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AUTHOR Williams, John Delane

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IDENTIFIERS Missing Data

ABSTRACT

Missing data for a given cohort of students in a longitudinal study occurs for at least two reasons: either the student has moved or otherwise become unavailable for testing, or the cohort was not in the testing range at a given testing time. A developmental sampling for time of testing x cohort x grade research plan of testing is used to illustrate this point. K. W. Schaie's (1965) proposed set of solutions addressing the developmental models of age, period, and cohort is considered. While the model is logically a three-way situation, computational/logical difficulties led to analyzing three two-way analyses, initially avoiding the use of missing cells and subsequently including missing cells. A model for time of testing x cohort x grade (age) research designs is proposed that follows the full three-way model. After a synthetic data set for grade, cohort, and period for standardized scores is constructed, linear models in a regression solution are applied. To analyze the data for cell, grade, cohort, and period, the sets of two-way design are addressed. The issue of the subjects effect is addressed after the two-way layouts are completed. The problem can then be viewed as a: (1) cohort x time of testing design, (2) grade x time of testing design, and (3) grade x cohort design. The issue of partial repeated measures and consideration of only the repeated measures are discussed. Alternative hypotheses are evaluated, including a time of testing x cohort x grade design with partial subject control with weighted and unweighted means hypotheses. Ten data tables illustrate the different designs. A 17-item list of references is included. (RLC)

Developmental Models for Time of Testing x Cohort x Grade (Age) Research Designs

John Delane Williams
University of North Dakota
Grand Forks, ND 58202-8158

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John Delane Williams
University of North Dakota

When longitudinal data are addressed, problems with missing data often occur. Missing data for a given cohort of students will occur for at least two reasons: either the student has moved or otherwise become unavailable for testing, or the cohort was not in the testing range at a given testing time.

A diagram is shown in Table 1 that would reflect the research design.

Table 1

Developmental Sampling for Time of Testing x Cohort x Grade Research Designs

Cohort	Time of Testing 1985	1987	1989	1991
Grade 6, 1985	cell 1	------	------	------
Grade 4, 1985	cell 2	cell 4	------	------
Grade 2, 1985	cell 3	cell 5	cell 7	------
Grade 2, 1987	------	cell 6	cell 8	cell 10
Grade 2, 1989	------	------	cell 9	cell 11
Grade 2, 1991	------	------	------	cell 12

The plan of testing is each second, fourth and sixth grade would be tested every other year, so that in a given year, three grades would be tested. At any given time, some groups would have only been tested once, while others would have been tested either two or three times; missing cells would occur quite logically.

Background of the Design

Schaie (1965) proposed a set of solutions that addressed the developmental models of age, period and cohort with specific interest in aging research. While the model is logically a three-way situation, computational/ logical difficulties led to analyzing three two-way analyses, avoiding the use of missing cells. Thus only a subset of the entire data set would be used in various portions of the analysis. While there were many critics of Schaie's original work, that seminal effort is such that it is still in use today.

Baltes' (1968) criticisms helped lead to the Schaie and Baltes (1975) compromise emphasizing the age x cohort layout. Each of the two-way layouts has side restrictions (assumptions) regarding their use. Also, at least two of the three two-way layouts would include missing cells. The missing cells issue was circumvented by truncating the analysis with the deletion of cells until no missing cells occurred. This was done in such a way as to minimize the loss of cells. Missing cell solutions are still only infrequently encountered in published research.

Schaie (1977) has addressed certain designs (2 x 2 or 2 x 2 x 2) with missing cells, developing specialized processes for each. Palmore's (1978) model (a 2 x 2) is drawn with a missing cell. A full three-way model was recently developed by Williams (in press). The present approach follows from that full three-way model.

A Synthetic Data Set

First, a synthetic data set is constructed for a situation similar to, but somewhat less complex than the one shown in Table 1. Let us assume, for the moment, that testing began in 1989 and a second test was administered in 1991; see Table 2.

Table 2

Developmental Sampling for Period x Cohort x Grade for Two Testing Periods

Cohort	1989	1991
1. Grade 6, 1989	cell 1	------
2. Grade 4, 1989	cell 2	cell 4
3. Grade 2, 1989	cell 3	cell 5
4. Grade 2, 1991	------	cell 6

For purposes of illustration, cohort 1 is assigned 4 members, cohort 2 is assigned 5 members, cohort 3 is assigned 6 members and cohort 4 is assigned 7 members. Clearly, actual class sizes will usually be much larger; the smaller groups are convenient for illustration, however. See Table 3.

Table 3

Synthetic Data for Grade, Cohort and Period for Standardized Scores

Cohort	Subject	Period 1989	1991
1	1	43	--
1	2	42	--
1	3	36	--
1	4	33	--
2	5	45	42
2	6	42	40
2	7	46	38
2	8	39	36
2	9	35	32
3	10	52	48
3	11	55	49
3	12	51	47
3	13	53	43
3	14	48	49
3	15	42	43
4	16	--	56
4	17	--	58
4	18	--	62
4	19	--	60
4	20	--	57
4	21	--	55
4	22	--	48

The data in Table 3 represent a test whose population mean for any grade is 50 and whose standard deviation (for the population) is 10. The approach uses linear models in a regression solution (Ward & Jennings, 1973; Williams, 1974); characteristic variables (1 or 0) sometimes called binary variables, are used. See Table 4. Subject coding is accomplished in the manner described by Pedhazur (1977) and Williams (1977b). For persons not retested, no subject totals are shown.

Table 4

Synthetic Data for Cell, Grade, Cohort, and Period

							Grade			Cohort				Period		Subject
Scores	1	2	3	4	5	6	2	4	6	1	2	3	4	1989	1991	Total
43	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	
42	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	
36	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	
33	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	
45	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	87
42	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	87
42	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	82
40	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	82
46	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	84
38	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	84
39	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	75
36	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	75
35	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	67
32	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	67
52	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	100
48	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	100
55	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	104
49	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	104
51	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	98
47	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	98
53	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	96
43	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	96
48	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	97
49	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	97
42	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	85
43	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	85
56	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	
58	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	
62	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	
60	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	
57	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	
55	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	
48	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	

Note that subject totals are not recorded for persons in either the first or fourth cohort; persons in these cohorts have only been tested once and could not (at this point) allow for subject control. This circumstance is also different from that shown in Williams (in press) which was a repeated measures design. To effect a solution, it is useful to define several variables which have been shown in Table 4:

Y = the standard score;

X_1 = 1 if the score is from a member of cell 1, 0 otherwise;

X_2 = 1 if the score is from a member of cell 2, 0 otherwise;

X_3 = 1 if the score is from a member of cell 3, 0 otherwise;

X_4 = 1 if the score is from a member of cell 4, 0 otherwise;

X_5 = 1 if the score is from a member of cell 5, 0 otherwise;

X_6 = 1 if the score is from a member of cell 6, 0 otherwise;

X_7 = 1 if the score is from a member of grade 2, 0 otherwise;

X_8 = 1 if the score is from a member of grade 4, 0 otherwise;

X_9 = 1 if the score is from a member of grade 6, 0 otherwise;

X_{10} = 1 if the score is from a member of cohort 1, 0 otherwise;

X_{11} = 1 if the score is from a member of cohort 2, 0 otherwise;

X_{12} = 1 if the score is from a member of cohort 3, 0 otherwise;

X_{13} = 1 if the score is from a member of cohort 4, 0 otherwise;

X_{14} = 1 if the score is from a member tested in 1989, 0 otherwise;

X_{15} = 1 if the score is from a member tested in 1991, 0 otherwise; and

X_{16} = the sum of scores for a given member.

To analyze the data, first, the sets of two-way designs are addressed. The issue of the subjects effect is addressed after the two-way layouts are completed.

Viewing the Problem as a Cohort x Time of Testing Design

For cohort x time of testing, Table 2 shows the layout of the cells. The cohort effect can be found by using

[1] $$Y = b_0 + b_{10}X_{10} + b_{11}X_{11} + b_{12}X_{12} + e_1,$$

which yields $R_1^2 = .730200$; $SS_{COHORT} = 1493.63$. This solution will correspond to testing the hypotheses

$$u_1 = \frac{n_2 u_2 + n_4 u_4}{n_2 + n_4} = \frac{n_3 u_3 + n_5 u_5}{n_3 + n_5} = u_6.$$

These hypotheses can be tested against the full model:

[2] $$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + e_2.$$

For equation 2, $R_2^2 = .76756$; $SS_T = 2045.51$, with $SS_{CELLS} = 1570.05$. The full model without an intercept term is given by

[3] $$Y = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6 + e_2.$$

The time of testing effect is measured by

[4] $Y = b_0 + b_{14}X_{14} + e_3$;

$R_{TIME}{}^2 = .05810$, $SS_{TIME} = 118.84$.

To find the cohort x time of testing interaction, it should first be noticed that the missing cells will be reflected in testing for interaction. The two missing cells will cause the degrees of freedom for interaction to be one rather than three. The single hypothesis for interaction can be stated as $u_2 - u_3 = u_4 - u_5$. In terms of the regression coefficients, the hypotheses can be tested by $b_2 - b_3 = b_4 - b_5$, or $b_2 = b_4 + b_3 - b_5$. Placing this restriction on the full model (equation 3) yields

$Y = b_1X_1 + (b_4 + b_3 - b_5)X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + e_4$, or

$Y = b_1X_1 + b_3(X_3 + X_2) + b_4(X_4 + X_2) + b_5(X_5 - X_2) + b_6X_6 + e_4$.

Letting $V_1 = X_3 + X_2$, $V_2 = X_4 + X_2$ and $V_3 = X_5 - X_2$, the previous equation becomes

$Y = b_1X_1 + b_3V_1 + b_4V_2 + b_5V_3 + b_6X_6 + e_4$; reparameterizing by letting one of the b's equal 0 (say b_6) yields

[5] $Y = b_0 + b_1X_1 + b_3V_1 + b_4V_2 + b_5V_3 + e_4$.

The use of equation 5 yields $R_5{}^2 = .76755$, $SS_5 = 1570.03$. The sum of squares for interaction will be $SS_T = 1570.05 - 1570.03 = .02$. An alternative, and simpler way, to address the interaction issue is to use

[6] $Y = b_0 + b_{10}X_{10} + b_{11}X_{11} + b_{12}X_{12} + b_{14}X_{14} + e_4$;

where X_{10}, X_{11} and X_{12} are variables that show membership respectively in cohorts 1, 2 and 3 (cohort 4 is then simply not a member of cohort 1, 2 or 3) and X_{14} is a binary variable showing time of testing. The results for R^2 and the sum of squares for the use of equation 6 are identical to equation 5.

<u>Viewing the Problem as a Grade x Time of Testing Design</u>

Table 5 shows the layout when the problem is viewed as a grade x time of testing design. This particular layout has no missing cells.

Table 5

Grade x Time of Testing Layout

Grade	1989	1991
Grade 6	cell 1	cell 4
Grade 4	cell 2	cell 5
Grade 2	cell 3	cell 6

While the layout will often involve disproportionate data together with the various interpretations associated therein (see, for example, Applebaum and Cramer, 1974; Cohen, 1968; Jennings, 1967; Overall, Spiegel and Cohen, 1905; Timm and Carlson, 1975, and Williams, 1972, 1977a) this portion of the analysis is at least not also burdened by missing cells.

The sum of squares for time of testing were previously found; thus only the grade effect and grade x time of testing effect need additionally to be found at this point. The grade effect is measured by

[7] $Y = b_0 + b_7X_7 + b_8X_8 + e_8$.

The use of equation 7 will correspond to testing the hypotheses

$$\frac{n_1u_1 + n_4u_4}{n_1 + n_4} = \frac{n_2u_2 + n_5u_5}{n_2 + n_5} = \frac{n_3u_3 + n_6u_6}{n_3 + n_6}.$$

For equation 7, $R_7^2 = .66722$ and $SS_{GRADE} = 1364.80$. To find the grade x time of testing interaction, the difference between the full model (equation 3) and a model including X_7, X_8 (grade) and X_{14} (time of testing) is found.

[8] $Y = b_0 + b_7X_7 + b_8X_8 + b_{14}X_{14} + e_6$.

For equation 8, $R_8^2 = .73073$, $SS_8 = 1494.72$. Then $SS_{GRADE\ x\ TIME} = 1570.05 - 1494.72 = 75.33$, which is also equal to $(R_2^2 - R_8^2)SS_T$.

<u>Viewing the Problem as a Grade x Cohort Problem</u>

Table 6 shows the layout when the problem is viewed as a grade x cohort design. Note the number of missing cells.

Table 6

Grade x Cohort Layout

Cohort	Grade 2	Grade 4	Grade 6
Grade 6, 1989	-------	-------	cell 1
Grade 4, 1989	-------	cell 2	cell 4
Grade 2, 1989	cell 3	cell 5	-------
Grade 2, 1991	cell 6	-------	-------

Inspection of Table 6 would allow the inference that, for the present design, there is no grade x cohort interaction that is testable. If a model for grade and cohort were attempted

[9] $Y = b_0 + b_7X_7 + b_8X_8 + b_{10}X_{10} + b_{11}X_{11} + b_{12}X_{12} + e_2$, then $R_9{}^2 = .76756$ and $SS_9 = 1570.05$, the same results that were obtained for the full model (or cell model, equation 2). Also, there are no degrees of freedom remaining for the grade x cohort design. Had more than two time of testing periods been used, then there would exist testable hypotheses regarding interaction on a limited part of the grade x period layout.

If the various parts of the outcomes are gathered into a table (see Table 7), the degree of overlap of the variables becomes even more apparent.

Table 7

Outcomes from Time of Testing x Cohort x Grade Design

Source of Variation	df	SS	MS	F
Time of Testing	1	118.84	118.84	6.75
Cohort	3	1493.63	497.88	28.27
Grade	2	1364.80	687.40	39.03
Time of Testing x Cohort	1	.02	.02	.00
Time of Testing x Grade	2	75.33	37.66	2.14
Within	27	475.46	17.61	
Total	32	2045.51		

Not only are the sums of squares, when totaled (SS_T = 3528.08) greatly larger than SS_T = 2045.51, but the sum of the degrees of freedom, 36, is larger than the total degrees of freedom, 32. The likelihood of confounding with missing cells is typical; what the researcher chooses to do, however, would seem to be directed by the choice of hypotheses that are viewed as appropriate for testing.

Addressing the Issue of Partial Repeated Measures

Of the four cohorts, two have two measures per subject, and two cohorts have only a single measure. This situation presents some difficulty, and an equation of the form

[10] $Y = b_0 + b_{16}X_{16} + e_7$

is not appropriate for capturing the subject effect, because X_{16}, by itself, would also contain information regarding the nontested cohorts; in conjunction with the other cells, the use of the X_{16} would allow the calculation of the subjects effect. See equation 11.

Considering Only the Repeated Measures

If only the two classes that are retested at the second time period are included, then a simple repeated measure design results. Such a design can be found either through a regression methodology (see, for example, Williams, 1974) or through several other computer packages, including $SPSS_X$ and SAS. Table 8 shows the summary table for this analysis.

Table 8

Summary Table for the Repeated Measures Design

Source of Variation	df	SS	MS	F
Among Subjects	10	656.27		
Cohorts	1	425.61	425.61	16.61
$Error_1$	9	230.66	25.63	
Within Subjects	11	132.50		
Time of Testing	1	76.41	76.41	10.57
Cohort x Time of Testing	1	.02	.02	.00
$Error_2$	9	56.07	7.23	
Total	21	787.77		

Two parts of Table 8 are useful in constructing a table that includes the two analysis reported earlier in Table 7 with the repeated measures information. The sum of squares for interaction is the same in both tables; this is because the interaction addresses only the subjects involved in the repeated measures. The sum of squares $error_1$ (the error among subjects) captures the variation due to subject control. A summary table including this source of variation is shown in Table 9.

Table 9

Time of Testing x Cohort x Grade Design with Partial Subject Control

Source of Variation	df	SS	MS	F
Time of Testing	1	118.84	118.84	8.74
Cohort	3	1493.63	497.88	36.61
Grade	2	1364.80	687.40	50.54
Time of Testing x Cohort	1	.02	.02	.00
Time of Testing x Grade	2	75.33	37.66	2.77
Error - Within	27	475.46	17.66	
$Error_1$ - Subjects	9	230.66		
$Error_2$ - Within Subjects	18	244.80	13.60	
Total	32	2045.51		

Another way to try to isolate the portion of the within error term due to subjects is to use the model

[11] $$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{16}X_{16} + e_8 .$$

Equation 11 will yield $R_{11}{}^2 = .88035$ or $SS_{11} = 1800.67$. Then, $SS_{11} - SS_2 = 1800.67 = 1570.05 = 230.62$. This value is close to $error_1$ in both Tables 8 and 9 (230.66).

Other Hypotheses of Possible Interest

Researchers who prefer the "full rank model" solutions of Timm and Carlson (1975) would prefer to test hypotheses somewhat different then those shown thus far. The hypotheses shown for testing the cohort effect,

$$u_1 = \frac{n_2u_2 + n_4u_4}{n_2 + n_4} = \frac{n_3u_3 + n_5u_5}{n_3 + n_5} = u_6 ,$$

will correspond to the hypotheses that would be tested by the approach suggested by Timm and Carlson (1975; but also see Williams, 1977a, in press), since $n_2 = n_4$ and $n_3 = n_5$.

For nonrepeated measures designs, this would not always be the case.

The time of testing effect already shown had as its tested hypothesis

$$\frac{n_1 u_1 + n_2 u_2 + n_3 u_3}{n_1 + n_2 + n_3} = \frac{n_4 u_4 + n_5 u_5 + n_6 u_6}{n_4 + n_5 + n_6}.$$

The corresponding "full rank model" hypothesis is $u_1 + u_2 + u_3 = u_4 + u_5 + u_6$, or in terms of the regression coefficients, $b_1 + b_2 + b_3 = b_4 + b_5 + b_6$ or $b_1 = b_4 + b_5 + b_6 - b_2 - b_3$. If this restriction is substituted into equation 3, then $Y = (b_4 + b_5 + b_6 - b_2 - b_3)X_1 + b_2 X_2 + b_3 X_3 + b_4 X4 + b_5 X_5 + b_6 X_6 + e_9$. Rearranging in terms of the regression coefficients, $Y = b_2(X_2 - X_1) + b_3(X_3 -X_1) + b_4(X_4 + X_1) + b_5(X_5 + X_1) + b_6(X_6 - X_1) + e_9$. Reparameterizing by letting any $b_i = 0$ (say b_6) yields $Y = b_0 + b_2(X_2 - X_1) + b_3(X_3 - X_1) + b_4(X_4 + X_1) + b_5(X_5 + X_1) + e_9$. Letting $V_4 = X_2 - X_1$, $V_5 = X_3 -X_1$, $V_6 = X_4 + X_1$ and $V_7 = X_5 + X_1$ yields:

[12] $Y = b_0 + b_1 V_4 + b_2 V_5 + b_3 V_6 + b_4 V_7 + e_9$.

The use of equation 12 yields $R_{12}{}^2 = .71875$ and $SS_{12} = 1470.21$. To find the "full rank model" measure of the time of testing effect, $SS_2 - SS_{12} = 1570.05 - 1470.21 = 99.84$, which is slightly lower than that found earlier for the time of testing effect.

The grade effect has as its hypotheses (using the Timm and Carlson [1975] approach)

$\frac{u_1 + u_4}{2} = \frac{u_2 + u_5}{2} = \frac{u_3 + u_6}{2}$, or in terms of the regression coefficients, $b_1 + b_4 = b_2 + b_5 = b_3 + b_6$ or $b_1 = b_2 + b_5 - b_4$ and $b_3 = b_2 + b_5 - b_6$. Substituting these coefficients into equation 3,

$Y = (b_2 + b_5 - b_4)X_1 + b_2X_2 + (b_2 + b_5 - b_6)X_3 + b_4X_4 + b_5X_5 + b_6X_6 + e_{10}$, or

$Y = b_2(X_2 + X_1 + X_3) + b_4(X_4 - X_1) + b_5(X_5 + X_1 + X_3) + b_6(X_6 - X_3) + e_{10}$.

Letting $b_6 = 0$ and since $X_1 + X_1 + X_3 = X_{14}$, we can let $V_8 = X_4 - X_1$, and let $V_9 = X_5 + X_1 + X_3$, yielding

[13] $Y = b_0 + b_2X_{14} + b_4V_8 + b_5V_9 + e_{10}$.

The use of equation 13 yields $R_{13}{}^2 = .12750$ and $SS_{13} = 260.18$. Thus, the grade effect for the Timm and Carlson (i.e., unweighted means) approach is $SS_2 - SS_{13} = 1570.05 - 260.18 = 1309.24$. This value is relatively close to the weighted means approach found earlier of 1364.80. A final summary table including the entire outcomes of this design are shown in Table 10.

Table 10

Time of Testing x Cohort x Grade Design with Partial Subject Control with Weighted and Unweighted Means Hypotheses

Source of Variation	df	SS	MS	F
Time of Testing (Weighted)	1	118.84	118.84	8.74
Time of Testing (Unweighted)	1	99.84	99.84	7.34
Cohort	3	1493.63	497.88	36.61
Grade (Weighted)	2	1364.80	687.40	50.54
Grade (Unweighted)	2	1309.24	654.62	48.13
Time of Testing x Cohort	1	.02	.02	.00
Time of Testing x Grade	2	75.33	37.66	2.77
Error - Within	27	475.46	17.66	
$Error_1$ - Subjects	9	230.66	25.63	
$Error_2$ - Within Subjects	18	244.80	13.60	
Total	32	2045.51		

In evaluating the outcome of such an experiment, many different strategies can be employed--one is suggested here. When the outcomes of both the weighted and unweighted hypotheses are the same, a conclusion can then be drawn; if the outcomes are different, then the results are deemed inconclusive (this follows the rationale of Applebaum and Cramer, 1974). If testing is conducted exclusively at the .01 level, there is a difference in outcome for the time of testing regarding the weighted ($p < .01$) and unweighted ($.01 < p < .05$) tests. Some researchers might prefer using the MS_W rather than MS_{ERROR_2} as the error term.

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