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USING MICROSOFT OFFICE EXCEL® 2007 TO CONDUCT GENERALIZED MATCHING ANALYSES

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The generalized matching equation is a robust and empirically supported means of analyzing relations between reinforcement and behavior. Unfortunately, no simple task analysis is available to behavior analysts interested in using the matching equation to evaluate data in clinical or applied settings. This technical article presents a task analysis for the use of Microsoft Excel to analyze and plot the generalized matching equation. Using a data-based case example and a step-by-step guide for completing the analysis, these instructions are intended to promote the use of quantitative analyses by researchers with little to no experience in quantitative analyses or the matching law.

DESCRIPTORS: choice, generalized matching equation, matching law, Microsoft Excel, technology

In recent years, behavior analysts have applied the generalized matching equation (see Baum, 1974, 1979; Davison & McCarthy, 1988) to topics outside the laboratory, such as problem behavior (Borrero & Vollmer, 2002), sports (Reed, Critchfield, & Martens, 2006; Romanowich, Bourret, & Vollmer, 2007; Vollmer & Bourret, 2000), academics (Mace, Neef, Shade, & Mauro, 1994; Reed & Martens, 2008), and social dynamics (Borrero et al., 2007). However, it can be inferred that all behavior-change procedures rely on some deviation from the matching law given the presence of concurrent schedules of reinforcement or differential consequences that underlie any reinforcement- or punishment-based procedure (see McDowell, 1988). These discussions highlight an increasing interest in bridge research, which seeks to translate the findings from basic laboratory studies to social concerns (see Fisher & Mazur, 1997). As discussed by Lerman (2003), the successful translation of basic findings to applied settings represents our field's primary goal of understanding the basic processes that underlie behavior in an effort to effectively and efficiently target behaviors for change. Through this process, applied behavior analysts offer generalizability to experimental procedures and ultimately arrive at interventions that are conceptually consistent with basic operant principles. Ultimately, such translation provides practitioners with the analytical tools used by basic and translational researchers, which achieves two goals: (a) Practitioners will better understand principles of learning theory and how basic research analyzes such data, and (b) practitioners will have an additional analytical tool that they can translate to their clinical work to better understand behavior–consequence interactions. Although the calculations involved in regression and matching analyses are surprisingly easy with regards to the difficulty of the mathematical operations involved, they are also relatively time consuming and may be tedious to compute by hand or calculator. Fortunately, Microsoft Office Excel 2007, a widely available and commonly used spreadsheet program, can quickly compute all of the regression calculations necessary for matching analyses using the generalized matching equation, as well as making matching plots. The purpose of this technical report is to guide the

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reader through the use of Excel in the calculation and plot generation of two alternative generalized matching analyses, using hypothetical data from an example case study. Although the focus of this tutorial is on Excel 2007, any noteworthy differences in the task analysis for previous versions of Excel are detailed.

As an example, imagine that an applied behavior analyst recently took a position in a private school setting serving children with developmental disabilities. In one classroom in which the analyst consults, she is asked to conduct a functional assessment of a recently admitted student's out-of-seat behavior. As she reviews the student's case history, she notices that a functional analysis was conducted by the student's previous consultant less than 1 month ago. The results of the previous functional analysis suggested that her student's out-of-seat behavior was maintained by social approval and disapproval (i.e., attention). Thus, she hopes to confirm these findings without having the student participate in another full functional analysis. In particular, as part of her descriptive assessment, she records the duration of in-seat and out-of-seat behavior across five 1-hr observations. In addition, she records the number of vocal statements directed to the student by all classroom staff and peers (including praise and reprimand statements) while the student is either in seat or out of seat. Using the generalized matching equation, she plans to determine whether or not there is indeed a relation between levels of behavior and contiguous (i.e., occurring together in time) attention from individuals in the classroom (cf. St. Peter et al., 2005). If a relation is found, then these data would lend some credence to the hypothesis that the student's out-of-seat behavior is attention maintained. These hypothetical data are displayed in Table 1. With these data in hand, she is now able to analyze her descriptive assessment data using the generalized matching equation.

Table 1
Hypothetical Data for Analysis Using Matching Equations

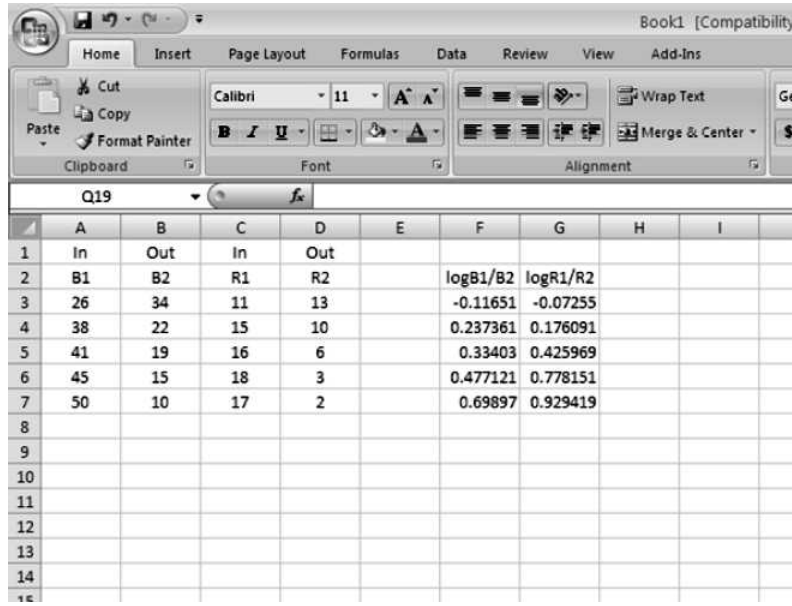
B_1 (Duration in seat)	B_2 (Duration out of seat)	R_1 (attention| in seat)	R_2 (Attention| out of seat)
26	34	11	13
38	22	15	10
41	19	16	6
45	15	18	3
50	10	17	2

Creating the Spreadsheet

1. To create the spreadsheet, open a new blank workbook in Excel 2007. Next, recreate Table 1 in the workbook by inputting the duration of in-seat behavior in Column A, the duration of out-of-seat behavior in Column B, the number of instances of the delivery of attention during in-seat behavior in Column C, and the number of the number of instances of the delivery of attention during out-of-seat behavior in Column D. Rows 1 and 2 are used to label the columns. Row 1 should denote which response alternative (i.e., in seat or out of seat in the current example) the data in the columns below represent. Thus, key the word "in" in Cells A1 and C1 and "out" in Cells B1 and D1. Row 2 will specify the kind of data presented (behaviors [B] or obtained reinforcers [R]). In Cell A2, key the term "B1" and in Cell B2 "B2." For the reinforcement columns, label Cells C2 and D2 by keying the terms "R1" and "R2," respectively.

2. Next, create the logarithmically transformed behavior and reinforcement ratios in order to conduct the regression to complete the matching analysis using the generalized matching equation. In an effort to keep the raw data separate from the transformed data, skip one column and place the cursor in Cell F2. Label Cell F2 by keying the term "logB1/B2." To the right of Cell F2, label Cell G2 by keying the term "logR1/R2."

3. To complete the logarithmic transformation, place the cursor in Cell F3 and key "=log10" and then key an open parenthesis "(" to specify Excel to use the base 10 logarithm of the data. Next, without pressing ENTER, direct



	A	B	C	D	E	F	G	H	I	J
1	In	Out	In	Out						
2	B1	B2	R1	R2		logB1/B2	logR1/R2			
3	26	34	11	13		-0.11651	-0.07255			
4	38	22	15	10		0.237361	0.176091			
5	41	19	16	6		0.33403	0.425969			
6	45	15	18	3		0.477121	0.778151			
7	50	10	17	2		0.69897	0.929419			
8										
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Figure 1. Screen shot depicting how the Excel spreadsheet should appear after completing Step 5 of creating the spreadsheet.

Excel to the cell in which the data are located. Because the first B_1/B_2 ratio to convert is for the behavior ratio data in Row 3, click Cell A3 and Excel will enter A3 into the equation in Cell F3—again, do not press ENTER at this point. However, the goal of this step is to transform the ratio of B_1/B_2, not just B_1. Thus, type in a forward-slash "/" to tell Excel to create a ratio and then click on Cell B3 to complete the ratio of B_1/B_2. To finish the operation, key a closed parenthesis by typing ")" and press ENTER on the keyboard. Excel will automatically compute the transformation, and the value −0.11651 will appear in Cell F3.

4. Continue following these procedures to complete the remaining logarithmic transformations for the B_1/B_2 ratios or simply click on F3 and then click on the black square in the lower right corner of Cell F3 and drag down to Cell F7 to have Excel automatically complete the transformations for all remaining B_1/B_2 data.

5. Follow Steps 3 and 4 above for the G column to complete the log R_1/R_2 transformations, making sure to use the data from Columns C and D. The spreadsheet should now be identical to that in Figure 1. These data are now formatted for the regression analysis using the generalized matching equation.

Creating the Plot

1. To begin the regression analysis, first create a scatterplot of the logarithmically transformed behavior and reinforcement ratios. To tell Excel where the data for the scatterplot are located, click on Cell F3 (i.e., the first log B_1/B_2 ratio) and drag the cursor to Cell G7 (i.e., the last log R_1/R_2 ratio), selecting all log ratios. A black rectangle will now surround the perimeter of the log-ratio columns.

2. Next, click on the INSERT tab on the toolbar to open the graphing options in Excel (in earlier versions, simply click the chart icon on the toolbar). There will now be a selection of graph options from which to choose. Select the SCATTER option (XY SCATTER in previous versions) to bring up the scatter types and select

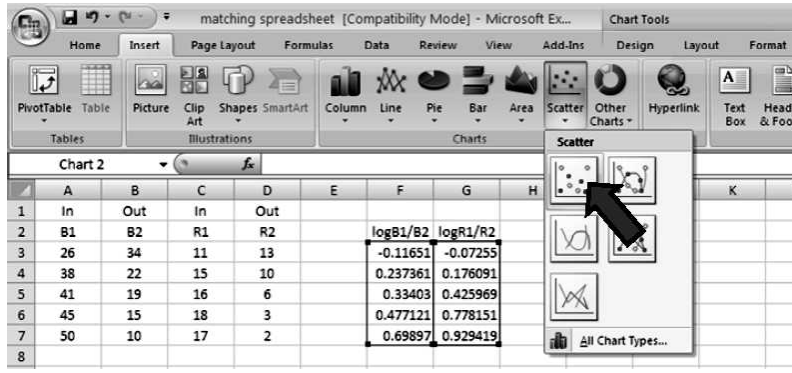

Figure 2. Screen shot depicting the scatterplot option to select in Step 2 of creating the plot, with an arrow directing the reader to the correct option.

the first option (i.e., data points with no connecting lines, titled "Scatter with only Markers"; see Figure 2). In Excel 2007, the plot will appear in the workbook (in earlier versions, the CHART WIZARD will appear; simply complete the CHART WIZARD using the specifications provided here for Excel 2007).

3. Add axis titles by clicking on the LAYOUT tab on the toolbar and then select the AXIS TITLES tab. For the PRIMARY HORIZONTAL AXIS TITLE, select the TITLE BELOW AXIS option (see Figure 3). AXIS TITLE should now appear on the *x* axis. Double click the title and highlight the text, then key "log R1/R2," move the mouse pointer somewhere outside the title, and left click.

4. Follow the same procedures to complete the PRIMARY VERTICAL AXIS TITLE, this time selecting ROTATED TITLE and keying "log B1/B2" to complete the *y* axis. Then move the axis labels by clicking on a label and dragging it to a desired position. In earlier versions, simply type in the axis labels on STEP 3 of the CHART WIZARD, then select FINISH.

5. To make the plot more visually appealing, right click on the *x* axis and then click FORMAT AXIS. Under the AXIS OPTIONS tab, click the buttons marked FIXED to the right of the MINIMUM and MAXIMUM labels and set the MINIMUM and MAXIMUM scale values to −1 and 1, respectively (note that these values were chosen to create a plot large enough to present each data point; other data sets may require differing values; see Figure 4). In earlier versions, you can do this by right clicking on any tick label (i.e., a number) on the *y* axis and then selecting the SCALE tab (if it is not already open) on the FORMAT AXIS window, clicking OKAY when finished.

6. Under the VERTICAL AXIS CROSSES header of the AXIS OPTIONS window, click on the AXIS VALUE button and then enter the same MINIMUM value from Step 5 above. Click CLOSE. In earlier versions, this step may be completed by right clicking on any number on the *x* axis and then selecting the SCALE tab (if it is not already open) on the FORMAT AXIS window and entering the minimum value (in this example, −1) under the VALUE (X) AXIS CROSSES AT option and then clicking OKAY.

7. Under the HORIZONTAL AXIS CROSSES header of the AXIS OPTIONS window, click on the AXIS VALUE button and then enter the same MINIMUM and MAXIMUM values from Step 5 above. Click CLOSE. In earlier versions, this may be achieved by right clicking on any number on the *x* axis and then selecting the SCALE tab (if

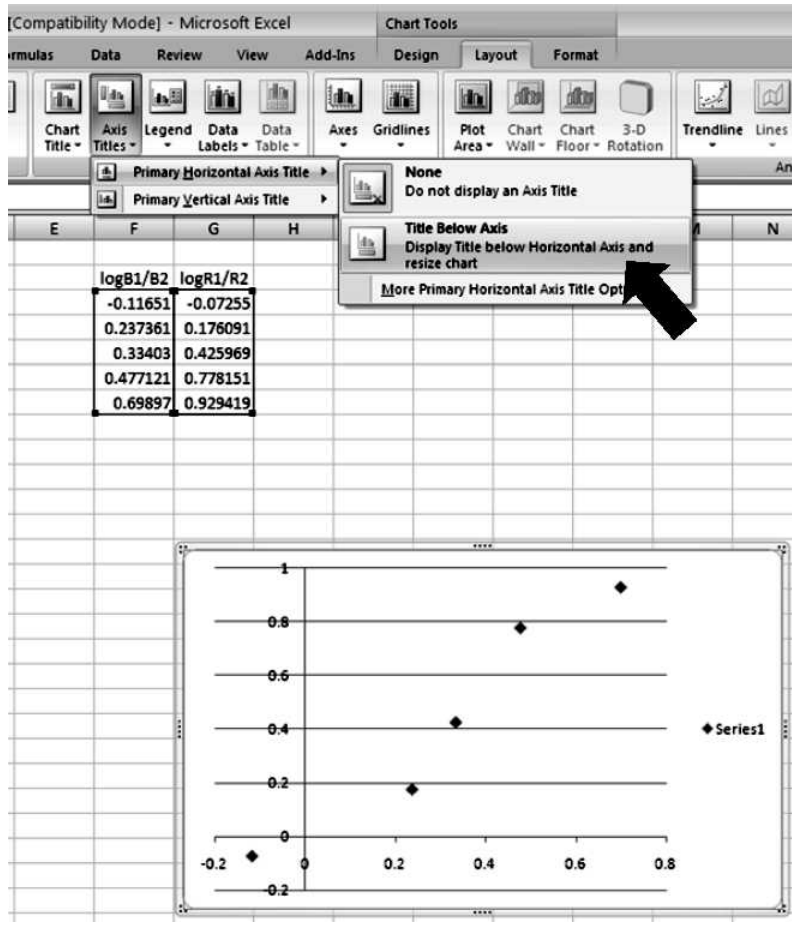

Figure 3. Screen shot associated with Step 3 of creating the plot, indicating the "title below axis" option with an arrow.

it is not already open) on the FORMAT AXIS window and entering the minimum value (in this example, −1) under the VALUE (Y) AXIS CROSSES AT option and then clicking OKAY.

8. Because there is only one series of data plotted, it is irrelevant to have a series label. Thus, click on the SERIES1 label to the right of the plot and press DELETE.

9. To delete the horizontal lines on the plot, simply click any of the horizontal lines above or below the *x* axis and press DELETE.

10. Click on the TRENDLINE option on the toolbar (assuming the LAYOUT tab is still open) and select the MORE TRENDLINE OPTIONS button (see Figure 5). With the TRENDLINE OPTIONS window up (see Figure 6), make sure that the button associated with LINEAR is marked. Next, click the boxes next to the DISPLAY EQUATION ON CHART and the DISPLAY R-SQUARED VALUE ON CHART options and click CLOSE. For earlier versions, open the ADD TRENDLINE window by right clicking on any data point on the plot, then clicking the CHART button on the toolbar. Close the window by clicking OKAY when all options are selected to display the regression equation on the plot (i.e., "$y = 1.3228x + 0.0159$, $R^2 = 0.9325$"). Next, point the mouse on the equation that now appears on the plot and left

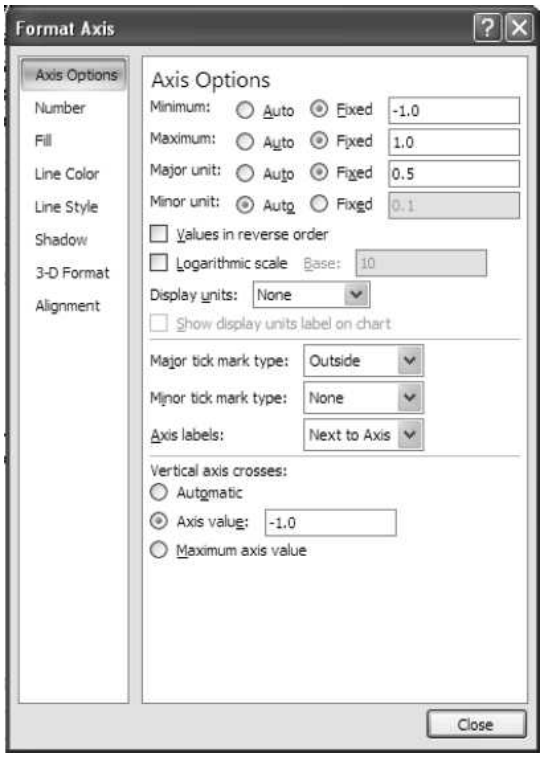

Figure 4. Screen shot of the Excel format axis option box with the correct modifications specified in Step 5 of creating the plot.

click to drag the equation to an open area within the plot.

11. Right click inside any corner of the plot to open the Excel options window and select the FORMAT CHART AREA option. Next, click BORDER COLOR and then select the NO LINE option and CLOSE (in earlier versions, select NONE under the BORDERS header on the PATTERNS tab and OKAY) and CLOSE.

12. In addition, for earlier versions, right click on the plot and select FORMAT PLOT AREA. With the FORMAT PLOT AREA window up, select NONE under both the AREA and PATTERNS headings to remove the gray background from the plot. Click OKAY to close the window. The plot (see Figure 7) is now complete and ready for any personal customization of formatting.

The generalized matching equation, adapted from and expanding on Herrnstein's matching law (cf. Herrnstein, 1961), compares units[1] of reinforcement from multiple response alternatives with the respective units[2] of responding at each alternative. Specifically, the generalized matching equation states that

$$\log\left(\frac{B_1}{B_2}\right) = a\log\left(\frac{R_1}{R_2}\right) + \log b,$$

where B represents the responding at two alternatives (Subscripts 1 and 2) and R represents the reinforcement. Plotting these relative behavior and reinforcement ratios derives the parameters a and b. Parameter a is the slope of the best fit line that is associated with how sensitive the individual is to the reinforcement contingencies (i.e., slopes near 1.0 suggest that the individual adapted his or her behavior to maximize the efficiency of obtaining reinforcement). Parameter b represents a bias that the individual may have for one alternative over another that cannot be explained by merely comparing rates of reinforcement (bias parameters greater than zero suggest a bias towards the first alternative, and parameters less than zero indicate a bias towards the second alternative). Thus, this equation permits the applied behavior analyst to quantify an individual's choice of behaviors during a reinforcement-based procedure to understand how well reinforcement accounts for changes in behavior. When the behavior analyst sees a slope (parameter a) near 1.0, he or she can reasonably assume that the individual may indeed be adapting his or her behavior to the

[1]In most applications of the matching law (including those using the generalized matching equation), the typical schedule of reinforcement is interval based. Ratio-based schedules are not commonly used in matching studies due to the natural relation between response rate and reinforcement rate. Specifically, because reinforcement rate is dependent on response rate in ratio-based schedules, the two are inherently correlated. Thus, any apparent matching relation may merely be an artifact of the schedule itself rather than a demonstration of the matching law.

[2]Another useful behavior metric that may be used in lieu of rates or intervals is duration (Baum & Rachlin, 1969), as is used in this article's case example. Recent published applied matching studies demonstrate the benefits of this unit of analysis (Borrero et al., 2007; Oliver, Hall, & Nixon, 1999).

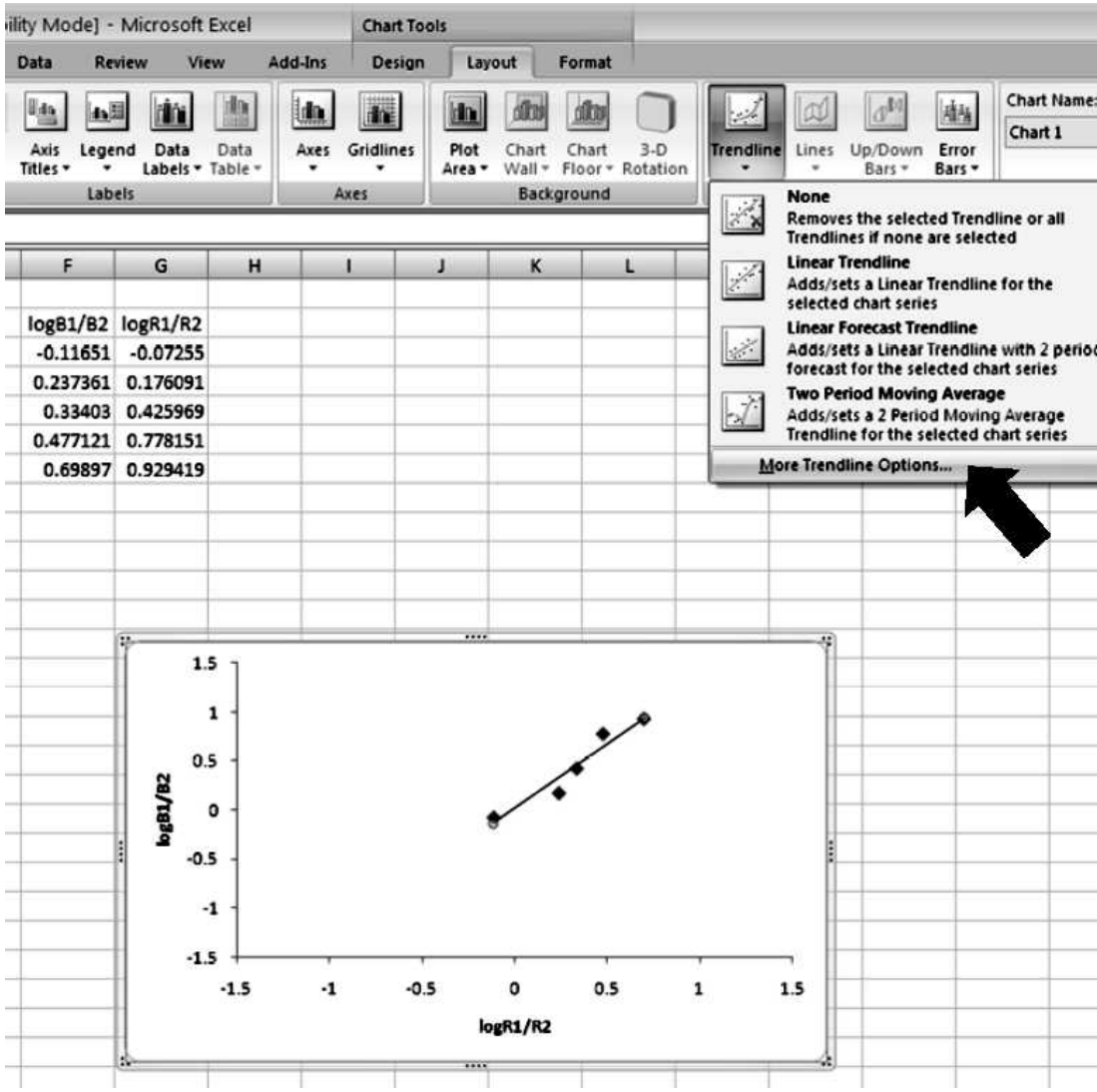

Figure 5. Screen shot using an arrow to direct the reader how to find the "more trendline options" menu referenced in Step 10 of creating the plot.

reinforcement schedules in the environment. Because the slope in the current example is 1.3228 (i.e., slightly greater than 1.0; see Figure 7), the behavior analyst would note that relative ratios of behavior seemed to match relative ratios of reinforcement, implying that attention was indeed serving as a reinforcer. Thus, from a functional assessment standpoint, these data suggest that attention may be the function for out-of-seat behavior. Likewise, the behavior analyst can inspect the bias parameter *b* to see if the individual is perhaps partial to one behavioral alternative over another, despite the reinforcement schedules he or she has put in place. If the bias parameter is substantially greater than zero, a bias exists for the response alternative in the numerator of the log ratios, and negative biases refer to the denominator. The bias parameter obtained in this example was near zero (i.e., 0.0159); thus, it did not appear that the student had a bias for either behavioral alternative that could not be ex-

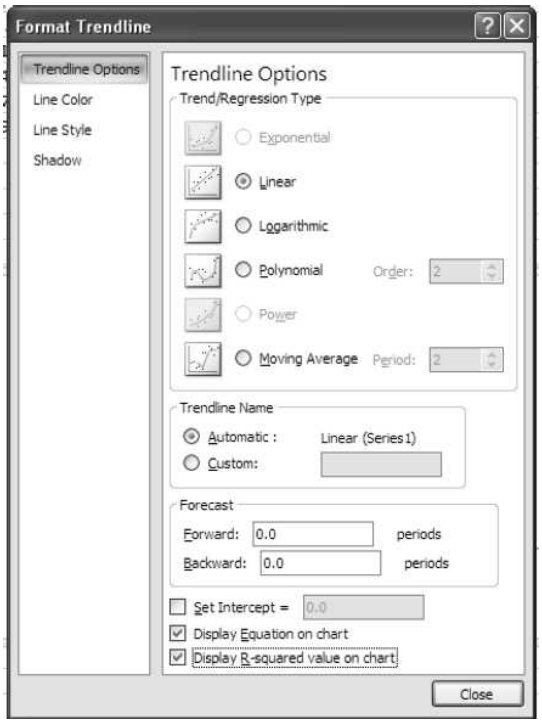

Figure 6. Screen shot of the "trendline options" tab of the "format trendline" menu box with the proper specifications made in reference to Step 10 of creating the plot.

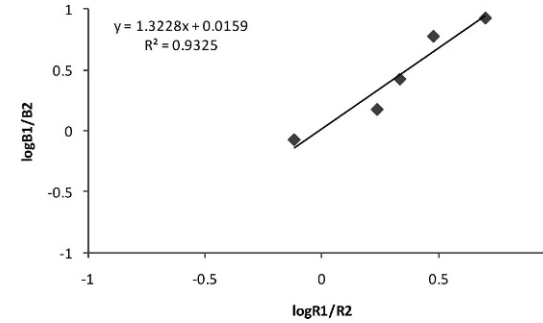

Figure 7. Final matching plot of the case example used throughout the task analysis, with the derived generalized matching equation displayed in the upper left corner.

plained by reinforcement alone. Finally, the generalized matching equation (similar to a correlation) allows the behavior analyst to quantify the degree to which the matching law accounts for the individual's distribution of behavior as a function of reinforcement schedules through a variance accounted for (VAF) metric denoted by R^2. The VAF metric ranges between 0 (i.e., matching does not explain the distribution of behaviors at all) and 1 (i.e., matching completely explains the distribution of behavior) and is often converted to a percentage. In applied studies using naturally occurring matching relations (i.e., not instances in which the researcher programs rates of reinforcement), VAF is typically deemed acceptable if the metric is greater than 50%. However, in highly controlled translational or basic studies, VAF metrics typically fall in the 85% to 100% range. Examining the end product of this matching analysis, the behavior analyst would observe that the generalized matching equation accounted for 93.25% of the variance in the direct observation data. Thus, the matching law appears to have described the behavior–consequence relations quite well.

The generalized matching equation is a robust and efficient means of examining the relations between reinforcers and behavior. Using simple logarithm functions and creating a scatterplot with linear regression in Excel, applied behavior analysts can quickly and accurately analyze naturally occurring relations between reinforcement and behavior using the generalized matching equation. With this task analysis detailing these technical procedures, applied behavior analysts with little to no experience conducting matching law analyses will be prepared to conduct quantitative analyses of clients' responsiveness to reinforcement contingencies in various research and clinical settings. Nevertheless, readers should be advised that the two-alternative approach detailed in this article is but one approach to analyzing matching, albeit the most commonly used form of the matching equation in the applied literature. Moreover, it is worth noting that the methods outlined in this article are merely suggestions of how to use a computer program to analyze and depict data from a two-alternative matching study. Numerous other spreadsheet and statistical software (e.g., Sigma-

Plot, SPSS, Minitab) are commercially available and could also accomplish these goals. As such, readers should explore and pilot these options to find the best resource for their individual analytical needs. Finally, readers are encouraged to modify and adapt these procedures to serve the assumptions of their research design as well as personal preferences for data analysis and display.

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