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REPRESENTING WITHIN-SESSION RESPONSE RATES PROPORTIONALLY AND ENTIRELY

DAVID W. SCHAAL

WEST VIRGINIA UNIVERSITY

In this technical article, methods for collecting and representing response rates maintained by schedules of reinforcement are presented. First, the time in a session that each important event (e.g., responses, reinforcers) occurs is collected and stored by a computer. Another computer program is used, then, to convert each response to a percentage of the total responses in a session and to plot these percentages cumulatively as a function of the time in the session that they occurred. In this manner, response rates may be expressed proportionally (i.e., using the same *y*-axis scale regardless of absolute response rate) without requiring the arbitrary selection of an interval over which responses are aggregated and expressed relative to the entire-session rate. A property of these records is that deviations in the slope of the obtained record from the diagonal, which connects $(x, y) =$ (start of session, 0%) to $(x, y) =$ (end of session, 100%), occurring at any point and for any duration, represent changes in the local response rate from the entire-session rate. This method of representing ongoing responding is illustrated by several records of key pecking of a pigeon on a variable-interval 60-s schedule of food reinforcement. Relative local response rates were also computed from these data at several levels of resolution (i.e., the time over which responses were aggregated), including the level typically employed by those interested in within-session changes in response rates.

Key words: within-session responding, variable-interval schedule, response rate, pigeon, key peck

In several recent investigations by McSweeney and her colleagues (McSweeney, 1992; McSweeney, Hatfield, & Allen, 1990; McSweeney & Hinson, 1992; McSweeney & Roll, 1993; McSweeney, Weatherly, & Swindell, 1995), rates of responding of rats and pigeons on schedules of positive reinforcement have been shown to vary during experimental sessions in an orderly manner. Most frequently the pattern of changes in response rates have been characterized as lowest near the beginnings of sessions, highest shortly thereafter, and decreasing to a second low rate near the ends of sessions. Because the regular variations in response rates occur under a wide variety of conditions, McSweeney et al. (1994) have argued that they may reflect processes other than those identified in most current theories of operant behavior. These findings have important implications for understanding schedule-controlled behavior and the variables that influence it.

A feature of these studies is that within-session response rates typically are represented by dividing rates obtained in 5-min segments of sessions by the rates obtained during entire sessions (i.e., overall rates) and plotting the results as a function of segment. Expressing local rates relative to overall rates facilitates comparisons among subjects that respond at different absolute rates and, thus, is an indispensable first step in many analyses of behavioral data. Investigators typically must decide, however, how many segments should be used and how long they should be. Their selections may influence the opportunity to observe regular changes in rates and alter their apparent magnitude. For example, although McSweeney et al. (1994) reported the magnitude of within-session changes in response rates as an average of 450%, this value depends critically on the size of the interval with respect to which the proportions were computed. Rates obtained during smaller intervals are likely to differ from each other to a greater extent than do rates obtained during larger intervals. In addition, relative measures are not independent of each other across intervals. If a lower relative rate is obtained in a particular 5-min interval of a session, the difference in that relative rate from the overall rate is distributed across the other intervals. These are important factors to consider when selecting an interval over which to calculate proportional rates.

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Reprints may be obtained from David W. Schaal, Department of Psychology, P.O. Box 6040, West Virginia University, Morgantown, West Virginia 26506-6040.

Because of the important implications of within-session response-rate changes, it may be useful to consider additional methods of representing and analyzing within-session rate deviations. A valuable contribution might be a method that shares the advantages of representing rates proportionally (i.e., the ability to compare across subjects with different absolute rates) but without the necessity of selecting an interval over which to compute the proportional rates. This paper presents such a method, which depends on the collection and storage by a computer program of the time during the session that each important event occurs (responses, reinforcers, etc.). In this method, each successive response increments a variable (*y*) by a value equal to (1/total responses) × 100. The variable *y* is then plotted over the time in the session that the response occurred. The result is a cumulative response record with a minimum of zero and a maximum of 100, that is, a cumulative percentage record (see Figure 4 in Melgren & Elsmore, 1991). Alterations in rates of responding during sessions are plainly visible as deviations in the slope of the obtained records from the slope of the straight line that connects $x = 0$, $y = 0$ to $x = \text{end of session}$, $y = 100$.

METHOD

These methods may be employed with any personal computer and programming language, including commercially available experimental control software (e.g., SKED®, MEDSTATE® Notation, Coulbourn's L2T2 System, etc.) combined with programs written in virtually any language. The data presented here were collected using an MSDOS-based computer with an 80386 microprocessor programmed in MEDSTATE® Notation (MED Associates & Tatham, 1991). To construct the percentage cumulative records, it is first necessary to save in the computer's memory the time that each response and reinforcer occurs. In our procedures, the session timer is resolved to 0.01 s, but a lower resolution (say, up to 0.05 s) is sufficient. It is most convenient to establish a large, real-number array in the experimental-control program that can, as responses and reinforcers occur, be filled with the times of these events. Responses may then be distinguished from reinforcers by a "tag" placed to the right of the decimal point, with ".1" indicating "response" and ".2" indicating "reinforcer" (this is the convention employed by MED Associates, Inc., in their cumulative record program, SoftCR). These data should then be saved to disk as ASCII text files. (Most programs allow the array to be written to disk and cleared during sessions if the number of responses and reinforcers during a session exceeds the computer's working memory.)

A computer program (written in Turbo Pascal, V. 6.0, in the application illustrated here) is then used to count the responses and reinforcers and to determine the total session time (excluding reinforcer durations). Next, the percentage value of each response is computed by dividing 1.0 by the total number of responses and multiplying by 100%. Starting with the first response, the cumulative percentage value of each response and its associated time of occurrence (converted from 0.01-s units to minutes) is written to a text file in two columns. A third column contains the cumulative response percentage at which reinforcers occur, thus allowing reinforcers as well as responses to be plotted (see Table 1 for an example of a portion of such a file). These three-column text files may then simply be imported into a graphics software program (in the present case, Axum V. 3.0, TriMetrix, Inc.) so that cumulative peck percentages can be plotted as a function of session time.

The same text files that contain the time-of-occurrence arrays may be analyzed with other programs that compute local rates over any interval (or window) that the experimenter chooses. Such a program may count the responses during a given interval, compute a local rate, and then express that rate relative to the entire-session rate. If the window over which proportional rates are computed *and* the amount of time that the window is moved forward after each local rate calculation are expressed as variables in the program, then one may quickly view deviations in local rates from the entire-session rate at several levels of aggregation.

RESULTS

Figures 1 to 3 depict, using the methods described, the key pecking of a pigeon main-

Table 1

Format employed for saving, in three columns, the time that responses and reinforcers occurred, the cumulative percentage of responses that have occurred, and the percentage of responses that have occurred at the time that each reinforcer was presented. This sample was taken from a session in which the pigeon made its first peck 2.37 min into the session and received its first reinforcer 2.59 min into the session.

Time in session (min)	Responses as cumulative % of total	Cumulative % of responses at reinforcement
2.37	0.05	
2.38	0.10	
2.41	0.14	
2.44	0.19	
2.45	0.24	
2.48	0.29	
2.51	0.33	
2.53	0.38	
2.55	0.43	
2.56	0.48	
2.57	0.52	
2.58	0.57	
2.58	0.62	
2.59	0.67	0.67
2.61	0.71	
2.63	0.76	
2.64	0.81	
2.65	0.86	
Time from 2.65 min to 40.34 min was removed		
40.34	99.62	
40.36	99.67	
40.39	99.71	
40.40	99.76	
40.41	99.81	
40.43	99.86	
40.45	99.90	
40.47	99.95	
40.47	100.00	100.00

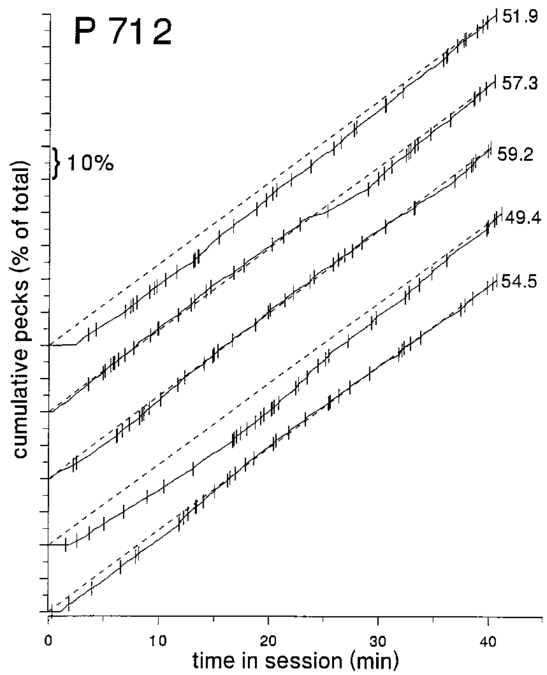

Fig. 1. Percentage cumulative records (solid lines) from the final five sessions of Pigeon 712's exposure to the VI 60-s schedule of reinforcement. Short vertical lines along the records depict food presentations. The absolute entire-session rate (pecks per minute) is indicated by the numbers to the right of each record. The dashed lines represent the record that would have been produced had the pigeon's rate of pecking been constant at that overall rate.

tained at 80% of its free-feeding weight. Food was presented by raising a grain hopper for 4 s, contingent on a key peck, according to a constant-probability variable-interval (VI) 60-s schedule of reinforcement. Sessions lasted until 40 reinforcers had been delivered. The figures are arranged so that those that represent every response (Figure 1) may be compared to those that represent response rates at several local levels of aggregation (Figures 2 and 3). In each case, the top-to-bottom order of the records is preserved from figure to figure. Figure 1 shows the percentage cumulative records. Performances from the last five sessions of this condition are depicted, with the last session's data at the bottom and the fifth-to-last session's data at the top. In order to view several sessions in the same figure, the cumulative peck percentages were incremented by 20% for the second record up, 40% for the third record up, and so on.

In each record, the dashed diagonal lines represent the rate that would have been observed had the pigeon's rates not deviated from the entire-session rate. Changes in response rates away from this constant-rate diagonal can be detected by comparing, over any time interval, the slopes of the obtained records from the diagonals. When the slopes differ, the response rate during that interval differs from the overall response rate; the position of the obtained record above or below the diagonal does not indicate whether the rate over a given interval deviates from the entire-session rate. If the obtained record is below the diagonal, but runs parallel to it, the obtained rate at that point is equal to the en-

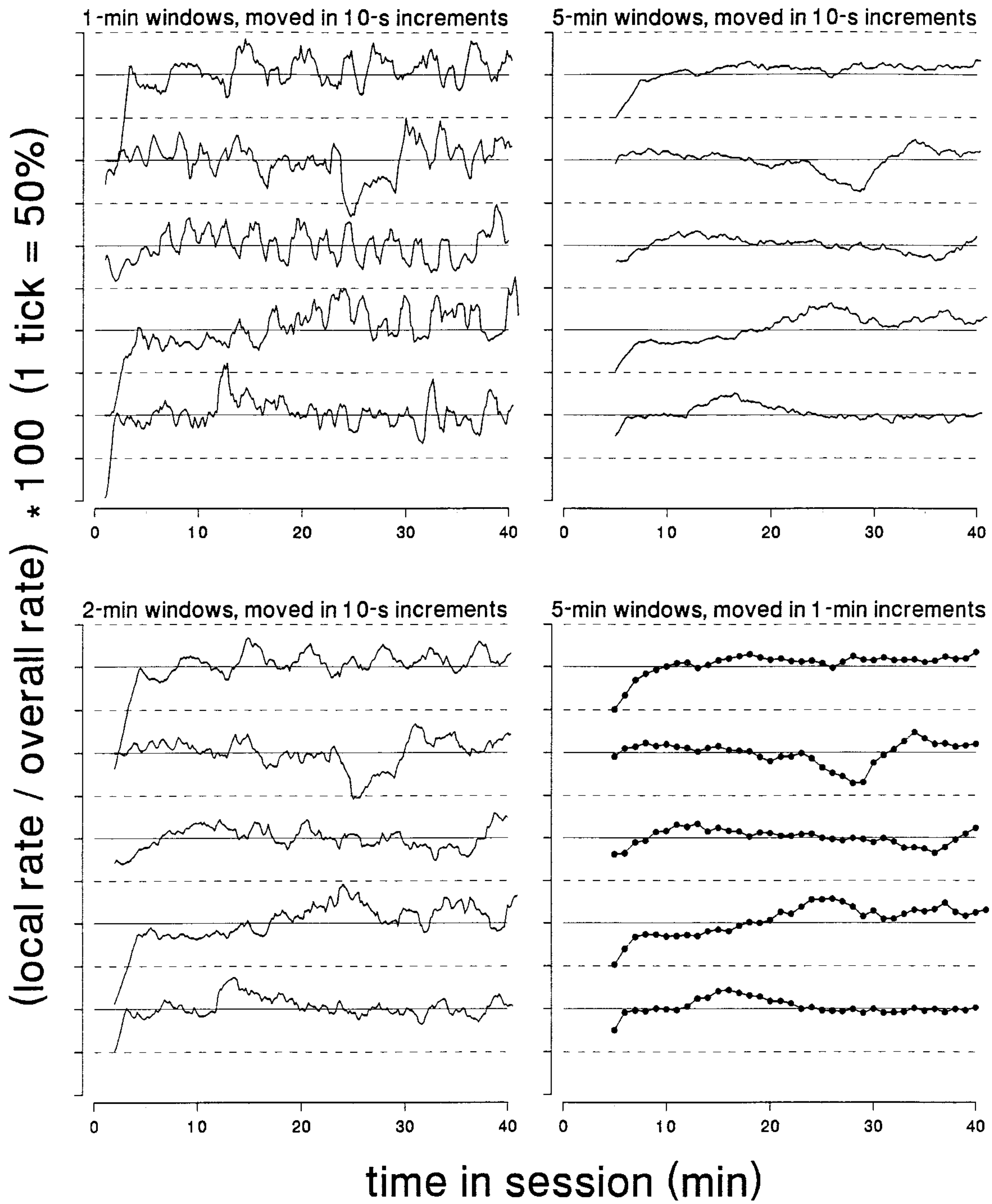

Fig. 2. Local response rates computed at various levels of aggregation and expressed as a percentage of the overall rate during the session for Pigeon 712. Solid horizontal lines represent the result that would be obtained if obtained rates did not differ from those predicted by the entire-session rate. The top-to-bottom order of the records corresponds to the order depicted in Figure 1.

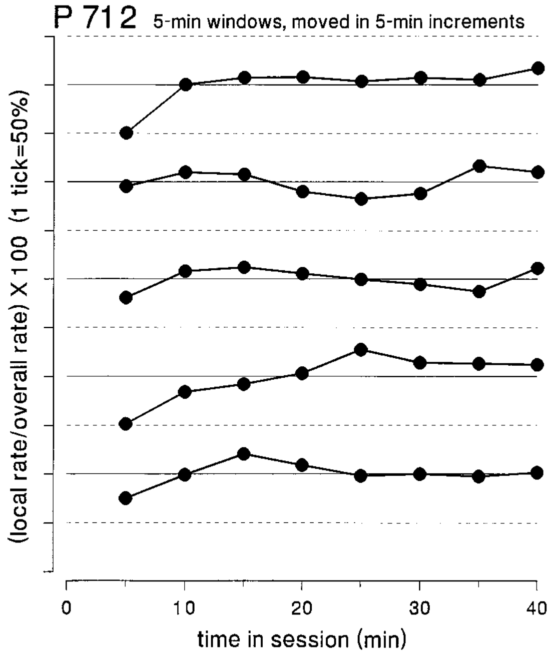

Fig. 3. Local response rates, computed by dividing rates obtained in 5-min segments of each session by the rates obtained during entire sessions and multiplying by 100%, for Pigeon 712. The data are the same as those in Figures 1 and 2, and the top-to-bottom order of the records corresponds to the order used in those figures.

tire-session rate. Therefore, one may track the courses of the obtained records relative to the diagonals, and identify the locations and durations of deviations of obtained rates from entire-session rates.

Deviations in local response rates from the entire-session rates are depicted at several levels of aggregation in Figure 2. The obtained rate in an *x*-min window was expressed as a percentage of the entire-session rate. For example, the upper left panel shows deviations in rates during 1-min windows moved forward 10 s after each relative rate calculation. Thus, six local rates were calculated per minute, approximately 240 per session. The solid horizontal lines correspond to the dashed lines in Figure 1, that is, they represent what would have been obtained if rates of responding during any segment of the session matched the entire-session rate. Thus, whenever the lines extend above or below the solid horizontal lines, a greater than or less than constant rate was obtained during that minute. These records reveal considerable deviation from entire-session response rates. As indicated by the records in Figure 1, the most reliable deviation appears at the beginnings of sessions when response rates were near zero for some variable duration. The other panels in Figure 2 show deviations from the entire-session rates for 2- and 5-min windows, moved forward in 10-s or 1-min increments. A comparison of the lines in the different panels reveals two likely features of the variability in response rates across a session. First, the magnitude of deviations in response rates from the entire-session rate depends on the sampling window. When responses are aggregated over 1 min, obtained rates vary considerably from the entire-session rate. As the window is increased in duration from 2 to 5 min, the magnitude of the deviations from the entire-session rates is reduced. Second, the period of the obtained rate deviations (roughly the time between the lows and the highs) is lengthened as the window is increased. Thus, local rates calculated over 5-min windows show smaller deviations from the entire-session rate and longer periods of relatively steady response rates than do local rates calculated over 1- or 2-min windows. The differences across panels support the assertion that a complete characterization of the manner in which response rates change during an experimental session depends critically on the interval over which local rates are compared to overall rates.

The records in Figure 3 were constructed using the same program that generated the data for Figure 2, except that obtained rates in each successive 5-min segment were expressed relative to the entire-session rate. This is similar to the method employed by McSweeney and associates, except that the deviations are represented as differences from the constant-rate prediction.

The methods used to generate the percentage cumulative records in Figure 1 can also be employed to depict responding on concurrent schedules. Figure 4 shows a record from a pigeon exposed daily to a concurrent VI VI schedule of reinforcement (arranged using a changeover-key procedure). From session to session, the assignment of VI schedule to key color was varied unpredictably. Cumulative pecks on either alternative were converted to percentages of the total pecks on both alternatives, and then plotted

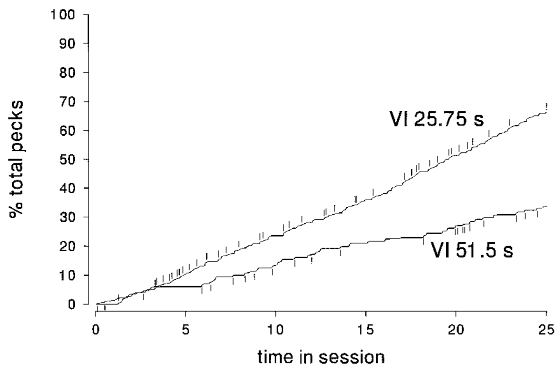

Fig. 4. Percentage cumulative records obtained from a pigeon pecking on a concurrent VI 25.75-s VI 51.5-s schedule of reinforcement using a changeover-key procedure. Pecks on either alternative were assigned a percentage value equal to 1.0 divided by total pecks on both alternatives.

above the time in the session that they occurred. The pigeon switched between alternatives during the initial portion of the session before responding predominantly on the richer of the two schedules. These records have proven to be useful in locating the point in the session that matching-like performance develops.

DISCUSSION

The key pecking of a pigeon under a VI 60-s schedule of food reinforcement was represented using percentage cumulative records. Shown in this way, it is apparent that response rates frequently deviated from what would have been obtained if the pigeon had pecked at a constant rate equal to that obtained for the entire session. Response rates were usually low near the beginnings of sessions, and the patterns within the session were roughly consistent across the session with previous reports of within-session changes in response rates. The properties and potential utility of the percentage cumulative records can be described as follows:

1. Their slope, over any interval of time, reflects the rate of response relative to the absolute rate. Thus, if the line that connects the y value at time = 20 min to the y value at time = 30 min has a greater slope than the constant-rate diagonal, then the response rate during that 10-min period is higher than the entire-session rate.

2. The magnitude of the deviations can be read directly from deviations in slope; and the time in the session at which deviations start and stop, and, hence, their duration, can also be read directly.

3. Because the interval over which proportional calculations are made is not fixed, relative increases or decreases of the obtained record from the constant rate can be computed over virtually any time interval one chooses (see Figures 3 and 4). Thus, perceived fluctuations in rates themselves can guide the investigator in the search for regular, within-session deviations from the constant-rate prediction.

The circumstances that gave rise to the method presented here included both the work of McSweeney and her associates and the state of the art of computer technology in the control and monitoring of operant experiments. The Turbo Pascal programs that calculated cumulative peck percentages and relative rates are fairly simple ones, and their functions are easily performed by programs written in other languages (e.g., VisualBasic, C++, Fortran, etc.). One could then either take advantage of the sophisticated scientific graphics programs that are available (Axum was used here, but several other programs would perform as well) or write additional code that handles the data presentation as well as its analysis. The memory capacity and processing speed of even inexpensive personal computers allow the rapid examination and presentation of volumes of data. The combination of extensive memory, rapid processing, and computer programming ability makes increasingly possible the examination of immense data sets in ways that depend only on the skill and goals of the individual researcher.

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