Computing lag sequential statistics on dyadic time interval data: The TLAG program

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Lag sequential statistics have been developed to assess contingency relationships within a series of behavioral codes (e.g., Allison & Liker, 1982; Bakeman, 1983; Bakeman & Gottman, 1986; Sackett, 1979; Sackett, Holm, Crowley, & Henkins, 1979). A common way of representing ongoing dyadic behavior is to code behavioral states and/or actions during successive time intervals (see Sackett, 1979). The purpose of the present paper is to describe a program written in IBM-BASIC that produces lag sequential statistics on two concurrent streams of interval codes. The TLAG program was written because this type of data cannot easily be analyzed by existing FORTRAN programs (Bakeman, 1983; Sackett et al., 1979), which were designed to analyze single streams of behavioral codes and are more effectively used with event codes (see the ELAG program, Bakeman, 1983). Mother-infant interaction research will be used to illustrate the use of TLAG.

General Capabilities

Interactive behavior is often coded either as a sequence of discrete events without a real-time base (event coding) or as a sequence of occurrences/non-occurrences of behavior during adjacent time intervals (interval coding). Event coding incorporates actions by both interactants into a single stream. Interval coding of interactive behavior can also be reduced into a single stream, but this method is most effective when each interactant's behavior is coded as an independent behavior stream. Although both event coding and interval coding have advantages and limitations (see Altmann, 1974; Sackett, 1979; Simpson, 1979), interval coding retains both sequential and real-time information.

The focus in the analysis of social interaction, and therefore in the TLAG program, is the contingency or sequential dependency between the actions of two interactants. The first stage of this analysis is the transformation of the original interval-coded data set for each interactant into a stream of intervals coded as including either a change or no change in behavior. The definition of change/no change, and thus the nature of this transformation, is a function of the question at hand. For example, maternal imitation of infant smiling may be evaluated by reducing a complex set of codes to "smile/no smile." The original stream of codes remains available for further transformation suiting different purposes.

The logic of the TLAG program can be illustrated with an example from a recent analysis in a research program in which Symons and Moran (1987) described free-play interactions between mothers and their 3-month-old infants. Behavior in four categories was independently coded as occurring (1) or not occurring (0). Vocalizations, smiles, and gazes at the partner were coded for both interactants. In addition, a mother's touching of her infant was coded for the mother, and the infant's crying was coded for the infant. Action in each category was coded in each of 180 1-sec intervals over a 3-min episode of continuous interaction. A data file for one episode thus was composed of 1s and 0s in a matrix of 8 columns (4 mother and 4 infant behaviors per second) and 180 rows (1-sec intervals).

In the most straightforward analysis when only one code, smiling, was entered into the transformation, we found that onsets of smiling by an infant were followed by onsets of smiling by the mother more frequently than expected by chance. This pattern of maternal imitation occurred at a number of 1-sec lags and in several other categories of behavior (Moran, Krupka, Tutton, & Symons, 1987). In a related study, we defined action for both interactants as a change in any coded category of behavior. The analyses revealed that both mothers and infants were behaviorally responsive to changes in behavior by their social partners (Symons & Moran, 1987). This analysis was derived from the version of TLAG presented in this article.

There has been recent discussion regarding the details of the statistic best suited to sequential analysis (see Allison & Liker, 1982; Bakeman, 1983). TLAG calculates z statistics for each subject-pair as the square root of the chi-square statistic for a 2×2 contingency table (see Dumas, 1986) of the change/no change in behavior of each of two interactants. This yields normalized values equal to those derived according to the formula proposed by Allison and Liker (1982). TLAG also calculates a mean z statistic for the sample, because any population of z scores has an expected mean of 0 and a standard deviation of 1, and this mean can be tested for significant deviation from the expected mean z score for a sample of a given size (as suggested by Sackett, 1979, p. 645). This is a conservative way of utilizing sequential analyses with groups of subject-pairs when the contingency tables have similar unconditional base rates of behavior and total number of observations (Moran & Symons, 1987). However, there is some concern about heterogeneity of Markov chains of behavior across dyads (see Gardner, 1987).

Gardner and Hartmann (1984) have explained two kinds of dependency contained in the coded behavior streams of two interactants: dependency within the data of each interactant (serial dependency or autocorrelation) and dependency between the interactants' data (joint dependency or cross-correlation) (see also Allison & Liker, 1982;

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Dumas, 1986; Gardner, Hartmann, & Mitchell, 1982). The presence of autocorrelation can significantly affect measures of cross-correlation. Therefore, any assessment of cross-correlation must be corrected for the autocorrelation within each interactant's data. TLAG employs such a correction for first-order Markov autocorrelation (see Dumas, 1986; Gardner & Hartmann, 1984).

In summary, the strengths of the current BASIC program are that (1) it reads parallel streams of multiple codes of dyadic time interval data, (2) it incorporates important controls for autocorrelation so that dependency between interactants can be accurately assessed, and (3) it is intended to be readily understood and modifiable by other users. The program is written in IBM-BASIC, but is easily convertible to other forms of BASIC and also requires very little computer memory to run. It can therefore be used with almost any type of computer system. Finally, the program can be converted to many types of contingency analyses by changing IF statements.

Specific Capabilities

TLAG is written in IBM-BASIC and functions by reading a data file for a dyad, calculating and saving sequential statistics, and then repeating all steps for subsequent dyads (see Listing 1).

Reading a Data File. Data is input in lines 100-120 using OPEN, READ, and INPUT statements from data files listed in line 90. Each of these is read as a $C \times N$ array, where C is the number of coded behaviors in

columns and N is the number of time blocks in rows, with C and N input in lines 40 and 50, respectively. A REM statement in line 130 allows a record of which columns contain which coded behaviors for each interactant. The program is currently set up to read the four maternal behaviors and four infant behaviors detailed earlier in this paper. It has been used with 1,0 dichotomous codes but can also read polytonous codes within each behavioral category with no modifications.

Recoding Data. TLAG analyzes the 2×2 contingency tables of the dichotomous variables $M(N)$ and $B(N)$, respectively representing maternal and infant change or no change in behavior. The IF statements in lines 160-230 designate the information from the data file that defines these changes in behavior. The IF statements are currently set to give $M(N)$ a value of 1 when any of the mother's coded behaviors change from the previous second and a value of 0 when there is no change. Similarly, $B(N)$ is given a value of 1 for any infant change in behavior and 0 for no change. The values of $M(N)$ and $B(N)$ can be functions of different codes to address many other theoretically relevant research questions. For example, in studies of imitation, data from the maternal and infant smiling codes would go into the recoding procedure to investigate the sequential relations of mother and infant change in smiling behavior.

Analysis of 2×2 Contingency Tables. The recoded streams of $M(N)$ and $B(N)$ are analyzed in a number of different ways to obtain meaningful measures of sequen-

LISTING 1
The TLAG Program Written in IBM-BASIC for Calculating Lag Sequential Statistics
on Dyadic Time Interval Data

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10 REM COMPUTING LAG SEQUENTIAL STATISTICS ON MULTIPLE STREAMS OF BEHAVIOURAL
20 REM TIME SAMPLE DATA: THE TLAG PROGRAM
30 REM SYMONS, WRIGHT, & MORAN, U.W.O., LONDON, ONT., CANADA, N6A 5C2
40 INPUT " HOW MANY CODES ARE IN THIS DATA SET";C
50 INPUT " HOW MANY BLOCKS ARE IN THIS DATA SET";N
60 INPUT " HOW MANY LAGS ARE TO BE ANALYZED";L
70 INPUT "HOW MANY SUBJECTS ARE IN THIS DATA SET";Q
80 DIM M(N),B(N),RES(Q,6,L+1),D(C,N),MEAN(6,L+1),SD(6,L+1)
90 DATA "DYAD1","DYAD2","DYAD3","DYAD4","DYAD5","DYAD6","DYAD7","DYAD8","DYAD9",
"DYAD10","DYAD11","DYAD12","DYAD13","DYAD14","DYAD15","DYAD16","DYAD17","DYAD18",
"DYAD19","DYAD20"
100 REM INPUT DATA FROM DATA MATRICES
110 FOR K=1 TO Q:READ A$:OPEN A$ FOR INPUT AS #1
120 FOR I=1 TO N:FOR J=1 TO C:INPUT #1,D(J,I):NEXT J:NEXT I:CLOSE
130 REM THE CODES FOR THIS DATA ARE 1=MV,2=ML,3=MS,4=MT,5=BV,6=BL,7=BS,8=BC
140 REM RECODE INTO CHANGE/ NO CHANGE. ENTER ALL MOTHER AND INFANT BEHAVIOURS
150 FOR I=1 TO N-1:M(1)=0:B(1)=0:M(I+1)=0:B(I+1)=0
160 IF D(1,I)<>D(1,I+1) THEN M(I+1)=1
170 IF D(2,I)<>D(2,I+1) THEN M(I+1)=1
180 IF D(3,I)<>D(3,I+1) THEN M(I+1)=1
190 IF D(4,I)<>D(4,I+1) THEN M(I+1)=1
200 IF D(5,I)<>D(5,I+1) THEN B(I+1)=1
210 IF D(6,I)<>D(6,I+1) THEN B(I+1)=1
220 IF D(7,I)<>D(7,I+1) THEN B(I+1)=1
230 IF D(8,I)<>D(8,I+1) THEN B(I+1)=1
240 NEXT I
250 REM CALCULATING THE LAG 1 AUTOCORRELATION CORRECTION FACTOR
260 AA=0:BB=0:CC=0:DD=0:FOR I=1 TO N-1
270 IF M(I)=1 AND M(I+1)=1 THEN AA=AA+1
280 IF M(I)=1 AND M(I+1)=0 THEN BB=BB+1
290 IF M(I)=0 AND M(I+1)=1 THEN CC=CC+1
300 IF M(I)=0 AND M(I+1)=0 THEN DD=DD+1
310 NEXT I:GOSUB 750:PHI2=PHI:PHI=(AA+BB)/N:AA=0:BB=0:CC=0:DD=0:FOR I=1 TO N-1
320 IF B(I)=1 AND B(I+1)=1 THEN AA=AA+1

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LISTING 1 (Continued)

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330 IF B(I)=1 AND B(I+1)=0 THEN BB=BB+1
340 IF B(I)=0 AND B(I+1)=1 THEN CC=CC+1
350 IF B(I)=0 AND B(I+1)=0 THEN DD=DD+1
360 NEXT I:GOSUB 750:PHI3=PHI:PR2=(AA+BB)/N:GAMMA=(1-PHI2*PHI3)/(1+PHI2*PHI3)
370 REM CALCULATING MATERNAL AND INFANT RESPONSIVENESS AT LAG L
380 FOR J=0 TO L:AA=0:BB=0:CC=0:DD=0:FOR I=1 TO N-J
390 IF M(I+J)=1 AND B(I)=1 THEN AA=AA+1
400 IF M(I+J)=1 AND B(I)=0 THEN BB=BB+1
410 IF M(I+J)=0 AND B(I)=1 THEN CC=CC+1
420 IF M(I+J)=0 AND B(I)=0 THEN DD=DD+1
430 NEXT I:GOSUB 750:CHIA=CHI*GAMMA:ZU=SQR(CHI):ZA=SQR(CHIA)
440 IF N3<0 THEN ZU=-ZU
450 IF N3<0 THEN ZA=-ZA
460 RES(K,1,J+1)=PR1:RES(K,2,J+1)=PR2:RES(K,3,J+1)=ZU:RES(K,4,J+1)=ZA
470 AA=0:BB=0:CC=0:DD=0:FOR I=1 TO N-J
480 IF B(I+J)=1 AND M(I)=1 THEN AA=AA+1
490 IF B(I+J)=1 AND M(I)=0 THEN BB=BB+1
500 IF B(I+J)=0 AND M(I)=1 THEN CC=CC+1
510 IF B(I+J)=0 AND M(I)=0 THEN DD=DD+1
520 NEXT I:GOSUB 750:CHIA=CHI*GAMMA:ZU=SQR(CHI):ZA=SQR(CHIA)
530 IF N3<0 THEN ZU=-ZU
540 IF N3<0 THEN ZA=-ZA
550 RES(K,5,J+1)=ZU:RES(K,6,J+1)=ZA:NEXT J:NEXT K
560 REM CALCULATING MEANS AND SD'S FOR DATA IN RESULTS ARRAYS
570 FOR J=1 TO L+1:FOR K=1 TO 6:M1=0:SD1=0:FOR I=1 TO Q
580 M1=RES(I,K,J)+M1:NEXT I:MEAN(K,J)=M1/Q:FOR I=1 TO Q
590 SD1=(RES(I,K,J)-M1/Q)^2+SD1:NEXT I
600 SD(K,J)=SQR(SD1/(Q-1)):NEXT K:NEXT J
610 REM PRINT FORMAT STATEMENTS FOR LINEPRINTER OUTPUT
620 LPRINT:LPRINT
630 FOR I=0 TO L
640 LPRINT "          P(SIGNALS)  MEASURES OF RESPONSIVENESS AT LAG";I
650 LPRINT "  DYAD      MOM      INFANT      MOMU      MOMA      BABYU      BABYA "
660 LPRINT
670 FOR K=1 TO Q
680 LPRINT USING "####.## " ;K,RES(K,1,I+1),RES(K,2,I+1),RES(K,3,I+1),RES(K,4,I+1),
690 RES(K,5,I+1),RES(K,6,I+1)
690 NEXT K:LPRINT
700 LPRINT "MEAN Z " ;
710 LPRINT USING "####.## " ;MEAN(1,I+1),MEAN(2,I+1),MEAN(3,I+1),MEAN(4,I+1),MEAN(5,I+1),MEAN(6,I+1)
720 LPRINT "S.D. " ;
730 LPRINT USING "####.## " ;SD(1,I+1),SD(2,I+1),SD(3,I+1),SD(4,I+1),SD(5,I+1),SD(6,I+1)
740 LPRINT:LPRINT:NEXT I:END
750 REM THIS IS THE SUBROUTINE CALCULATION
760 PHI=0:CHI=0:N2=AA+BB+CC+DD:N3=(AA*DD)-(BB*CC)
770 N4=(AA+BB)*(AA+CC)*(CC+DD)*(BB+DD):PHI=N3/SQR(N4):CHI=N2*PHI*PHI
780 RETURN

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tial dependency between interactants. A number of analyses consist of chi-square statistics based on 2×2 contingency tables, so these calculations are conducted in a subroutine in lines 750-780.

First, measures of autocorrelation are determined at lag 1 for M(N) data and B(N) data in lines 250-360. These measures are used to calculate the correction for autocorrelation, GAMMA, by which all subsequent chi-square measures of sequential dependency between interactants are multiplied.

Second, measures of sequential dependency at L lags (input in line 60) are calculated. Sequential measures are of both mother at time T versus infant at time T+L (infant responsiveness in lines 480-510) and infant at time T versus mother at time T+L (maternal responsiveness in lines 390-410). Measures saved are z scores, unadjusted and adjusted for autocorrelation.

Compiling and Printing Information. TLAG allows the analysis of Q data sets (input in line 70; matches the number of data sets listed in line 90). For each data set, an LPRINT statement outputs the dyad number, the base rates of mother and infant change in behavior, and unadjusted and adjusted z scores for co-occurrence and maternal and infant responsiveness at L lags. The means and standard deviations of each of these variables are calculated in lines 560-600, and printing instructions are given in lines 610-740.

Other print formats and statements can be utilized to output additional relevant information, such as measures of autocorrelation or actual cell values of the 2×2 contingency tables. The output modality is currently the line printer, but minor modifications can send output to either the computer screen or an output file using PRINT or WRITE statements, respectively.

Availability

The authors have prepared a 5.25-in. flexible disk that contains the TLAG program and dummy data sets to illustrate its use. This disk can be obtained along with documentation by sending a disk and \$5 for postage and handling to: Douglas K. Symons, Department of Psychology, University of Western Ontario, London, ON N6A 5C2, Canada.

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