2000

Is math skill a factor in reducing interference effects in arithmetic stroop tasks

Hoan C. Nguyen
San Jose State University

IS MATH SKILL A FACTOR IN REDUCING INTERFERENCE EFFECTS IN ARITHMETIC STROOP TASKS?

A Thesis

Presented to

The Faculty of the Department of Psychology

San Jose State University

In Partial Fulfillment

Of the Requirement for the Degree

Master of Arts

By

Hoan C. Nguyen

December 2000

APPROVED FOR THE DEPARTMENT OF PSYCHOLOGY

Robert Cooper, Ph. D., Thesis Chairperson

Ronald Rogers, Ph. D., Thesis Committee Member

Megumi Hosoda, Ph. D., Thesis Committee Member

APPROVED FOR THE UNIVERSITY

ABSTRACT

IS MATH SKILL A FACTOR IN REDUCING

INTERFERENCE EFFECTS IN ARITHMETIC STROOP TASKS?

By Hoan C. Nguyen

This experiment was designed to examine whether the reduction of interference effects is a function of skill in an arithmetic Stroop task. The results of this study were analyzed and used to assess whether automatic processing is controllable. An arithmetic Stroop task was used to measure the stability of automatic processing and interference effects. Eighty-three college students grouped into four different major types (psychology-related major, math-related major, business-related major, and biology-related major) were randomly selected to participate in the experiment, which consists of 64 trials of two conditions – addition and multiplication. The results showed that although there were statistically significant differences in response time (RT) among four major categories, no significant reduction in errors was found among the students with different major types. The results suggested that performers with advanced math skill appeared to respond faster to an arithmetic Stroop task but were unable to reduce Stroop-like interference effects and suffered similar interference as those with lesser skill. In lights of the results of the present study, implications and limitations of the study were discussed.

ACKNOWLEDGMENTS

My heartfelt thanks go to many people, who have enabled me to complete this writing. My gratitude, first, goes to my thesis chair, Dr. Robert Cooper who has tirelessly supported and helped me achieve my academic goals. Thanks also to Dr. Robert Fox for inspiring me and providing invaluable recommendations, and Dr. Alicia Knoedler for painstakingly editing my writing. My gratitude also goes to the other members of my thesis committee, Dr. Megumi Hosoda and Dr. Ronald Rogers who have generously contributed their parts in helping me complete this thesis sooner. Finally, my thankfulness goes to my family and friends, who have believed in me and always been on my side.

TABLE OF CONTENTS

LISTS OF TABLES

LIST OF FIGURES

Is Math Skill a Factor in Reducing Interference Effects in Arithmetic Stroop Tasks?

We often process and retrieve information without having the conscious intention to do so. This automatic processing is important in our daily lives because we need not monitor everything we do. With practice and the development of automatic processing, we can retrieve information faster and more accurately (Logan, 1985). Professional and novice performers, for example, can be discriminated in various activities such as driving, typing, or playing chess because the ways they handle and process the information are significantly different. Because tasks or components of tasks have become automatized through consistent practice, skilled performers devote less attentional resources to the tasks at hand. However, unwanted automatic processes can sometimes cause disruptions in information processing. This is illustrated in the study combining Stroop and priming effects, in which participants were asked to attend to one stimulus or one aspect of it and ignore other stimuli or aspects. In this research, the priming event was either a target letter string - "bird", "body", "building", or "xxx" – which were each visually presented in a speeded word-nonword classification task. The word primes appeared to facilitate nonword decisions but inhibit reaction times to word targets (Neely, 1977; Stroop, 1935). The results indicated that similar stimuli appear to cause disruptions in processing the attended stimulus, especially those that are processed automatically.

This brings up the questions of whether automaticity is hard to control or if automaticity is highly controlled with skill and practice (Logan, 1985; Salthouse, 1986). When testing participants who have consistently practiced on the Stroop tasks, conflicting results were found. For example, when testing selective attention skills of experienced sonar operators, Merrill, Lewandowski, and Kobus (1994) administered a color-only version of the Stroop test to each subject, who was instructed to respond verbally to the color of ink of the 100 color-words. They found that the skilled operators did not seem to differ significantly in speed or accuracy of Stroop performance as compared to the novices. This suggests that the Stroop interference effects are a function of specific skills that are used to perform the tasks presented. That is, skilled performers in a specific field may not generalize to other tasks such as the Stroop tasks. In addition, another factor appears to have a certain impact on the performance of Stroop tasks as well. Rogers and Fisk (1991), in a study of age-related differences in arithmetic Stroop interference, asked the subjects to respond "true" or "false" to 24 arithmetic Stroop equations, which were generated for each of the six conditions (addition and multiplication versions of the congruent, incongruent, and neutral types). The congruent type was defined as arithmetic equations that are correct (e.g., 3 + 4 = 7; 4 x 2 = 8). The incongruent type was arithmetic equations that incorrect operational signs were substituted for the places of correct signs (e.g., 3 + 4 = 12; 5 x 2 = 7). The neutral type like the incongruent one was also incorrect equations but would not be true in any substitutions of any conventional arithmetic operation (e.g., 4 + 3 = 9; 2 x 5 = 11). The results demonstrated that overall younger adults (aged 19-24) seemed to show a decrease in the interference effects with practice, whereas older adults (aged 70-89) showed no significant reduction in the interference effects with practice, especially in the associative Stroop tasks.

Although reports regarding the relationship between automaticity and skilled performance in arithmetic tasks have been scarce, studies on the issue have shown that subjects with high skill in math performed better and more effectively than low-skilled subjects as measured by reaction time and accuracy (LeFevre & Kulak, 1994; Rogers & Fisk, 1991). The goal of this study is to investigate the role of skilled performance in processing and retrieving arithmetic facts.

General Definition of Skill

Skill, in general, is described as a specialized ability to do a complex task. People who perform better on a task are considered more skilled than those who perform more poorly. More precisely, one who can attain the goals of a complex task is said to be more skilled than one who cannot attain the goals (Logan, 1985). When performing a complex task, automaticity and control, which are two closely related characteristics of skill, are activated (Tzelgov, Henik, & Leiser, 1990). These two functions of skilled performance have been at the center of a controversial debate over the issues of automaticity.

What are Automatic and Controlled Processes?

Automatic processes are generally defined as effortless, autonomous, and involuntary. They do not need an act of will or an individual's awareness to be initiated (Cohen, Schreiber, & McClelland, 1992; Logan, 1988; Tzelgov, Henik, & Leiser, 1990). Once triggered, these processes "run to completion" regardless of whether they are intended or not (Zbrodoff & Logan, 1986). That is, automatic processes do not require any efforts or intention to run from start to end and are not inhibited by attention or awareness. On the other hand, controlled or conscious processes, which are activated under intentional control, are effortful and inhibited by the availability of processing resources (Logan, 1988). People consider automaticity as an all-or-none phenomenon. That is, a process is either automatic or controlled. A classic example of this is the widely accepted explanation of Stroop effect. In the Stroop (MacLeod, 1991) classic experiment the names of colors (e.g., "yellow") were printed in different colors of ink (e.g., "green"). Subjects were told in one condition to name its color of the ink and in another condition to read the color word. Word reading is considered automatic because it is fast, it produces interference even when subjects strive to ignore the word, and it is not subject to interference by ink color. In contrast, color naming is considered to be controlled because it is slower, it can be voluntarily inhibited, and it is subject to interference (Cohen et al., 1992).

The opposing definitions of these two concepts demonstrate two different views about automaticity. For example, evidence of Stroop effects has shown the uncontrollable aspects of automaticity (MacLeod, 1991). In Stroop experiments, the unattended stimulus often interferes with the processing of the attended stimulus, regardless of efforts to ignore them. This implies that automatic processing, when initiated, may not be suppressed or controlled whether subjects are highly skilled or not (Besner, Tolz, & Boutilier, 1997; Merrill, Lewandowski, & Kobus, 1994). However, Logan (1988) argued that automatic processing coupled with skill might not be so difficult to control.

According to his view, performers with high skill have better control of automaticity and greater automaticity because they are able to respond faster and suffer less interference effects than less skilled performers in task performances (Logan, 1985;

Salthouse, 1986). Other studies have demonstrated that although automaticity and control are both characteristics of skill, each reflects a different aspect and subserves a different function of our cognitive system (Cohen et al., 1992; Tzelgov et al., 1990). That is, automatic and controlled processes may collaterally work together and may complement each other in processing information, instead of being an all-or-none process.

Theoretical Explanations of Automaticity

Some theorists have provided alternative explanations for the relationships between the two components of automaticity. The Parallel Distributed Processing (PDP) approach, for example, explains how both automaticity and cognitive control influence each other in certain ways. According to the PDP theory, automaticity operates as a continuum and the speed of processing and interference effects may take place interactively, rather than independently along this continuum (Cohen et al., 1992). The model emphasizes the strengths and weights of pathways where information is processed through the interactions of interconnected processing elements called units. The speed of processing in the PDP system is determined by the propagative strengths of activation among the units, through weighted connections. The stronger activation among the units leads to a larger connection of weights; therefore, the information gets processed more rapidly. For example, the Stroop model consists of two processing pathways, one for color naming and one for word reading. The word reading pathway is hypothesized to be faster because the units are activated more strongly and not subject to interference by color. Whereas, the color-naming pathway is slower because the strength in activating the units is weaker and interfered with by word reading.

On the other hand, the Instance approach (Logan, 1988), which describes automaticity in terms of underlying memory processes, assumes that automatic processing is controllable based on the single-step, direct access retrieval from memory. That is, novice (controlled) performance is based on a general step-by-step procedure for solving problems, whereas automatic performance is based on a single-step, direct access retrieval of past solutions from memory. According to the Instance approach, each stimulus is encoded separately and stored in a form of an "instance" or "exemplar" representation. When the stimulus is encountered again, each of the stored representations is retrieved independently. A person's goals in completing a task are to filter, then select the responses to be executed, and this selection is a form of controllable processing.

An Overview of the Study

A few studies have investigated automatic processing in the arithmetic domain. For example, Rogers and Fisk (1991) found that the age of the subjects was significantly related to the magnitude of the interference effects in the arithmetic Stroop tasks. The younger participants, aged 19 to 24, were much better in decreasing the interference effects than the older participants, aged 70 to 89. Additionally, in an attempt to investigate whether automatic processes are controllable Zbrodoff and Logan (1986) had subjects respond to Stroop-like problems under different arithmetic operations. They defined a process as autonomous if it could start and run on to completion without any intentions. They found that the subjects either showed completely autonomous or completely non-autonomous processing in arithmetic Stroop tasks. That is, the subjects' responses to simple arithmetic tasks were partially autonomous. The evidence indicated that autonomous processes should not be construed as an all-or-none phenomenon but rather a continuous dimension. The results of these research studies have not directly addressed why automaticity operates differently in arithmetic problems compared to the Stroop studies on color naming and word reading (Zbrodoff and Logan, 1986, LeFevre & Kulak, 1994). In the present research, the participants will be requested to respond manually either "correct" or "incorrect" to arithmetic Stroop equations (e.g. 2 x 5 = 10, 3 + 6 = 18, etc...) generated for each of the six conditions, which includes three equation types (congruent, incongruent, and neutral) of addition and multiplication versions. The purpose of this study will be to examine the relationship between automaticity and controlled processes in skill performance in arithmetic tasks, and to assess the relationship of arithmetic skills to the magnitude of Stroop-like interference effects. The focus of this research will be on the reaction time and the accuracy of high and low skilled groups. The hypothesis of the study is that although Stroop-like interference effects will always be present, highly skilled performers will be able to reduce or control them automatically and respond with better accuracy. If the hypothesis is supported, it will give further support to the hypothesis that automatic processing is controllable to a certain extent.

Methods

Participants

Eighty-three college students were recruited from the research subject pool in the Psychology Department at San Jose State University. The selection was random, but those who volunteered were classified into one of four major types: Psychology-related major group (n = 30), engineering-related major group (n = 22), biology-related major group (n = 16), and business-related major group (n = 15). The math-related major group included students whose majors were strongly involved with mathematics, such as engineering. Their ages were at least 18 years or older. The participants were given appropriate credit for their participation. High ethnic diversity was expected because of the diversity in the San Jose State student population. All participants were administered the level II arithmetic subtest of the Wide Range Achievement Test (WRAT; Jastak & Jastak, 1978 Ed.), for which scores ranged from 1 to 46. They had ten minutes to do the test. The results were used to measure the correlation between the participants' majors and their math skill level.

Apparatus

The experiment was programmed on an IBM PC with Pentium Processor using the MEL professional program (Rodgers et al., 1995). The computer presented the appropriate stimuli, recorded responses (reaction time and accuracy), and controlled the timing of the display presentations. A standard super VGA monitor was used to present the stimuli. Participants, who were monitored by the experimenter, were tested in a small private room.

Stimuli

The stimuli were all possible combinations of the numbers 2 through 9, which made up 3 conditions of arithmetic equations (congruent, incongruent, and neutral). The congruent equations included correct answers (e.g., 5 + 2 = 7, 3 x 2 = 6). The incongruent and neutral equations included incorrect answers (e.g., 5 + 2 = 10, 3 x 2 = 7). The incongruent were equations that were incorrect but could become correct if appropriate operational signs were substituted – multiplication for addition, or addition for multiplication (e.g. 4 + 3 = 12, 4 x 3 = 7). The neutral equations also consisted of incorrect answers that remained incorrect if any of the two operations (addition and multiplication) were substituted (e.g. 4 + 3 = 15, 4 x 3 = 20).

The stimuli included addition and multiplication equations in 3 equation types (congruent, incongruent, and neutral). Equations for each condition (congruent, incongruent, and neutral) were randomly presented in each of two conditions (addition and multiplication) with additional stimuli of the operational signs (x & +) functioning as distraction factors.

Procedure

The experiment began with an orientation session about the tasks, followed by the practice trials and the experimental session that were presented electronically on the testing computers. During the orientation, the participants were given the level II arithmetic subtest and the written instructions on the experimental procedure. The practice session of 15 trials were provided for the participants to get used to the procedure before the actual experimental session took place. The whole experiment lasted approximately 45 minutes to an hour.

Each trial consisted of the following sequence of events. The subjects were instructed to press the space bar on the IBM keyboard to initiate the experimental trials. To answer each equation the subjects simply pressed either the number 1 key on the keyboard for a "true" response and the number 3 for a "false". The equation remained on the screen approximately 2000 ms. If the subjects did not respond to the stimulus within the appropriate time allowed (2000 ms.), that trial was considered an error.

The subjects were instructed to take a short break whenever they felt the need to rest. To continue with the experiment, the subjects simply pressed the space bar on the keyboard.

Feedback for reaction time and accuracy appeared on the screen after each trial. After each block of trials, a cumulative average of reaction time and accuracy was displayed. The subjects were encouraged to respond as accurately as possible, but not to "hold on" or delay their responses.

Design

The order of stimulus conditions, which consisted of the congruent, incongruent, and neutral, was randomly varied within each subject. The experiment was a 2 x 3 x 4 mixed factorial design. The between factors were subjects' scores on the level II arithmetic subtest and their major groups (psychology-related, math-related, biology-related, and business-related). Within factors were mathematical operations (addition and multiplication) and stimulus conditions (congruent, incongruent, and neutral). The independent variables in the study were two arithmetic operations (addition and multiplication) utilized in three trial types (congruent, incongruent, and neutral). The dependent variables were response time (RT) and accuracy.

Results

The two dependent variables used in this study are RT and accuracy. First, the analyses of the RT data will be presented. Second, the analyses of the accuracy data will be addressed. Third, the interference effect will be presented. Then, the correlation analyses among math score, RT, and accuracy will be reported to examine the relationships between participants with high to low-math skill score in RT and accuracy. Finally, the results will be depicted and discussed, followed by the general analyses of the Demographic factors (gender and age) to detect any confounding problems contributed by these two factors. Only significant results will be reported here. The complete analysis of variance tables for response time, accuracy, and the interference effect are in Appendix A, B, and C, respectively.

Response Time

The RT data were analyzed by 4 x 3 x 2 analysis of variance (ANOVA) with the participants' major category (biology-related, psychology-related, business-related, and engineering-related) as a between-subject factor, and equation type (congruent, incongruent, and neutral) and math operator (addition and multiplication) as two within-subject factors. The means for each cell in the analysis are presented in Table 1. To compare the significant differences among means for significant main effects involving

Table 1

Response Time Means and Standard Deviations for Each Equation Type for All Major Category

	Yes		No			
	Congruent		Incongruent		Neutral	
Major Category	Mult.	Add.	Mult.	Add.	Mult.	Add.
Biology-Related	558.47	529.68	631.44	601.51	612.66	524.48
	(197.06)	(184.27)	(221.71)	(191.46)	(191.22)	(192.77)
Psychology-Related	618.23	592.63	697.12	675.89	665.77	607.93
	(164.34)	(166.77)	(172.48)	(178.14)	(159.22)	(153.53)
Business-Related	620.21	589.24	651.17	644.58	637.42	577.98
	(178.46)	(190.49)	(145.07)	(160.70)	(160.52)	(191.22)
Engineering-Related	427.51	392.74	473.89	457.27	493.04	408.95
	(137.19)	(109.77)	(134.35)	(103.09)	(161.54)	(104.81)
Total	556.51	526.90	616.99	597.95	604.62	533.69
	(183.07)	(180.14)	(189.28)	(181.64)	(177.91)	(175.38)

Note: Values enclosed in parentheses represent standard deviations.

more than two, a set of independent-t tests were used. The dependent variable for analysis was each participant's averaged RT performance within each condition. To avoid the problem of uneven sample sizes, the averaged RT was used rather than each RT on each trial.

All three main effects were statistically significant: major category, $F(3, 79) = 7.74$, $p < .001$ with the students in the engineering-related major having faster verification times overall than did the students in the other major category (the biology-related, the business-related, and the psychology-related); equation type, $F(2, 158) = 38.98$, $p < .001$ with the congruent faster than the neutral and the incongruent respectively; and math operator, $F(1, 79) = 43.84$, $p < .001$ with addition faster than multiplication. Several independent t-test were performed to explore the significant main effect for each major category. The results indicated that the students in the engineering-related major were significantly different from the students in the other three major categories (the biology-related major, $t(36) = 2.74$, $p < .01$, the psychology-related major, $t(50) = 5.01$, $p < .001$, and the business-related major, $t(35) = 3.96$, $p < .001$). However, no statistically significant differences were found among the other major category (the biology-related vs. the psychology-related, $t(44) = -1.25$, $p > .05$; the biology-related vs. the business-related, $t(29) = -.76$, $p > .05$; and the psychology-related vs. the business-related, $t(43) = .34$, $p > .05$). There was only one significant interaction, the two way interaction between the equation type and the arithmetic operator, $F(2, 158) = 10.61$, $p < .001$. Further analysis of equation type results show that the incongruent was statistically significant with the neutral, $F(1, 79) = 18.53$, $p < .001$, but not with the congruent, $F(1, 79) = .87$, $p > .05$.

The RT data were also analyzed by 4 x 2 x 2 analysis of variance (ANOVA) with major category as a between-subject factor, and response category (yes and no) and mathematic operator as two within subject factors. The means for each cell in the analysis are also in Table 1. The significant results were found as follows: major category, $F(3, 79) = 7.71$, $p < .001$ with the students in the engineering-related major fastest in both conditions, followed by the students in the biology-related, the business-related, and the psychology-related majors; response category, $F(1, 79) = 50.53$, $p < .001$ with performance in yes condition faster than in no condition; and mathematic operator, $F(1, 79) = 34.45$, $p < .001$ with addition, overall, faster than multiplication. No significant interactions were found in this analysis.

Accuracy

The mean accuracy rates are presented in Table 2. The same data analysis of variance (ANOVA) used for RT was performed on accuracy (4 x 3 x 2). The only significant main effects were for equation type, $F(2, 158) = 5.31$, $p < .01$ with the neutral more accurate than the congruent and the incongruent respectively; and math operator, $F(1, 79) = 4.62$, $p < .05$ with addition less error than multiplication. The results indicate that no speed-accuracy tradeoff occurred among major category since they were not significantly different. That is, there were not significantly different among the students of all major categories, who committed more errors due to carelessly fast responses.

Table 2

Accuracy Means and Standard Deviations for Each Equation Type for All Major Category

	Yes		No			
	Congruent		Incongruent		Neutral	
Major Category	Mult.	Add.	Mult.	Add.	Mult.	Add.
Biology-Related	.88	.91	.91	.86	.85	.97
	(.009)	(.009)	(.010)	(.135)	(.126)	(.003)
Psychology-Related	.92	.92	.91	.84	.85	.96
	(.006)	(.007)	(.009)	(.127)	(.153)	(.005)
Business-Related	.92	.94	.96	.83	.91	.97
	(.006)	(.007)	(.006)	(.161)	(.129)	(.004)
Engineering-Related	.90	.92	.91	.88	.85	.96
	(.110)	(.008)	(.009)	(.144)	(.152)	(.008)
Total	.91	.92	.92	.85	.86	.97
	(.008)	(.008)	(.009)	(.138)	(.143)	(.006)

Note: Values enclosed in parentheses represent standard deviations.

However, the students in the business-related major were overall more accurate than the engineering-related, the psychology-related, and the biology-related major respectively. For equation type, further analysis reveals that the incongruent type was statistically significant with the congruent, $F(1, 79) = 8.37$, $p < .01$, and with the neutral, $F(1, 79) = 7.21$, $p < .01$. Major category overall was less accurate in the incongruent type of addition and the neutral type of multiplication. In terms of math operator, the mean accuracy rate for the addition ($M = .91$) was higher than the mean rate for the multiplication ($M = .89$).

Again, to test whether there were any significant differences between major category in overall accuracy, a set of independent-t tests were performed. The results reveal that there were no significant differences among major category (engineering-related major vs. biology-related major, $t(36) = -.13$, $p > .05$, engineering-related vs. psychology-related, $t(50) = -.05$, $p > .05$, and engineering-related vs. business-related, $t(35) = .86$, $p > .05$.). The only significant interaction found was between equation type and math operator, $F(2, 158) = 38.16$, $p < .001$ just as was found for RT.

An accuracy data analysis of variance (ANOVA) for major category and response category in addition and multiplication (4 x 2 x 2) was also performed. The results show that only math operator was significant, $F(1, 79) = 5.72$, $p < .05$ with addition more accurate than multiplication.

Taken together, the RT and the accuracy analyses present the following pattern. The students in the engineering-related major were faster in overall verification times than the other major category. For all major categories, the mean RT rates for the incongruent were slower and less accurate than the other types. However, both the students in the psychology-related and in the business-related majors, on average, were slowest in all conditions. Although the students in all major category appeared to experience the same patterns, in which the RT scores were always faster in the congruent, followed by the neutral and then the incongruent, the students in the engineering-related major were relatively stable and consistent in their RTs, compared to the other major category. In terms of accuracy rates, although there was no significant difference among major, the students were statistically different in equation type. It should be noted that the students in the business-related major were more accurate than the students in the psychology-related, the engineering-related, and the biology-related majors respectively. Further, they all responded more accurate in the addition than in the multiplication operation.

To test the consistency of the results in using major category as the independent variable, the students' math scores were grouped into 4 categories - High (30-38), high-Middle (27-29.5), low-Middle (23-26.5), and Low (17-22.5); then were analyzed with all equation types in both RT and accuracy conditions. The results indicate that the students with higher score were significantly faster only in the congruent and neutral trials in the addition, $F(3, 79) = 2.84$, $p < .05$ and $F(3, 79) = 3.70$, $p < .05$ respectively, but not in the other equation types. Similarly, the results also show that the students of all levels were not significantly different in errors, except of the neutral trials in the addition condition, $F(3, 79) = 3.71$, $p < .05$. These results compatibly supported what we found with major category, which demonstrated that the students with math-related major were, although faster in RT, not significantly different in accuracy.

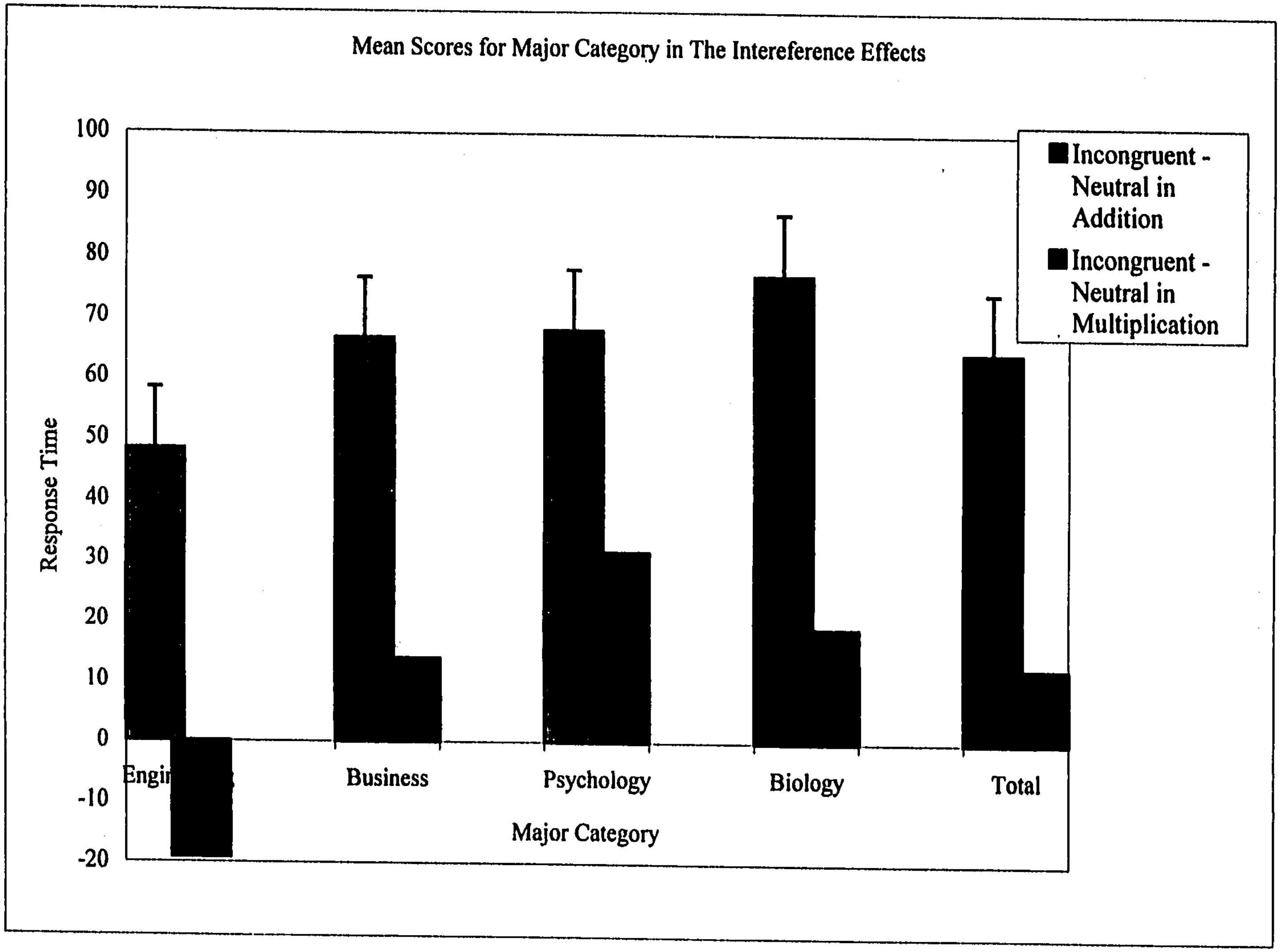

Figure 1: Mean scores for major category and total in the interference effects

Overall, the analyses suggest that although the incongruent types seemed to cause certain disruptions and confusions in all major categories, the students, whose majors were less math-related (the psychology-related, the business-related, and the biology-related), tended to respond significantly slower than those majoring in math-related major (the engineering-related) but similar to those with better math skill in accuracy. In order to assess how students in major category responded to the interference effects, an analysis based on different scores in all equation types was performed.

The Interference Effect

To be consistent with the past analyses and to directly assess the interference effects we used the subtraction of the neutral from the incongruent in both addition and multiplication since the answer category for both conditions is "no." This derived score provides an estimate of the interference effects (Rogers & Fisk, 1991; Zbrodoff & Logan, 1986). The derived mean scores for major category and the interference effects are plotted in Figure 1. Again, only significant results were reported here. A full ANOVA table is presented in Appendix C.

An ANOVA analysis of 4 x 2 with major category as a between-subject factor and math operator interference effects (addition and multiplication) as a within-subject factor was performed. The results reveal that there was only a significant difference for mathematic operator, $F(1, 79) = 18.53$, $p < .001$. It should be noted that the interference effect means in addition was overall higher than the means in multiplication, which indicates that participants appeared to suffer less interference effects in multiplication than addition condition. Surprisingly, the standard deviations of all major categories were higher than the mean interference effects in multiplication (for engineering-related major, M = 13.61, SD = 90.70; for business-related major, M = 22.35, SD = 82.76; for biology-related major, M = 45.88, SD = 76.28; for psychology-related major, M = 55.13, SD = 82.47). This will be examined in the next part, where the analyses of the relationships between math skill levels and the interference effects are performed.

In summary, although the participants in all major categories showed significant differences in RT, they were not statistically different in terms of the interference effects. However, they were significant in math operator, in which they all suffered more in the addition than in the multiplication trials. Furthermore, the participants, whose major category was less math-related, tended to suffer more than those in the engineering-related major. Thus, our first hypothesis, that people with high level of math skill are able to reduce the interference effects with faster RT, was not supported. In addition, to be able to further the investigation of whether the automatic processing is different due to skill level, the math skill scores with the RT and the accuracy in all conditions as well as the interference effects will be calculated and examined.

The Correlations of Math Skill Score with RT, Accuracy, and Interference Effects

Before taking the computer task, participants were administered the level II arithmetic subtest of the Wide Range Achievement Test (WRAT) (Jastak & Jastak, 1978) of which scores ranged from 1 to 46. The results showed that participants' scores ranged from 17 to 38 with the mean of 26.9 (SD = 4.61). To investigate whether there was any correlation between participants' test score and their RT, a correlation analysis was performed. The results reveal that there were significantly negative correlations across

Table 3

Correlations between Math Skill Scores and Equation Type in Response Time and Accuracy

Equation Type	Response Time	Accuracy
Congruent in Addition	-.30**	.130
Incongruent in Addition	-.25*	.33**
Neutral in Addition	-.33**	.26*
Congruent in Multiplication	-.25*	.30**
Incongruent in Multiplication	-.26*	-.00
Neutral in Multiplication	-.26*	.20
Overall	-.28**	.30**

Note: ** $p < .01$

* $p < .05$

equation type and math skill score, as illustrated in Table 3. This statistically negative relationship indicates that the participants with higher math skill tended to take less time in responding to the arithmetic Stroop tasks, while the participants with lesser math skill needed more time for responses. In terms of accuracy, the math skill score was positively correlated with all equation type, except the incongruent and the neutral in multiplication operation. Again, the positive relationships in accuracy reveal that the participants, who scored high in the math skill test, tended to respond more accurately than those, who had lower scores in the math test. The exception in the incongruent and the neutral in multiplication operation might indicate that the participants have experienced certain confusions due to the priming effect of the operation signs (+ and x), which were presented before the arithmetic equation in each trial.

The calculation between the math skill score and the interference effect shows that there was no significant relationship between these two variables, $\underline{r}$ (83) = .18, $\underline{p} > .05$ for addition trials; and $\underline{r}$ (83) = - .03, $\underline{p} > .05$ for multiplication trials, although the significant mathematic operation indicates a larger interference effect in addition than in multiplication. Further, the standard deviations for both addition and multiplication were surprisingly high, and even bigger than the means of the multiplication interference effects ($\underline{M}$ = 36.42, $\underline{SD}$ = 84.06). This suggests that individual differences might be a factor in influencing the outcome.

With the math skill scores divided into 4 different levels – High (30-38), high-Middle (27-29.5), low-Middle (23-26.5), and Low (17-22.5), an ANOVA analysis of the interference effect as a within-subject and the math score level as a between-subject was performed to test the consistency of the results with major category as the independent variable; and to investigate whether individual difference factor might play any parts in affecting the correlation outcomes. The results indicate that although math score was not statistically different, F (3, 79) = .37, $p > .05$, the students experienced significantly more interference effects in the addition condition than in the multiplication, F (1, 79) = 16.92, $p < .001$. However, regardless of their math score levels all students suffered similar interference effects, F (3, 79) = .37, $p > .05$. That is, the students with a higher math score did not significantly reduce the interference effects compared to those with a lower math score. Further, no significant interactions were found between the math score level and the interference effects (F (3, 79) = 1.76, $p > .05$).

The outcomes were supported by the fact that the interference effects affected the students, on average, more in the addition (M = 64.26, SD = 71.54) than in the multiplication (M = 12.36, SD = 94.56). However, the fluctuation between the mean and the standard deviation was much higher in the multiplication condition. Thus, the results seemed to imply that the individual differences among the participants, especially in the multiplication condition, might be partially attributable to the non-significant correlations between the math skill scores and the interference effects.

Demographic Factors (Age & Gender)

To find out whether there were any nuisance or confounding variables in demographic factors contributing to the significant differences in the interference effects, age and gender of the participants were analyzed. The results reveal that there were no significant interactions between major and gender in all conditions, F (3, 75) = .13, $p >$

.05. This outcome indicates that gender could not be a factor in affecting the interference effects and the automatic processing issues.

Like the results reported by Rogers and Fisk (1991), we found that age, when divided into old (27 - 47), middle (21 - 26), and young (18 - 20), was statistically significant, $F(2, 73) = 8.51$, $p < .001$ in addition, and $F(2, 73) = 8.51$, $p < .001$ in multiplication. Young participants were superior to the older in RT, and there was no speed-accuracy tradeoff. However, age did not have any statistical interactions with major category in an ANOVA analysis for both conditions, $F(4, 73) = 1.92$, $p > .05$ in addition, and $F(4, 73) = 1.09$, $p > .05$ in multiplication. Thus, age was not a factor in affecting the main effect of major in the arithmetic Stroop interference effects.

In short, gender and age did not play any significant roles in influencing the major-related differences in the automatic processing in skill levels. However, since age was not normally distributed in this research, a precaution should be taken in interpreting this outcome.

Discussion

The purpose of the current study was to examine the relationship between automatic and controlled processing of skilled performers in an arithmetic Stroop task, and to assess whether the relationship accounts for any change in Stroop-like interference effects. Two components (math skill test score, and speed and accuracy in RT) were used to measure skill factor. Stroop interference was measured by differences between RT in the incongruent and the neutral conditions. The results of the experiment reveal that the students in the engineering-related majors were faster at verifying arithmetic equations across conditions than the students in the other majors that were less math-related (the psychology-related, the business-related, & the biology-related majors). There were no significant differences in accuracy as a function of major type. However, the correlation between the math skill scores and accuracy was significant. No speed-accuracy trade-off was found since the students in the different major categories were not significantly different in accuracy across conditions. These findings support the hypothesis that performers with majors that require higher level of mathematics have the skills needed for reducing the time and errors in performing simple arithmetics.

As the review of previous studies has shown (Macleod, 1991), on a Stroop interference task the dimension where processing is more automatic is more likely to produce interference than the dimension that is less automatic. Furthermore, the more automatic a process becomes with practice or skill, the greater the interference it causes. However, this kind of pattern has not been found in the present results. Instead, the students in the engineering-related majors were able to maintain the lowest RT in both congruent and incongruent conditions.

The present findings have fundamental implications, both theoretically and from a skilled performance perspective. Theoretically, it should be noted that response times for the incorrect condition and the incongruent equation for all majors were slower than the correct condition and the neutral and congruent equations. The results were consistent with past findings suggesting that correct and congruent equations would produce more resonance or strong activation than incorrect equations because they completely match the representation of problem-answer relations in memory (Zbrodoff and Logan 1990).

More interestingly, the Resonance Model also explains the RT and accuracy differences among equations with congruent, incongruent and neutral answers. According to Zbrodoff and Logan (1990), the type of equation is essential in producing different levels of activation or resonance for verification decision. Equations that produce either very high or very low levels of resonance will produce high accuracy and fast RT, whereas equation producing inter-immediate levels of resonance will cause low accuracy and longer RT. Like correct equations, congruent equations would usually produce more resonance because they totally match the problem-answer representation in memory. Thus, the expectation for congruent equations is that they would be faster in RT and have fewer errors than incongruent equations because incongruent equations partially match the problem-answer association in memory, and therefore activate an immediate level of resonance which is difficult to distinguish from that produced by correct equations. The results here are consistent with the model in terms of the faster speed prediction but not with the expected accuracy.

The straightforward explanations of the Resonance Model and the results found in the present study have raised some questions about the concept of controlled and automatic processes as an all-or-none phenomenon, which was discussed in the introduction. If a controlled process can be voluntarily inhibited, then with advanced skill and extensive practice it should be enhanced, as demonstrated by many previous studies (Cohen et al., 1992; Macleod, 1991; Roger & Fisk, 1991). However, the results in this experiment did not show any significant change in the interference effects between participants with advanced level of math skill and those with lower level although skill factor did play a part in reducing the RT and increasing accuracy. Thus, the notion suggesting that automatic and controlled processes may be collaterally interactive and may complement each other in processing information in certain ways is not unreasonable. For example, Macleod and Dunbar (1988) have tested this idea in a study in which they placed color naming in competition with a novel task, such as training subjects to learn to respond to each of four shapes that had been arbitrarily assigned to a color name. The results showed that with extensive practice shape naming produced the interference effects with ink-color naming and not vice versa. These findings suggest that more practice in processing a dimension influences, but not completely eliminates, the processing of another dimension (Macleod, 1991).

It is worth noting that the design of the task itself might also have certain effects on the outcome of this study as compared to the traditional color-word Stroop task. Both tasks are designed so that they create a competition pathway between a congruent stimulus and an incongruent one. In the traditional Stroop, the processes of reading words and naming colors proceed in a parallel fashion initially but the faster processing of the word reading occupies the response channel, thereby interfering with the output of the color naming (Macleod, 1991). In a similar pattern, the congruent stimulus ($5 + 2 = 7$) in the arithmetic Stroop task possesses the processing pathway faster than its counterpart, the incongruent ($5 + 2 = 10$), thereby interfering with the response output. However, the task in the traditional Stroop depends on an instructional manipulation. That is, subjects are instructed to respond to one or the other aspects of the stimuli. The arithmetic Stroop task, on the other hand, creates its stimuli based on the specifiedcorrect-action response. The similarity and difference of the task design may contribute differently to the results; therefore, caution should be taken in interpreting the outcomes and comparisons of these two task designs.

From a skilled performance perspective, the results of the present study can be interpreted to support the hypothesis stating that there seems to be a "positive relationship" between controllability of automatic processing and skilled performance because people with better skill are able to respond more rapidly without committing more errors; however, the magnitude of the relationship cannot be explained as a significant improvement of the interference effects because no significant differences in the arithmetic-Stroop interference were found among the students of different major types. That is, skilled practitioners perform better at response time but suffer similar interference effects as those with lesser skill. The more skilled participants are not only responding faster, which implies greater automaticity, but also must be improving their control skills so their greater speed does not cause more errors. In this study, the results, however, have shown the superior performance in speed, but not in accuracy, of the students in the math-related majors (engineering) to those, whose majors were less math-related (psychology, biology, and business), and this implies that participants with more advanced math skill seem to be able to respond faster at the concurrent task but are unable to "control" or reduce the interference effects as compared to those with lesser math skill.

The current findings also do not support the notion that more skill improvement would eliminate interference effects. The present results show that increased skill as measured by RT can be acquired without a decrease in controlled processing. Many studies have shown that early in skill training, practice leads to a reduction in errors and interference effects (Rogers & Fisk, 1991; Macleod, 1991; Salthouse, 1986); however, as the practice at novel tasks becomes redundant, the reduction in interference effect reaches its asymptote, and therefore no more improvement can be achieved (Macleod & Dunbar, 1988; Cohen et al., 1992). This depiction is compatible with the current findings, which show that despite the significant reduction in RT for participants with advanced math skill (engineering-related major) there were no significant reductions in Stroop interference found among the students as a function of major categories, or high-low levels of math scores. That is, regardless of the advanced level of math skill or high scores in math skill test, all participants suffered similar level of the Stroop interference effects.

Interestingly, it should not be forgotten that the methods used in measuring the Stroop interference effects could also play a critical part in the validity of the results. Two measures had been considered in the present study, the absolute difference in RT scores and the difference as a proportion of average RT. Lacking clear information on how an RT scale of arithmetic performance might differ from an interval scale we chose to use absolute difference in RT as our measure of interference. However, if the proportional approach had been used then we would have found greater Stroop-interference effects being associated with faster overall performance.

Practically, the findings have implications for development of training for activities like driving. The findings further support the role of extensive practice in learning to control the information processing with speed. Therefore, it is reasonable to provide constant job trainings or career enhancement programs to improve job performance, especially for work that requires speed and control. However, the present results also suggest that although extensive practice or advanced skill may be helpful in processing information faster, it does not completely eliminate the interference effects attributable to automatic responses to irrelevant task features. In addition, to improve people in their speed performance and keep errors in-check a training program would be designed to keep speed constant and gradually increase with extensive practice. This would lead to speed increase and error reduction, which was what was expected and found from this present study.

Finally, there are some problems in this study that should be addressed. Despite the results of the significant reduction in response time for those with high-level of skill (the engineering-related subjects), the individual differences, as shown in the results, seemed to be the controlling factor in the non-significant improvement in the Stroop interference effects. This might be due to the fact that some young freshmen, although their majors were less-math-related, just moved up from high school where they had more involvement with math. Whereas, the others, whose math practice had been disrupted for a while, were in the same less math-related major thereby slower in response to math problems. Further, although the overall sample size appeared to be reasonable ($N = 83$), the participants were unequally divided among the four major types. The psychology-related ($n = 30$) and the engineering-related major ($n = 22$) were almost double the business-related ($n = 15$) and the biology-related major ($n = 16$).

Conclusion

In conclusion, the present study tested two hypotheses to see the degree to which processing arithmetic information is automatic or controlled; and whether the relative degree is influenced by the levels of skill. If the lower RTs of the students in the math-related majors were the result of greater automaticity, then we would expect greater Stroop interference. The results of lower RTs without increased errors found in the present study means that either that the differences in RT are not the result of differences in automaticity or increases in automaticity are compensated by increased speed of the controlled process that prevents errors. These data cannot differentiate between these two explanations. The findings, therefore, were not totally conclusive. Although higher skill has its advantage in reducing processing time and errors, the math skill level does not decrease the interference effects. Future studies should focus on different skills to see whether they generate any different patterns of Stroop interference.

References

Besner, D., Tolz, J. A., & Boutilier, C. (1997). The Stroop effect and the myth of automaticity. Psychonomic Bulletin & Review, 4, 221-225.

Cohen, J. D., Schreiber, D. S., & Mc Clelland, J. L. (1992). A parallel distributed processing approach to automaticity. American Journal of Psychology, 105, 239-269.

Jastak, J., & Jastak, S. (1978). Wide range achievement test manual of instructions. Los Angeles: Western Psychological Services.

LeFevre, J. A., & Kulak, A. G. (1994). Individual differences in the obligatory activation of addition facts. Memory & Cognition, 22, 188-200.

Logan, G. D. (1985). Skill and automaticity: Relations, implications, and future direction. Canadian Journal of Psychology, 39, 367-386.

Logan, G. D. (1988). Towards an instance theory of automatization. Psychological Review, 95, 492-527.

MacLeod, C. M. (1991). Half a century research on the Stroop effect: An integrative review. Psychological Bulletin, 109, 163-203.

MacLeod, C. M., & Dunbar, K. (1988). Training and Stroop-like interference: Evidence for a continuum of automaticity. Journal of Experimental Psychology: Learning, Memory, and Cognition, 14, 126-135.

Merrill, L. L., Lewandowski, L. J., & Kobus, D. A. (1994). Selective attention skills of experienced sonar operators. Perceptual and Motor Skill, 78, 803-812.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. Journal of Experiment Psychology: General, 106, 226-254.

Rodgers, K., Schneider, W., Pitcher, E., & Zuccolotto, A. [computer software]. (1995). M.E.L. Professional [Psychology software tools]. Pittsburgh, PA: University of Pittsburgh, Learning Research & Development Center.

Rogers, W. A., & Fisk, A. D. (1991). Aged-related differences in the maintenance and modification of automatic processes: Arithmetic Stroop interference. Human Factors, 33, 45-56.

Salthouse, T. A. (1986). Perceptual, cognitive, and motoric aspects of transcription typing. Psychological Bulletin, 99, 303-319.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18, 643-662.

Tzelgov, J., Henik, A., & Leiser, D. (1990). Controlling Stroop interference: Evidence from a bilingual task. Journal of Experimental Psychology: Learning, Memory, and Cognition, 16, 760-771.

Zbrodoff, N. J., & Logan, G. D. (1986). On the autonomy of mental processes: A case study of arithmetic. Journal of Experimental Psychology: General, 115, 118-130.

Zbrodoff, N. J., & Logan, G. D. (1990). On the relation between production and verification tasks in the psychology of simple arithmetic. Journal of Experimental Psychology: Learning, Memory, and Cognition, 16, 83-97.

Appendices

Appendix A

Analysis of Variance for Major Category by Equation Type by Math Operator in RT and Accuracy

		F	
Source	df	RT	accuracy
Major Category	3	7.74**	0.43
Error	79	(23,969.62)	(4.338E-03)
Equation Type	2	38.98**	5.31*
Major Cat. x Equation Type	6	1.37	0.54
Error	158	(3976.82)	(8.781E-03)
Operator	1	43.84**	4.62*
Major Cat. x Operator	3	0.41	2.14
Error	79	(4,283.39)	(7.077E-03)
Equation Type x Operator	2	10.61**	38.16**
Major x Equation Type x Operator	6	0.31	0.72
Error	158	(2,912.31)	(7.393E-03)

Note: Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .001$.

Appendix B

Analysis of Variance for Major Category by Response Category by Math Operator in RT and Accuracy

		F	
Source	df	RT	accuracy
Major Category	3	7.71**	0.44
Error	79	(24,073.39)	(4.192E-03)
Response Category	1	50.53**	2.60
Major Cat. x Response Category	3	1.27	0.81
Error	79	(2,945.59)	(5.431E-03)
Operator	1	34.47**	5.72*
Major Cat. x Operator	3	0.25	1.69
Error	79	(3,182.56)	(3.930E-03)
Response Category x Operator	1	2.17	0.01
Major x Response Cat. x Operator	3	0.25	1.55
Error	79	(2,115.11)	(3.734E-03)

Note: Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .001$.

Appendix C

Analysis of Variance for Major Category by Math Operator in the Interference Effects

Source	*df*	*F* Interference Effect
Major Category	3	1.47
Error	79	(4,026.17)
Operator	1	18.53**
Major Category x Operator	3	0.36
Error	79	(6,008.95)

Note: Values enclosed in parentheses represent mean square errors.

* $p < .05$. ** $p < .001$.

San José State
UNIVERSITY

Office of the Academic Vice President

Associate Vice President Graduate Studies and Research

One Washington Square
San Jose, CA 95192-0025
Voice: 408-924-2480
Fax: 408-924-2477
E-mail: gstudies@wahoo.sjsu.edu
http://www.sjsu.edu

TO: Hoan Cong Nguyen
97 Foss Ave
San Jose, CA 95116

FROM: Nabil Ibrahim,
AVP, Graduate Studies & Research

DATE: February 18, 2000

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"Is Math Skill a Factor in Reducing Interference Effects in Stroop Tasks"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Nabil Ibrahim, Ph.D., immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.