panels show the rate of changing from the left alternative (CO/min) and the right panels show the rate of changing from the right alternative both as a function of the programmed rate of reinforcers arranged at the respective alternatives (the sum of the programmed rate for staying at the alternative plus the programmed rate for switching from that alternative).

Fig. 3.

This figure shows the obtained values of the logs of the ratios of ratios and of the ratios of sums. The experiment successfully explored combinations of the independent variables that sampled widely from the range of possible combinations. On average 10 data points were within or near (± 0.2 log units) the programmed range of values of the independent variables. Of the 58 data points falling outside the programmed area 57 were because the

ratio of sums was more extreme than expected. In only 14 of these conditions was the ratio of the ratios also outside the programmed range.

Table 1

Sequence of conditions and the values of the RI schedules (sec) in each condition.

Condition	Stay at left	Switch from left	Stay at right	Switch from right
1	35.6	320.0	320.0	35.6
2	320.0	35.6	35.6	320.0
3	60.0	60.0	60.0	60.0
4	10.7	96.0	767.9	85.3
5	200.0	66.7	22.2	66.7
6	18.0	18.0	144.0	144.0
7	96.0	10.7	85.3	767.9
8	66.7	200.0	66.7	22.2
9	200.0	200.0	25.0	25.0
10	118.5	1066.5	133.3	14.8
11	72.0	24.0	72.0	216.0
12	36.0	36.0	108.0	108.0
13	1066.5	118.5	14.8	133.3
14	24.0	72.0	216.0	72.0
15	100.0	100.0	33.0	33.0

Table 2

Results of least squares linear regressions the using stay/switch equation (Equation 3) and the data from all conditions. For each regression $df = 12$.

Rat	<i>l</i>	<i>SE</i>	<i>m</i>	<i>SE</i>	<i>log k</i>	<i>SE</i>	<i>R</i> ²
Stay-response ratios							
No changeover delay							
826	0.13	0.05	1.04	0.04	-0.11	0.05	.98
827	0.17	0.04	0.86	0.05	-0.07	0.05	.97
828	0.24	0.05	0.86	0.07	-0.14	0.06	.97
830	0.12	0.03	1.15	0.04	-0.05	0.04	.99
831	0.13	0.10	1.17	0.12	-0.09	0.11	.94
Changeover delay							
826	0.33	0.06	0.57	0.08	-0.02	0.06	.96
827	0.27	0.02	0.45	0.03	0.00	0.02	.99
828	0.39	0.06	0.58	0.08	-0.01	0.07	.97
830	0.21	0.04	0.77	0.05	-0.19	0.05	.98
831	0.36	0.13	0.85	0.16	-0.19	0.14	.91
Visit duration ratios							
No changeover delay							
826	0.20	0.08	0.35	0.08	-0.17	0.08	.77
827	0.21	0.02	0.42	0.02	-0.03	0.02	.98
828	0.31	0.03	0.31	0.04	0.03	0.03	.97
830	0.22	0.07	0.52	0.08	-0.04	0.08	.91
831	0.21	0.05	0.52	0.06	-0.09	0.06	.95
Changeover delay							
826	0.28	0.03	0.38	0.04	-0.01	0.03	.98
827	0.26	0.02	0.33	0.03	0.01	0.02	.98
828	0.27	0.08	0.27	0.11	-0.04	0.08	.85
830	0.13	0.09	0.63	0.12	0.08	0.09	.89
831	0.30	0.05	0.54	0.06	-0.04	0.05	.98

Table 3

The results of least-squares linear regressions using run lengths and visit durations at each alternative and Equation 2. For each regression, $df = 12$.

Left					Right									
Rat	t' SE	m' SE	$\log k'$ SE	R^2	t' SE	m' SE	$\log k'$ SE	R^2						
No changeover delay														
Run lengths														
826	0.06	0.09	0.92	0.08	1.12	0.07	.94	0.13	0.15	0.88	0.14	1.22	0.11	.82
827	0.14	0.07	0.82	0.08	1.35	0.07	.92	0.17	0.11	0.80	0.11	1.41	0.09	.87
828	0.18	0.07	0.66	0.08	0.96	0.06	.91	0.39	0.15	0.72	0.19	1.13	0.14	.80
830	0.06	0.08	0.95	0.08	1.40	0.06	.95	0.10	0.11	1.16	0.11	1.51	0.07	.94
831	0.28	0.17	0.95	0.20	1.36	0.13	.82	0.02	0.11	1.15	0.12	1.52	0.07	.93
Visit duration														
826	0.28	0.05	0.50	0.04	1.20	0.04	.96	0.15	0.24	0.48	0.23	1.36	0.18	.38
827	0.19	0.05	0.41	0.06	1.09	0.06	.87	0.22	0.04	0.49	0.04	1.17	0.03	.97
828	0.26	0.09	0.42	0.11	1.24	0.08	.80	0.22	0.07	0.51	0.09	1.25	0.07	.88
830	0.21	0.04	0.58	0.04	1.40	0.03	.97	0.17	0.15	0.60	0.17	1.44	0.10	.74
831	0.24	0.05	0.51	0.06	1.36	0.04	.95	0.12	0.07	0.62	0.08	1.47	0.05	.92
Changeover delay														
Run lengths														
826	0.25	0.11	0.44	0.13	1.26	0.08	.86	0.25	0.14	0.49	0.21	1.31	0.11	.70
827	0.26	0.04	0.34	0.06	1.38	0.03	.94	0.23	0.05	0.55	0.06	1.47	0.04	.94
828	0.12	0.13	0.51	0.18	1.28	0.12	.74	0.16	0.24	0.90	0.27	1.37	0.17	.68
830	0.14	0.08	0.75	0.09	1.52	0.05	.95	0.21	0.05	0.72	0.07	1.68	0.04	.97
831	0.09	0.34	1.10	0.37	1.33	0.25	.73	0.14	0.14	0.91	0.20	1.49	0.12	.88
Visit duration														
826	0.32	0.04	0.33	0.05	1.30	0.03	.98	0.20	0.03	0.41	0.05	1.37	0.02	.97
827	0.24	0.05	0.26	0.06	1.24	0.04	.90	0.24	0.04	0.43	0.05	1.29	0.03	.95
828	0.27	0.08	0.41	0.11	1.37	0.07	.91	0.13	0.26	0.53	0.30	1.51	0.18	.42
830	0.27	0.05	0.49	0.05	1.48	0.03	.98	0.22	0.05	0.53	0.06	1.44	0.04	.96
831	0.24	0.06	0.59	0.09	1.40	0.06	.96	0.21	0.03	0.57	0.05	1.44	0.03	.99

Table 4

Results of regressions using a simpler stay/switch equation (Equation 8) and data from all conditions. For each regression $df = 12$.

Rat	<i>a</i>	<i>SE</i>	<i>b</i>	<i>SE</i>	$\log c$	<i>SE</i>	r^2
Run lengths							
No COD							
826	0.69	0.05	0.36	0.06	-0.11	0.05	.98
827	0.61	0.04	0.26	0.05	-0.05	0.04	.98
828	0.66	0.04	0.19	0.07	-0.15	0.05	.97
830	0.72	0.03	0.44	0.05	-0.02	0.04	.99
831	0.76	0.07	0.43	0.12	-0.03	0.09	.96
COD							
826	0.66	0.05	-0.12	0.09	-0.04	0.07	.95
827	0.52	0.02	-0.06	0.04	0.00	0.03	.98
828	0.74	0.05	-0.19	0.11	-0.02	0.08	.94
830	0.66	0.03	0.15	0.07	-0.19	0.05	.98
831	0.92	0.10	-0.06	0.20	-0.18	0.16	.89
Visit durations							
No COD							
826	0.38	0.08	-0.03	0.11	-0.17	0.09	.73
827	0.42	0.02	-0.01	0.03	-0.02	0.02	.98
828	0.45	0.02	-0.16	0.04	0.03	0.03	.97
830	0.48	0.06	0.03	0.09	-0.02	0.07	.90
831	0.48	0.04	0.03	0.07	-0.05	0.06	.95
COD							
826	0.49	0.02	-0.11	0.04	-0.03	0.03	.98
827	0.42	0.02	-0.10	0.03	0.01	0.02	.98
828	0.41	0.07	-0.17	0.15	-0.06	0.10	.75
830	0.54	0.02	-0.04	0.03	0.07	0.02	.99
831	0.65	0.04	-0.10	0.07	-0.03	0.06	.97

Table 5

The results of linear regressions using the run lengths and visit durations at each alternative and Equation 6. For each regression, $df = 12$.

Rat	Left					Right				
	a'	SE	b'	SE	$\log c'$	SE	$\log c'$	b'	SE	r^2
No changeover delay										
Run lengths										
826	0.64	0.08	-0.33	0.11	1.52	0.10	.93	0.63	0.14	.80
827	0.55	0.08	-0.23	0.10	1.64	0.11	.89	0.61	0.10	.86
828	0.53	0.05	-0.18	0.08	1.28	0.07	.95	0.78	0.10	.87
830	0.60	0.09	-0.38	0.14	1.83	0.11	.91	0.82	0.08	.95
831	0.81	0.12	-0.25	0.21	1.85	0.16	.87	0.72	0.07	.95
Visit duration										
826	0.59	0.05	0.08	0.07	1.40	0.07	.94	0.42	0.21	.39
827	0.40	0.05	-0.01	0.07	1.25	0.08	.87	0.48	0.04	.94
828	0.48	0.08	0.06	0.13	1.41	0.13	.79	0.49	0.07	.85
830	0.54	0.06	-0.05	0.09	1.65	0.07	.93	0.54	0.12	.72
831	0.53	0.05	0.02	0.09	1.58	0.07	.93	0.50	0.08	.86
Changeover Delay										
Run lengths										
826	0.57	0.06	0.01	0.13	1.53	0.11	.90	0.63	0.11	.73
827	0.47	0.03	0.10	0.05	1.54	0.04	.96	0.57	0.04	.95
828	0.55	0.08	-0.06	0.14	1.55	0.15	.79	0.78	0.16	.74
830	0.65	0.06	-0.17	0.13	1.88	0.09	.94	0.69	0.04	.97
831	0.87	0.21	-0.33	0.40	1.94	0.31	.72	0.77	0.06	.94
Visit duration										
826	0.55	0.03	0.24	0.08	1.42	0.07	.96	0.49	0.03	.96
827	0.41	0.04	0.13	0.06	1.35	0.06	.91	0.51	0.04	.93
828	0.59	0.06	0.18	0.10	1.54	0.11	.91	0.49	0.20	.41
830	0.60	0.04	0.07	0.08	1.71	0.06	.96	0.56	0.05	.92
831	0.70	0.06	0.06	0.11	1.65	0.08	.94	0.66	0.08	.87