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ABSTRACT

The effects of various discourse variables on the psycholinguistic processing of sentences within paragraphs by 36 competent adult readers were investigated. Eye movement measures were used as the dependent variables reflecting psycholinguistic processing. When all of the constraints within which the study had to be performed were examined, it became obvious that none of the traditional research designs would be appropriate. Hence, a new experimental design, Latin square matched with other Latin squares, was conceived which met the constraints of the study. This design has some features which make it very useful for research in many different fields of education. Furthermore, from a statistical analysis point of view, this design has several desirable characteristics: it allows the researcher to test a larger set of hypotheses than is possible under other designs employing the same number of individuals, and it allows the researcher to gain sufficient power for the hypothesis tests while using only a small number of individuals. A description of the study and its constraints, an explanation of why the traditional designs cannot be used, and an introduction to the conceived design are given. The statistical analysis techniques to be employed on data collected using this design are then explained in detail. (Author/PN)

Matched Latin Squares: A Nifty Solution to a Tricky Design Problem

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Abstract

The authors were interested in studying the effects of various discourse variables on the psycholinguistic processing of sentences within paragraphs by competent adult readers. Eye movement measures were used as the dependent variables reflecting psycholinguistic processing. When all of the constraints within which the study had to be performed were examined, it became obvious that none of the traditional research designs would be appropriate. Hence, a new experimental design was conceived which met the constraints of the study. This design has some features which make it very useful for research in many different fields of education. Furthermore, from a statistical analysis point of view, this design has several desirable characteristics. In this paper, a description of the study along with its constraints is given. It is then explained why none of the traditional designs can be used. The design that was conceived by the authors is introduced. The statistical analysis techniques to be employed on data collected using this design are then explained in detail.

The authors were interested in studying the effects of various discourse variables on the psycholinguistic processing of sentences within paragraphs by competent adult readers. When all of the constraints within which the study had to be performed were examined, it became obvious that none of the traditional research designs would be appropriate. Hence, a new experimental design was conceived which met the constraints of the study. This design has some features which make it very useful for research in many different fields of education. Furthermore, from a statistical analysis point of view, this design has several desirable characteristics. In this paper, a description of the study along with its constraints will be given. It will then be explained why none of the traditional designs can be used. The design that was conceived by the authors will then be introduced. The statistical analysis techniques to be employed on data collected using this design will be explained in detail.

Background

In this study the effects of various discourse variables on the processing of target syntactic structures within paragraphs was to be explored. The discourse variables of interest were aspects of passage coherence; specifically, the grounding of the target sentences. Grounding refers to the method in which the paragraph is constructed around the target sentence and has three levels, foregrounded, backgrounded, and inferred.

A paragraph is called foregrounded (Symbol = F) if the paragraph explicitly introduces, thematizes, and foreshadows the information in the target sentence. A paragraph is called backgrounded (Symbol = B) if it is identical to a foregrounded paragraph except that two sentences of semantically neutral filler are added immediately prior to the target sentence in order to background the concepts in the target sentence. A paragraph is called inferred (Symbol = I) if it is coherent in nature and no information within the target sentence is explicitly introduced prior to the target sentence. The sentence variables of interest were the syntactic structures of the target sentences· specifically, the embeddedness of the target sentences. Embeddedness refers to the grammatical structure of a sentence and has two levels, left and right. A sentence is said to be right-embedded (Symbol = R) if its grammatical structure is Subject + Verb + Object + Relative Clause and left-embedded if its structure is Subject + Relative Clause + Verb + Object.

Thus, when embedding and grounding conditions are crossed, a total of six types of paragraphs are obtained. That is, RF (a right-embedded structure within a foregrounded paragraph), RB, RI, LF, LB, and LI. The main purpose of the study was to determine if there was a difference in the ease of processing of the target syntactic structures within these six types of paragraphs. Ease of processing was defined by individuals' scores on several different variables. These variables were measures of eye movement behavior while reading the target sentence and were obtained through the use of an eye movement camera. Since it is possible that the subject matter content of a paragraph could also affect the visual processing of a target sentence, the subject matter content was varied across paragraphs. For reasons which will become clear below, subject matter content has six levels (i.e., six different subject matter areas were used).

Design

One possible design that could have been used was to obtain some multiple of six individuals and randomly give each individual one paragraph to read. Since variance of subject matter was also important, in order to gain sufficient power for the testing of main effects, many individuals (e.g., 108 if only three different subject matters were used) would have to be involved in the study if each individual read only one paragraph. However, because of the time and complexity involved in obtaining and analyzing visual processing data through the use of an eye movement camera, the number of individuals used in such a study has to be limited to a manageable number. For this study the manageable limit was 40. Hence, some design has to be used where each individual was given more than one paragraph to read. Once repeated measures are introduced on the same person, researchers must be careful to control for any effects that the order of presentation of the measures may have on the results of the study. This is especially important in the area of reading research. Hence, it was decided that a variation in the order of the presentation of paragraph conditions and of the subject matter content must be built into the design.

Given the constraints just described, the design to be introduced presently was conceived. Since there are only six embedding x grounding paragraph combinations, it was decided that each individual should receive each of these six paragraph combinations exactly once. Also, the same subject matter content could not be used twice with any of the individuals because of fear of memory effects. Hence a different content had to be used, within each individual, for each embedding x grounding combination. So, it was decided to use six different subject matter areas. Further, in order to avoid the complications of unbalanced designs, each subject matter content had to appear the same number of times within any particular embedding x grounding combination. Latin squares are ideal under this set of constraints.

Consider, for the moment, a study with only six individuals. Figure 1 illustrates a 36 cell matrix with two dimensions, individuals and embedding x grounding combinations. In this figure the symbols are as defined earlier. A subject matter content is then assigned to each cell so that no person nor any embedding x grounding combination receives the same content twice. There are many ways of completing this assignment process; Figure 2 illustrates one of these ways. See

Combinations

Individuals	LF	LB	LI	RF	RB	RI
1						
2						
3						
4						
5						
6						

Figure 1

Combinations

Individuals	LF	LB	LI	RF	RB	RI
1	A	B	C	D	E	F
2	B	D	E	C	F	A
3	F	C	A	E	B	D
4	D	A	B	F	C	E
5	C	E	F	A	D	B
6	E	F	D	B	A	C

Figure 2

Dénes and Keedwell (1974) for a listing of other possibilities. In Figure 2 the letters A, B, C, D, E, and F represent the six chosen subject matter content areas. Figure 2 represents what is traditionally called a Latin square design. But, this design suffers from a lack of power because of the small number of individuals used. To increase the power, the just-illustrated process of using a Latin square to assign content x embedding x grounding discourse conditions to individuals is repeated as many times as feasible, each time using a new sample of six individuals.

But, the order of the embedding x grounding conditions still must be varied. One way of doing this is to employ a new Latin square which assigns orders to groups of individuals. It is this use of Latin squares matched with other Latin squares that is the unique feature of this particular design. Figure 3 illustrates how this matching is done. The row headings refer to groups of six individuals each. Within each group, the individuals have already been assigned to content x embedding x grounding discourse conditions by the use of a Latin square of the form of Figure 2. The order of the paragraphs for each group is then determined by reading across the rows of Figure 3. For example, for the first group of six individuals the order of presentation is the left-embedded inferred paragraph first, then the left-embedded foregrounded paragraph followed by the right-embedded inferred, the left-embedded backgrounded, etc.[1]

Order

Groups	1	2	3	4	5	6
1	LI	LF	RI	LB	RB	RF
2	LF	LB	LI	RF	RI	RB
3	LB	RF	LF	RB	LI	RI
4	RF	RB	LB	RI	LF	LI
5	RB	RI	RF	LI	LB	LF
6	RI	LI	RB	LF	RF	LB

Figure 3

Because of this matching of the Latin squares the number of individuals included in the study must be some multiple of 36. This particular study was restricted to exactly 36 individuals because, as was explained earlier, it was felt that 72 individuals would be too unwieldly. Although the matched Latin squares design is very similar to a Graeco-Latin square type design, it is not the same. In fact, Graeco-Latin squares could not have been used for this study because no Graeco-Latin square of order 6 exists. In the remainder of this paper the focus will be on the analysis of a matched Latin square design involving only 36 individuals. The analysis when a multiple of 36 individuals is used is straightforward and will not be discussed here.

Analysis

The independent variables or factors in this study are embedding condition, grounding condition, subject matter content, and order of presentation. The matched Latin square design allows the researcher to study all of these factors. An additional factor is the individuals who are nested within order of presentation. For ease of later explanation, suppose temporarily that embedding conditions, grounding conditions, subject matter content, and individuals are crossed rather than prescribed by the six Latin squares of the type displayed in Figure 2. That is, suppose that each individual is given all 36 of the possible embedding x grounding x content combinations instead of just the six prescribed by the rows of the Latin squares of the type in Figure 2.

If an ANOVA table were set up for this supposed crossed design, the columns corresponding to Sources of Variation, degrees of freedom, and Expected Mean Squares would be as in Table 1. In determining the Expected Mean Squares it was decided to treat embedding and grounding conditions as fixed and subject matter content and individuals as random. In Table 1 the Expected Mean Squares are given when order is considered both as fixed and as random. The authors have chosen to consider order of presentation as random because they wanted to be able to generalize to orders other than those in Figure 3, but we realize that others may want to consider order as fixed.[2]

Recall that a complete factorial design was not really used here. Instead, a design based on matched Latin squares was used. The use of Latin squares causes several Sources of Variation to be confounded. In order to remove this confounding the researcher must assume that certain Sources of Variation are negligible in the setting being studied. For the study being described here the assumption was made that all interactions, except ExG and ExGxO, involving two or more of E, G, S, and I:O are considered to be negligible. This assumption was chosen both because it made sense from a psycholinguistic point of view and because it is the assumption needed to insure that a test exists for the main effects of embedding and grounding conditions, which are of most interest in this study.[3] Making this assumption reduces Table 1 to Table 2.

By examining Table 2 the tests of the various Sources of Variation can be derived. These tests are given in Table 3. The Mean Squares, except for $MS_{Residual}$, are all computed by the formulas that would be used in the usual ANOVA of the crossed design presented in Table 1. To compute $MS_{Residual}$ the following expression is used:

$$\frac{SS_{Total} - (SS_E+SS_G+SS_S+SS_O+SS_{I:O}+SS_{ExG}+SS_{ExO}+SS_{GxO}+SS_{SxO}+SS_{ExGxO})}{120}$$

Notice that both when order of presentation is fixed and when order is random that the main effect for Order is not testable. A test of order effects, which is needed to be able to determine whether fatigue has occurred, is given by looking at the design in a slightly different manner:

Individual	Score for 1st paragraph read	Score for 2nd paragraph read	. . .	Score for 6th paragraph read
1	x	x	. . .	x
2	x	x	. . .	x
3	x	x	. . .	x
. . .	. . .	. . .		. . .
36	x	x		x

It is realized that the scores will differ widely within each time point because different individuals have read different paragraphs. But, if no fatigue (i.e., order) effects are present it would be expected that the means for all six time points would be identical. The ANOVA table when the design is looked at in this manner with individuals considered as random and Temporal Order as fixed is

Sources of Variation	df	Expected Mean Squares
Temporal Order (T)	5	$\sigma_e^2 + 36\cdot\sigma_T^2 + \sigma_{TxI}^2$
Individuals (I)	35	$\sigma_e^2 + 6\cdot\sigma_I^2$
TxI	175	$\sigma_e^2 + \sigma_{TxI}^2$

Hence, by inspection of this ANOVA table, it can be seen that the order effects are tested using $F_{5,175} = \frac{MS_T}{MS_{TxI}}$.

Summary

In this paper a new experimental design, which the authors call a matched Latin squares design, was introduced. The paper provided the motivation for this design and a detailed discussion of the methods of data analysis to be used when this design is employed. This design has several advantages. Sometimes researchers employ traditional well-known designs which allow them to test some of their hypotheses of interest, but which also force them to ignore other hypotheses they are interested in. The first advantage of the matched Latin square design is that it allows the researcher to test a larger set of hypotheses than is possible under other designs employing the same number of individuals. For the study which motivated the creation of the matched Latin squares design, all of the hypotheses of interest become testable once this design is employed. A second advantage of the matched Latin squares design is that it allows the researcher to gain sufficient power for the hypothesis tests while using only a small number of individuals. Those readers interested in examining the results of the analyses described in this paper are referred to either Pearce (1981) or Pearce, Bader, and Blumberg (1983).

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Footnotes

[1]Notice that Figure 3 is a special type of Latin square which is called complete (or balanced or counterbalanced, depending on the source). A Latin square is said to be complete if every "treatment" follows each other "treatment" exactly once. For this study, the "treatments" are the embedding x grounding conditions.

[2]Actually the choice is between whether order of presentation is fixed or finite. If one supposes that order is finite then the correction factor in the Expected Mean Squares would be $1 - \frac{6}{720}$, which is approximately equal to 1. Hence the correction factor can be ignored and order can be treated as if it were random rather than finite.

[3]This assumption follows the pattern of assumptions used by Winer (1962) in his chapter on Latin squares. Plan 8 in that chapter is the plan which is most similar to matched Latin squares.

Sources of Variation	df	Expected Main Squares When Order is Fixed
Embedding (E)	1	$\sigma_e^2+648\cdot\sigma_E^2+108\cdot\sigma_{ExS}^2+18\cdot\sigma_{ExI:O}^2+3\cdot\sigma_{ExSxI;O}^2$
Grounding (G)	2	$\sigma_e^2+432\cdot\sigma_G^2+72\cdot\sigma_{GxS}^2+12\cdot\sigma_{exI:O}^2+2\cdot\sigma_{GxSxI:O}^2$
Subject Matter (S)	5	$\sigma_e^2+216\cdot\sigma_S^2+6\cdot\sigma_{SxI:O}^2$
Order (O)	5	$\sigma_e^2+216\cdot\sigma_O^2+36\cdot\sigma_{I:O}^2+36\cdot\sigma_{SxO}^2+6\cdot\sigma_{SxI:O}^2$
Individuals:Order (I:O)	30	$\sigma_e^2+36\cdot\sigma_{I:O}^2+6\cdot\sigma_{SxI:O}^2$
ExG	2	$\sigma_e^2+216\cdot\sigma_{ExG}^2+36\cdot\sigma_{ExGxS}^2+6\cdot\sigma_{ExGxI:O}^2+\sigma_{ExGxSxI:O}^2$
ExS	5	$\sigma_e^2+108\cdot\sigma_{ExS}^2+3\cdot\sigma_{ExSxI:O}^2$
ExO	5	$\sigma_e^2+108\cdot\sigma_{ExO}^2+18\cdot\sigma_{ExI:O}^2+18\cdot\sigma_{ExSxO}^2+3\cdot\sigma_{ExSxI:O}^2$
ExI:O	30	$\sigma_e^2+18\cdot\sigma_{ExI:O}^2+3\cdot\sigma_{ExSxI:O}^2$
GxS	10	$\sigma_e^2+72\cdot\sigma_{GxS}^2+2\cdot\sigma_{GxSxI:O}^2$
GxO	10	$\sigma_e^2+72\cdot\sigma_{GxO}^2+12\cdot\sigma_{GxI:O}^2+12\cdot\sigma_{GxSxO}^2+2\cdot\sigma_{GxSxI:O}^2$
GxI:O	60	$\sigma_e^2+12\cdot\sigma_{GxI:O}^2+2\cdot\sigma_{GxSxI:O}^2$
SxO	25	$\sigma_e^2+36\cdot\sigma_{SxO}^2+6\cdot\sigma_{SxI:O}^2$
SxI:O	150	$\sigma_e^2+6\cdot\sigma_{SxI:O}^2$
ExGxS	10	$\sigma_e^2+36\cdot\sigma_{ExGxS}^2+\sigma_{ExGxSxI:O}^2$
ExGxO	10	$\sigma_e^2+36\cdot\sigma_{ExGxO}^2+6\cdot\sigma_{ExGxI:O}^2+6\cdot\sigma_{ExGxSxO}^2+\sigma_{ExGxSxI:O}^2$
ExSxO	25	$\sigma_e^2+18\cdot\sigma_{ExSxO}^2+3\cdot\sigma_{ExSxI:O}^2$
ExGxI:O	60	$\sigma_e^2+6\cdot\sigma_{ExGxI:O}^2+\sigma_{ExGxSxI:O}^2$
ExSxI:O	150	$\sigma_e^2+3\cdot\sigma_{ExSxI:O}^2$
GxSxO	50	$\sigma_e^2+12\cdot\sigma_{GxSxO}^2$
GxSxI:O	300	$\sigma_e^2+2\cdot\sigma_{GxSxI:O}^2$
ExGxSxO	50	$\sigma_e^2+6\cdot\sigma_{ExGxSxO}^2+\sigma_{ExGxSxI:O}^2$
ExGxSxI:O	300	$\sigma_e^2+\sigma_{ExGxSxI:O}^2$

TABLE 1(a)

ANOVA TABLE FOR CROSSED DESIGN (with Order fixed)

Sources of Variation	df	Expected Mean Squares When Order is Random
Embedding (E)	1	$\sigma_e^2+648\cdot\sigma_E^2+108\cdot\sigma_{ExS}^2+108\cdot\sigma_{ExO}^2+18\cdot\sigma_{ExI:O}^2+18\cdot\sigma_{ExSxO}^2+3\cdot\sigma_{ExSxI:O}^2$
Grounding (G)	2	$\sigma_e^2+432\cdot\sigma_G^2+72\cdot\sigma_{GxS}^2+72\cdot\sigma_{GxO}^2+12\cdot\sigma_{GxI:O}^2+12\cdot\sigma_{GxSxO}^2+2\cdot\sigma_{GxSxI:O}^2$
Subject Matter (S)	5	$\sigma_e^2+216\cdot\sigma_S^2+36\cdot\sigma_{SxO}^2+6\cdot\sigma_{SxI:O}^2$
Order (O)	5	$\sigma_e^2+216\cdot\sigma_O^2+36\cdot\sigma_{I:O}^2+36\cdot\sigma_{SxO}^2+6\cdot\sigma_{SxI:O}^2$
Individuals:Order (I:O)	30	$\sigma_e^2+36\cdot\sigma_{I:O}^2+6\cdot\sigma_{SxI:O}^2$
ExG	2	$\sigma_e^2+216\cdot\sigma_{ExG}^2+36\cdot\sigma_{ExGxS}^2+36\cdot\sigma_{ExGxO}^2+6\cdot\sigma_{EXGxI:O}^2+6\cdot\sigma_{ExGxSxO}^2+\sigma_{ExGxSxI:}^2$
ExS	5	$\sigma_e^2+108\cdot\sigma_{ExS}^2+18\cdot\sigma_{ExSxO}^2+3\cdot\sigma_{ExSxI:O}^2$
ExO	5	$\sigma_e^2+108\cdot\sigma_{ExO}^2+18\cdot\sigma_{ExI:O}^2+18\cdot\sigma_{ExSxO}^2+3\cdot\sigma_{ExSxI:O}^2$
ExI:O	30	$\sigma_e^2+18\cdot\sigma_{ExI:O}^2+3\cdot\sigma_{ExSxI:O}^2$
GxS	10	$\sigma_e^2+72\cdot\sigma_{GxS}^2+12\cdot\sigma_{GxSxO}^2+2\cdot\sigma_{GxSxI:O}^2$
GxO	10	$\sigma_e^2+72\cdot\sigma_{GxO}^2+12\cdot\sigma_{GxI:O}^2+12\cdot\sigma_{GxSxO}^2+2\cdot\sigma_{GxSxI:O}^2$
GxI:O	60	$\sigma_e^2+12\cdot\sigma_{GxI:O}^2+2\cdot\sigma_{GxSxI:O}^2$
SxO	25	$\sigma_e^2+36\cdot\sigma_{SxO}^2+6\cdot\sigma_{SxI:O}^2$
SxI:O	150	$\sigma_e^2+6\cdot\sigma_{SxI:O}^2$
ExGxS	10	$\sigma_e^2+36\cdot\sigma_{ExGxS}^2+6\cdot\sigma_{ExGxSxO}^2+\sigma_{ExGxSxI:O}^2$
ExGxO	10	$\sigma_e^2+36\cdot\sigma_{ExGxO}^2+6\cdot\sigma_{ExGxI:O}^2+6\cdot\sigma_{ExGxSxO}^2+\sigma_{ExGxSxI:O}^2$
ExSxO	25	$\sigma_e^2+18\cdot\sigma_{ExSxO}^2+3\cdot\sigma_{ExSxI:O}^2$
ExGxI:O	60	$\sigma_e^2+6\cdot\sigma_{ExGxI:O}^2+\sigma_{ExGxSxI:O}^2$
ExSxI:O	150	$\sigma_e^2+3\cdot\sigma_{ExSxI:O}^2$
GxSxO	50	$\sigma_e^2+12\cdot\sigma_{GxSxO}^2$
GxSxI:O	300	$\sigma_e^2+2\cdot\sigma_{GxSxI:O}^2$
ExGxSxO	50	$\sigma_e^2+6\cdot\sigma_{ExGxSxO}^2+\sigma_{ExGxSxI:O}^2$
ExGxSxI:O	300	$\sigma_e^2+\sigma_{ExGxSxI:O}^2$

TABLE 1(b)

ANOVA TABLE FOR CROSSED DESIGN (with Order random)

Sources of Variation	df	Expected Mean Squares When Order is Random	Expected Mean Squares When Order is Fixed
E	1	$\sigma_e^2+648\cdot\sigma_E^2+108\cdot\sigma_{ExO}^2$	$\sigma_E^2+648\cdot\sigma_E^2$
G	2	$\sigma_e^2+432\cdot\sigma_G^2+72\cdot\sigma_{GxO}^2$	$\sigma_e^2+432\cdot\sigma_G^2$
S	5	$\sigma_e^2+216\cdot\sigma_S^2+36\cdot\sigma_{SxO}^2$	$\sigma_e^2+216\cdot\sigma_S^2$
O	5	$\sigma_e^2+216\cdot\sigma_O^2+36\sigma_{I:O}^2+36\cdot\sigma_{SxO}^2$	$\sigma_e^2+216\cdot\sigma_O^2+36\cdot\sigma_{I:O}^2+36\sigma_{SxO}^2$
I:O	30	$\sigma_e^2+36\cdot\sigma_{I:O}^2$	$\sigma_e^2+36\sigma_{I:O}^2$
ExG	2	$\sigma_e^2+216\cdot\sigma_{ExG}^2+36\cdot\sigma_{ExGxO}^2$	$\sigma_e^2+216\sigma_{ExG}^2$
ExO	5	$\sigma_e^2+108\cdot\sigma_{ExO}^2$	$\sigma_e^2+108\cdot\sigma_{ExG}^2$
GxO	10	$\sigma_e^2+72\cdot\sigma_{GxO}^2$	$\sigma_e^2+72\cdot\sigma_{GxO}^2$
SxO	25	$\sigma_e^2+36\cdot\sigma_{SxO}^2$	$\sigma_e^2+36\cdot\sigma_{SxO}^2$
ExGxO	10	$\sigma_e^2+36\cdot\sigma_{ExGxO}^2$	$\sigma_e^2+36\cdot\sigma_{ExGxO}^2$
Residual	120	σ_e^2	σ_e^2

TABLE 2

ANOVA TABLE FOR MATCHED

LATIN SQUARES DESIGN

Source of Variation	F Test When Order is Random	F Test When Order is Fixed
E	$F_{1,5} = \frac{MS_E}{MS_{ExO}}$	$F_{1,120} = \frac{MS_E}{MS_{Residual}}$
G	$F_{2,10} = \frac{MS_G}{MS_{GxO}}$	$F_{2,120} = \frac{MS_G}{MS_{Residual}}$
S	$F_{5,25} = \frac{MS_S}{MS_{SxO}}$	$F_{5,120} = \frac{MS_S}{MS_{Residual}}$
O	Not Testable	Not Testable
I:O	$F_{30,120} = \frac{MS_{I:O}}{MS_{Residual}}$	$F_{30,120} = \frac{MS_{I:O}}{MS_{Residual}}$
ExG	$F_{2,10} = \frac{MS_{ExG}}{MS_{ExGxO}}$	$F_{2,120} = \frac{MS_{ExG}}{MS_{Residual}}$
ExO	$F_{5,120} = \frac{MS_{ExO}}{MS_{Residual}}$	$F_{5,120} = \frac{MS_{ExO}}{MS_{Residual}}$
GxO	$F_{10,120} = \frac{MS_{GxO}}{MS_{Residual}}$	$F_{10,120} = \frac{MS_{GxO}}{MS_{Residual}}$
SxO	$F_{25,120} = \frac{MS_{SxO}}{MS_{Residual}}$	$F_{25,120} = \frac{MS_{SxO}}{MS_{Residual}}$
ExGxO	$F_{10,120} = \frac{MS_{ExGxO}}{MS_{Residual}}$	$F_{10,120} = \frac{MS_{ExGxO}}{MS_{Residual}}$

TABLE 3

HYPOTHESIS TESTS