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**Language and Mathematics:
The Relation Between English-French Bilingualism
and Simple Arithmetic**

by

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**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of**

Master of Arts

Department of Psychology

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Acceptance of the thesis:**

The Relation Between English-French Bilingualism and Simple Arithmetic

submitted by

Alex P. Stringer

**in Partial fulfillment of the requirements for
the degree of Master of Arts**

Chair

Thesis Supervisor

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Abstract

This experiment examined the relation between English-French bilingualism and simple arithmetic. The experiment was a replication of Campbell (1994), with the addition of a second response language (French), and a third problem format (French words). Participants were 32 bilingual undergraduate university students in either the ‘English Group’ (English first language, French second language), or the ‘French Group’ (the reverse). All participants answered simple arithmetic questions presented in digits, English words and French words. The two groups of participants were analyzed separately due to significant differences in mathematical proficiency, frequency of second language use, and other factors. Consistent with Campbell (1994), effects of format (i.e., digits versus words), operation (i.e., addition versus multiplication), and problem size (i.e., small versus large) were found. For the English group, conditions involving French word format and/or French response language showed higher response latencies and error rates. Further, this group translated problems presented in French into English. In contrast, participants in the French group did not appear to translate problems presented in English into French. While the results of the English group argued for the language-independent view, findings from the French group also found support for the language-specific view of number processing.

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**Language and Mathematics:
The Relation Between English-French Bilingualism
and Simple Arithmetic**

In societies where there are large numbers of individuals who speak more than one language, it is of interest to examine the effects of bilingualism on certain common tasks, such as mathematics. Language is essential for communication, however mathematics is also an important means of conveying information. Mathematics is a universal tool used in the fields of technology, science, and other areas in society to convey precise information. Although different aspects of arithmetic have been studied extensively in cognitive psychology, the interactions that may exist between language and arithmetic are fairly new areas of research in the field. The goal of the present research was to examine the relation between English-French bilingualism and simple arithmetic. It was hypothesized that language does have an effect on arithmetic; further, that performing simple arithmetic in one's first language would be superior to performing simple arithmetic in one's second language.

In terms of simple arithmetic, at least three prominent theorists have attempted to explain how individuals process numbers in arithmetic. McCloskey and colleagues have proposed the *abstract-modular* model (McCloskey, Caramazza, & Basili, 1985; McCloskey, Harley, & Sokol, 1991; McCloskey & Macaruso, 1994; McCloskey, Maracuso, & Whetstone, 1992). This model depicts a modular view of number processing, and contains three separate cognitive systems; the number comprehension system, the calculation system, and the number production system. These three components are

hypothesized to make use of abstract codes that are used for processing. The processing that occurs within each system is independent of the processing in any other system. In the comprehension system, the number format (e.g., digits or words) is converted into an abstract quantity code. This abstract quantity code is used for processing in the calculation system. The main assumption of this model is that no interactions are hypothesized to exist among the three systems. For an illustrative interpretation of this model, see Figure 1.

Dehaene proposed the *triple-code theory* of number processing (Dehaene, 1992; Dehaene & Cohen, 1995). Dehaene suggests that number processing occurs in three different codes, rather than in one abstract quantity code as proposed by McCloskey. These three codes include a visual-Arabic number form, an auditory-verbal code, and an analog magnitude representation. The basic premise of this model is that, for any numerical operation, only one of the three codes is responsible for the processing. Input into the model is translated by encoding processes into the code that matches the internal representation of the particular task (Dehaene, 1992; Dehaene & Cohen, 1995). Therefore, arithmetic problems are transcoded into the auditory-verbal code. After transcoding of input to the appropriate internal code, number processing occurs independently of the initial format of the input. With this model, the encoding processes should be independent of the calculation and production processes. For an illustrative interpretation of this model, see Figure 2.

Campbell and Clark (1992) proposed the *encoding-complex* view of cognitive number processing. In this model, number processing is mediated by specific, rather than abstract number codes. Modality-specific processes and structures (e.g., visual, visuo-

spatial, and phonological codes) are responsible for the coding and the processing of mathematical tasks. Campbell and Clark (1992) also hypothesized that a single numerical function can actually make use of many different codes, and that each code may be involved in several numerical functions. The encoding-complex view implies that different surface formats (e.g., digits versus number words) vary in the degree to which they trigger the specific internal codes that are used for performance, and therefore the representational basis of performance can differ depending on the surface format (Campbell, 1994). Overlapping processes, shared underlying representations, and associative mechanisms all contribute to the comprehension, calculation, and production of number processing, each of which may differ in terms of specific information and response requirements (Clark & Campbell, 1991). Hence, the complex network of the encoding-complex model predicts format interactions that are not predicted in the abstract-modular or triple-code models. For an illustrative interpretation of the encoding-complex model, see Figure 3.

Although the models of Campbell and Clark (1992), and Dehaene (1992) are not perhaps as clear and well specified as McCloskey's abstract-modular model, they are motivated by findings that contradict the abstract-modular model of number processing. Evidence supports format- or modality-specific processes rather than only abstract or format-independent processes as McCloskey has suggested (Dehaene et al., 1993; Campbell & Clark, 1992). Further, interactions have been found that contradict McCloskey's assumption of independent systems. Blankenberger and Vorberg (1997) found a strong interaction between format and operation. Campbell (1994) also found

many interactions, including format by operation and format by problem size. LeFevre, Bisanz, and Mrkonjic (1988) also found interference at the calculation level when looking at a number-matching task that should have only required comprehension processes.

Further, although these models have advanced cognitive psychology in the domain of mathematics and number processing, none of the models mentioned have attempted to include the effects of knowledge of different languages and cultures on number processing and mathematics. Researchers have found differences among individuals varying in their linguistic and cultural backgrounds in terms of solving simple arithmetic problems (LeFevre & Liu, 1997; Geary, 1996). For example, LeFevre and Liu (1997) found that Chinese speakers made fewer errors, and different types of errors than English speakers when solving simple arithmetic problems. In addition, Chinese speakers demonstrated much quicker response times to similar problems than did English speakers.

Many linguistic theories assume that language is learned separately from cognitive skills, and is based upon different principles than other learned behaviours (O'Malley & Chamot, 1990). Following these theories, language should not really have a significant impact on mathematical skill; the assumption would be that mathematics uses a different set of rules and parts of the brain than language does. However, a more realistic view is that language acquisition is best understood as a complex cognitive skill, just as mathematics acquisition is a complex cognitive skill (O'Malley & Chamot, 1990). These skills were learned independently and most likely at different times in life. Presumably, simple arithmetic is learned after a first language has already been acquired. However, many individuals learn a second language, either during or after simple arithmetic

acquisition. With second language acquisition, the view that both mathematics and language are indeed complex cognitive skills allows us to directly examine the relation between mathematics and language; in particular, any interactions that may exist based on levels of proficiency with each of these complex cognitive skills.

Mathematical proficiency is usually tested using arabic digits, the most common form of representing numbers and quantities. However, when mathematical tasks are presented in different formats (e.g., words versus numbers), there are significant effects on mathematical performance (Campbell, 1994; Noel, Fias, & Brysbaert, 1997). Similarly, the level of proficiency of second language acquisition may depend on the domain in which the second language is being used.

For example, individuals may be fluent in their second language for informal speech and everyday conversation, but have difficulties in other settings. Spanos and Crandall (1990) report that language minority students in the United States who appear to be proficient in English when speaking with their peers or teachers do not necessarily function equally well when using the language in their academic work. Spanos and Crandall (1990) use the term *academic language* to refer to the language of mathematics, of science, or any other discipline, and describe it as being more abstract and cognitively demanding language than everyday language. Therefore, the relation between language and mathematics may depend on the extent of second language experience *in mathematics* and *numbers* that an individual possesses, and not just on the 'apparent' proficiency that the individual has in his/her second language.

A suitable way to examine the relation between language and mathematics, and the criteria outlined above, would be to use a similar experimental design to Campbell (1994), with some additions. Campbell (1994) examined the effect of using digits versus words on addition and multiplication performance; the *problem format*. Campbell (1994) found that response times and error rates were much higher with the word format than with the digit format. Other manipulations of problem format have been examined as well.

Blankenberger and Vorberg (1997) examined the effects of digits, number words, and 6-sided dice on addition and addition-plus-one performance. *Addition-plus-one* requires the participant to name the successor of the sum of the displayed numbers (Blankenberger & Vorberg, 1997). An effect of problem format was found; response times were fastest for digits, then for dice, and slowest for words (Blankenberger & Vorberg, 1997). Noël and Seron (1997) also studied the effect of problem format using words and roman numerals.

In the context of these studies, “format” refers to the manner in which numbers are presented to the participants (Noël & Seron, 1997). The most commonly used formats for numbers in experiments are the verbal and arabic formats. In arabic format, the positioning of 10 symbols (i.e., digits) is used to express quantity. Some examples of numbers expressed in arabic format are “12”, “40”, “3”, etc. The verbal system, on the other hand, is composed of a larger number of lexical primitives (i.e., words), arranged in classes (e.g., units, teens, decades) and also in terms of mathematical relationships (i.e., sequences of embeddings of multiplications and additions; Noël & Seron, 1997).

In the present research, in order to examine the effects of first and second languages on mathematics, the verbal problem format variable that Campbell (1994) had used (i.e.,

words) was extended to create two verbal formats; English number words and French number words. The arabic problem format (i.e., digits) remained the same as Campbell (1994). Two groups of students participated in this study. Gender differences were controlled in that each group had an equal number of males and females. The 'English Group' spoke English as a first language and French as a second language, and the 'French Group' spoke French as a first language and English as a second language. Campbell (1994) maintains that people use different cognitive processes for each problem format (i.e., numbers versus words). However, one of the questions addressed in the present experiment was whether or not people use different cognitive processes to perform simple arithmetic for each verbal format as well (i.e., English words versus French words)?

Frenck-Mestre and Vaid (1993), found that English-French bilingual participants who spoke English as their first language were slower on problems presented in French than on problems presented in English. If there are separate cognitive processes for each verbal format (i.e., English number words and French number words), error rates and response latencies should have been affected by the individual's *proficiency* in both mathematics and in their second language. If an individual is not proficient in mathematics and not proficient in their second language, then he or she was expected to have increased difficulties in controlled processing that can be attributed to performing two complex cognitive tasks simultaneously (Rabinowitz & Chi, 1987). Individuals asked to solve mathematical problems in their second language may therefore translate the problems from their second to their first language in order to reduce the extra load placed on the cognitive processing system.

Number processing is theorized to occur at three levels – the input, or encoding level; the processing, or calculation level; and the output, or response level. Translation could occur at the input stage of number processing. Once the problem has been solved, individuals would then translate the problem back into their second language to generate a verbal response; the output stage of the number processing system. Presumably, translation would take time at both the input and output stages of number processing, and therefore the use of translation should result in increased response latencies. Support for this would come from longer response times in a participant's second language than in a participant's first language. Further, any time more steps are taken to solve a simple problem, the likelihood of making an error is increased. Therefore, the error rate was expected to be higher when translation occurred.

Although translation may be used as a means of reducing the difficulty of a mathematical problem in a second language, some individuals may translate sporadically, and without the realisation of doing so until after responding. Selinker (1972) has suggested that bilingual individuals develop an internal representation of language termed *interlanguage*. *Interlanguage* is defined as “the intermediary form of a second language that often contains elements of both the native and the target language” (Selinker, 1972; cited in O'Malley & Chamot, 1990, p.58). Support for interlanguage would come from individuals responding (out loud) to questions in a language other than the language of presentation (e.g., using their first language to respond to questions presented to them in their second language), and then quickly changing their response language to the language

of presentation. It is hypothesized that some degree of evidence for interlanguage will be found in the present experiment.

In the present study, three dependent measures were collected, including *response latency*, *error rate*, and *types of errors*. These dependent measures were very similar to those examined by Campbell (1994). Further, four main independent variables were manipulated. Three were consistent with Campbell (1994); *problem format* (problems presented in either digits or words – and words was expanded to include both English word and French words), *operation* (addition or multiplication), and *problem size* (small or large operands and answers). And the fourth was added to the design of Campbell (1994); *response language* (problems were to be responded to in either English or French, depending on the problem set – see Method section). Not only did Campbell (1994) find an effect of problem format, he also found an interaction between format and arithmetic operation. Campbell (1994) found that operation errors (e.g., $2 + 5 = 10$), operand-naming errors (e.g., $2 + 8 = 8$), and operand-intrusion errors ($5 \times 6 = 36$) each had a different format X operation interaction.

Mathematical proficiency was measured using the "French-Kit" test, a paper-and-pencil arithmetic test (French, Ekstrom & Price, 1963). Second language proficiency was measured using two separate tests within the Peabody Picture and Vocabulary Test, third edition (PPVT-III) (Dunn & Dunn, 1997), and a short set of interview-type questions targeted language of computation, methods of solving math in second versus first languages, and attitudes relating to any relationship between language and mathematics, in both pre-test and post-test conditions. In addition, a longer questionnaire asked various

other questions aimed at different possible procedures used in mathematics, general mathematics, and questions pertaining to spoken language, and reading and writing.

In this study, I examined both hypotheses related strictly to mathematics and hypotheses about the relation between English-French bilingualism and mathematics. The hypotheses about math performance were tested against a virtually identical design to that used by Campbell (1994). First, the effect of *problem format* was examined. Problems were given in either digits, English words, or in French words. It was hypothesized that due to the familiarity with the use of digits in mathematics, coupled with the greater simplicity of the arabic versus the verbal format of number representation, the error rates would be higher with words than digits, as would the response times. This is consistent with the findings of Campbell (1994), and Noël et al. (1997). Second, the effect of *operation* (multiplication vs. addition) was examined, with the hypothesis that due to the increased complexity and difficulty of multiplication tasks, higher error rates and longer response times were expected. This is also consistent with previous findings (Campbell, 1994). Another phenomenon that was examined is the problem size effect. The *problem size* effect for simple multiplication and addition arithmetic refers to the finding that both reaction time and errors increase as the size of a problem's operands, hence its answer, increases (Ashcraft, 1995). Small problems (i.e., problems with sums less than 10 or products less than 25) were expected to demonstrate lower error rates and shorter response times, concurrent with Campbell (1994), LeFevre, Sadesky, and Bisanz (1996), and LeFevre, Bisanz et al. (1996).

In terms of the relation between English-French bilingualism and mathematics, further hypotheses were examined. First, a response language by problem format interaction was expected. Although the format effect was expected to occur in both language groups (i.e., word problems would have higher error rates and higher response latencies than digit problems), it was hypothesized that individuals would have higher error rates and response latencies when problems were presented in their second language (i.e., when the problem was presented in French for a participant in the English group individual, or vice versa) than when problems were presented in their first language. This hypothesis was based on an extension of the findings of Frenck-Mestre and Vaid (1993), discussed above, who found that English-French bilingual participants who spoke English as their first language were slower on problems presented in French than problems presented in English; here, the expectation was extended for the opposite to be true for the French group. It was hypothesized that the higher response latencies and error rates for second language problems would be due to translation at input and output levels of number processing in many cases. As discussed, translation would require more time and increase the chance of error. However, although translation should increase response times, higher response times do not necessarily indicate translation. Therefore, patterns of errors were also examined for indicators of translation.

If translation was occurring at the input stage, the patterns of errors should have been identical for problems presented in English and French words for each individual participant, since the input to be encoded for processing would always be English words in either case. If translation was occurring at the output stage of number processing, the

patterns of errors should also have been similar for problems responded to in English compared with French. This is again based on the notion that all responses coming out of the calculation system are encoded into English before being translated into French. However, if the pattern of errors was different for a participant's first language than for their second language (either at the input stage – English word versus French word formats; or at the output stage – response language), this would indicate that this particular participant was encoding problems from their second language directly into the processing stage rather than via encoding (translating) to their first language before encoding a second time into the calculation stage. The pattern of errors for participants whose first language was English and responded to the problems in English was expected to mirror the pattern of errors found by Campbell (1994), who also used English participants in his experiment.

Further, a three-way interaction between response language, operation, and format was predicted. The hypothesis that multiplication tasks would produce higher response latencies and error rates than would addition tasks was maintained for both language groups. Similarly, the problem format hypothesis still applies; that word problems would produce higher error rates and response latencies than digit problems. However, the difference between digits and words across operations was expected to be larger when problems were given in the second language than when problems were given in the first (i.e., for the English group receiving problems in French, and for the French group receiving problems in English). This hypothesis is based on the assumption that the increased difficulty of second language words coupled with the increased difficulty of multiplication problems would result in a operation effect with second-language words

than with first-language words or digits. Further, this finding would be augmented when the response language was the second-language versus the first. This hypothesis is consistent with the findings of Suuronen (1998).

In summary, in the present experiment I examined the relation between language and simple arithmetic by manipulating four independent variables. Although main effects of response language (English, French), format (digits, English words, French words), operation (addition, multiplication), and problem size (small, large) were hypothesized, the interactions among these main effects, and patterns of types of errors were of particular interest. Along with the role of language at the input and output stages of number processing, the role of language at the calculation stage was examined for support in either the language-specific or the language-independent views of simple arithmetic processing.

Method

Participants

Thirty-two students enrolled in the first-year undergraduate Psychology course at Carleton University participated in this study. Sixteen participants (8 males; 8 females) spoke English as a first language and French as a second language. The mean age of this group (the 'English' group) was 21.7 years. Sixteen participants (8 males; 8 females) spoke French as a first language and English as a second language. The mean age of this group (the 'French' group) was 21.9 years. All participants involved spoke both English and French, and all participants received their elementary school education in Canada in their first language. None of the participants were in French Immersion prior to Grade 7. Twenty-eight of the participants received two experimental participation credits towards their grade in the course, and the remaining four students were compensated with \$15.

Materials

Each participant read a description of the research and gave their consent to participate (see Appendix A). Each participant answered six questions related to language and mathematics (pre-test measure – see Appendix B).

Each participant completed four blocks of 108 simple arithmetic problems. All problems contained two operands, each between the values of 2 and 9. Each of the four blocks contained a randomized set of every paired combination of the numbers from 2 to 9 (e.g., 2 2, 2 3, 2 4, etc.). All participants responded to two blocks in English (one of addition problems and one of multiplication problems) and two blocks in French (one addition and one multiplication). The ordering of blocks, operation, and response language

was predefined by the experimenter in a table to counterbalance the ordering as best as possible. For example, the first participant in the English group was asked to respond in English to block 2 in addition then to block 4 in multiplication, followed by response in French to block 1 in addition then block 3 in multiplication. For a more detailed description of the counterbalancing that was used, see Appendix C. Questions in all four blocks were presented to the participant on a computer screen in three different formats: digits, English words and French words. The first question in each block was presented in digits, the next question in English words, the third question in French words, and then the fourth was presented in digits again, etc. This rotation of presentation format was used in all four blocks of questions.

The six verbal questions were asked again by the experimenter after the participant completed the computer trials (post-test – see Appendix B). All participants completed two subtests of the “French-Kit” (French, Ekstrom & Price, 1963) mathematical proficiency pencil-and-paper test (see Appendix D). The first subtest required the participant to answer two sets of addition questions on paper as quickly and as accurately as possible. Each question contained three operands of either single or double digits. For each of the two sets, the experimenter instructed the participant to turn his/her paper over when he/she was ready to begin. Using a stopwatch, the experimenter allowed exactly two minutes of time to elapse before instructing the participant to stop. The second subtest also consisted of two sets of questions, however the questions were a mixture of subtraction and multiplication problems, organized in six lines by a line of ten subtraction problems followed by a line of multiplication problems. Each question contained two operands of

either single or double digits. The same procedure was used as for the first subtest; two minutes per question set were allowed, and the participant was instructed to answer as many questions as possible, and as accurately as possible, in the time allowed. Overall scores for the French-Kit test were calculated as the sum of correct responses across the four sets of questions (i.e., two sets from each subtest).

Each participant also completed an 8-page self-report questionnaire (see Appendix E). This questionnaire was composed of five parts: General Background (demographics questions, such as province of education, date of birth, gender); Procedure Use (questions looking at techniques used to perform simple arithmetic); Mathematics (questions pertaining to mathematical skill-level, comfort-level, and the individual's history with math); Language: Spoken (questions pertaining to what languages the participant speaks, and how often they use these languages); and Language: Reading and Writing (questions about reading and writing skills, comfort-level, and the individual's history with reading and writing).

The Peabody Picture Vocabulary Test (PPVT-III), Third Edition, was used as a measure of second language proficiency (Dunn & Dunn, 1997). One form (Form IIIA) of the PPVT-III was used for participants who spoke French as a second language, and another form (Form IIIB) of the PPVT-III was used for participants who spoke English as a second language.

Each participant was given a debriefing letter, outlining the goals and expectations of the experiment (see Appendix F).

Procedure

Each participant was tested individually in room A500A of the Loeb building at Carleton University. Each participant read and signed the consent form before commencing the experiment. The experimenter then asked the six pre-test questions.

Following this, participants were asked to place a microphone-equipped headset on their head. Simple arithmetic problems were presented on a computer screen. Before the experimental trials began, the experimenter told the participants that they would solve four sets of 108 questions; two sets of which they would be responding to in English, and two of which they would be responding to in French. Participants were instructed to answer the questions as quickly and as accurately as possible, and were told not to speak into the microphone unless they were responding to the question (i.e., to try not to say “umm” or “ahh” etc., before responding). The experimenter then prompted the computer program to begin by keying in the order and operation of the first two blocks specific to that participant (see Appendix C). The participant then received further detailed instructions on the screen in front of them. These instructions demonstrated to the participant the three formats of problems that would be seen – digits (e.g., $3 + 5$), English words (e.g., three + five), and French words (e.g., trois + cinq), and that the questions would always be asked in the order: digits, English word, French words. The instructions also indicated whether the questions to follow would be addition or multiplication problems. Before starting a block of questions, the experimenter reminded the participant which language they would need to respond in, and again stressed the need for both speed and accuracy. After the first set, the computer indicated that the operation (addition or multiplication) would be

changed for the second set. After the first two sets were completed, the participant was given a brief break and then told that they would now be answering in the other language (English or French) from the first two sets. For each question, the computer program measured the latency between when the question appeared on the screen and when the participant triggered the microphone with his/her response. Once the microphone had been triggered, the experimenter coded the response. For the majority of trials, the experimenter would key in the response of the participant. However, if the response was invalid (e.g., participant coughed), the experimenter coded the response to be 'invalid'. Also, if the participant answered in the wrong language, the experimenter coded the response accordingly. In addition, the experimenter could control the "threshold" of the sensitivity of the microphone (i.e., the microphone could be made more/less sensitive to sound if needed).

After the computer testing procedure, the participant answered the six post-test questions (see Appendix B). The "French-Kit" (French, Ekstrom & Price, 1963) mathematical proficiency pencil-and-paper test was then administered to each participant.

Following this, the participant was asked to complete an 8-page self-report questionnaire which included various questions pertaining to the individual's general background, mathematical and language history and abilities. Next, the Peabody Picture and Vocabulary Test, third Edition (PPVT-III), was administered to the participant in their second language. In this test, the experimenter and participant sat across the table from each other, and the experimenter read a word in English or French (depending on which was the participant's second language). Four pictures were shown for each word that was

read, and the participant chose the picture that represented the word. This continued through progressively more difficult lists of words until a “ceiling” was reached. The ceiling list was defined as the list of words from the PPVT-III from which the participant made 8 or more errors. Raw scores were calculated according to the PPVT-III scoring manual (Dunn & Dunn, 1997); the total number of errors made from all questions asked was subtracted from the question number of the last question in the ceiling list. Raw scores were then standardized based on chronological age, again in accordance with a set of instructions, using a table of norms found in the PPVT-III scoring manual (Dunn & Dunn, 1997).

Analyses

Separate ANOVAs were conducted on median correct latencies for each of the two participant groups. Also, separate ANOVAs were conducted on the percentage of errors for each of the two groups. For calculating problem size, a ‘small’ problem was defined as any addition problem with a sum equal to or less than 10, or any multiplication problem with a product equal to or less than 25. A ‘large’ problem was therefore any addition problem with a sum greater than 10 or any multiplication problem with a product greater than 25. Using these analyses, main effects and interactions were examined in detail for each of the independent variables.

Results and Discussion

Of the 13824 trials, 547 (3.9%) were coded as being invalid either due to the microphone being triggered by a noise other than the response, or due to the response time being outside the allowable minimum (i.e., 250 ms) and maximum times (i.e., 10,000 ms). English participants had 302 invalid responses (4.4% of their total responses) and French participants had 245 invalid responses (3.5% of their total responses). A t-test comparing the percentage of invalid responses for each subject in the English group against the percentage of invalid responses for each subject in the French group found no difference between the two groups, $t(29)=.49$, ns.

Comparison of the English Group and the French Group

In order to determine whether the performance of the English and French participants could be compared directly, measures of skill and language proficiency were analyzed for the two groups (see Table 1).

Although the two groups were very closely matched in age (21.7 vs. 21.9 years for the English vs. French participants), they differed on other measures. The French group scored significantly higher on the mathematical proficiency test than the English group (means of 85 and 64), $t(30)=2.28$, $p<.05$. Findings supported the hypothesis that reaction times would be dependent on mathematical proficiency. Mean reaction times were negatively correlated with the scores on the French-Kit test for both the English group, $r(14) = -.63$, $p<.01$; and the French group, $r(14) = -.52$, $p<.05$. Increased math proficiencies therefore corresponded with faster reaction times. However, the correlation found between error rates and scores on the French-Kit test was just outside of the significant level for the

English group, $r(14) = -.46$, $p = .07$; and was minimal for the French group, $r(14) = -.27$, ns, in contradiction of the hypothesis that error rate would be dependent on mathematical proficiency. Analyses of errors and of error types are discussed in more detail in a later section.

The French group also scored slightly higher on standardized scores of the PPVT-III test of second language proficiency than the English group (106 vs. 98, respectively), although this difference was not significant, $t(30) = 1.47$, ns. As hypothesized, reaction time and PPVT-III scores were negatively correlated for the English group, $r(14) = -.64$, $p < .01$; however, this correlation was minimal with the French group, $r(14) = -.21$, ns. This finding presumably reflects the differences in second language proficiency level of the two groups, and also the differences in level of second language use between the two groups (see below). Further the hypothesis that error rates and scores on the PPVT-III would be negatively correlated was supported for both the English group, $r(14) = -.71$, $p < .01$; and by the French group, $r(14) = -.57$, $p < .05$. Therefore, higher error rates were associated with lower levels of second language proficiency. This is not surprising considering the roles of second language involved in this experiment; that is, both as a problem format and as a response language. Difficulty in the second language would no doubt affect performance.

Further, while the majority of the findings from the self-report questionnaire were similar between the groups, the results of the questionnaire revealed some important differences between the English and French groups. For a detailed breakdown of the results of the questionnaire, please refer to Table 2. The French group rated their basic mathematical skill close to the "Very High Skill" level, whereas the English group only

rated their basic math skill just above the “Moderate Skill” level. Further, the French group reported using their second language (English) an average of 57% of the time whereas the English group reported using their second language (French) an average of 10% of the time, $t(28)=11.01$, $p<.01$. To summarize, not only were the French group slightly more proficient in their second language, they also used their second language much more frequently than the English group. A last very important finding from the self-report questionnaire was that while the 100% of the English group stated that they typically used their first language when talking about anything concerning numerical information, only 19% of the French group reported that they used French when discussing numbers! In other words, 81% of the French group actually used their second language, English, rather than their first, when talking about anything dealing with numbers. This finding is of obvious importance to the present experiment, and further strengthens the realization that the two groups are different and should therefore be analyzed separately.

An analysis of the pre-test/post-test questions also revealed differences between the groups (see Figures 4 and 5). When asked at the beginning of the experiment, 69% of the English group indicated that in order to solve a simple arithmetic problem in their second language, they would first translate the problem into their first language. With the French group, only 37% responded that they would translate in this situation. Further, 63% of the French group compared with only 25% of the English group reported that they would solve a problem in their second language without translation. After the computer testing procedure, a higher percentage of the English group (87%) responded that they translate problems into their first language to solve them, whereas the percentage of the French

group indicating the use of translation remained the same (37%). Therefore, another striking difference between the English and French groups was in how they claimed to solve a problem in their second language; the English group indicated that they tend to translate the problem into their first language before solving it, and the French group indicated that they tend to solve problems in their second language in the same way as their first language (i.e., without translating first).

Summary

Thus, the English group and the French group differed greatly on mathematical proficiency, slightly on second language proficiency, and greatly in how they perceived that they solve simple arithmetic problems in their second languages. Further, the two groups should be viewed as distinctly different subsamples from the bilingual populations; the English group is dominant in English and uses French less than 10% of the time, whereas the French group is more probably balanced, and claimed to use English more often than French. Based on these differences, the analyses of the performance on the experimental task were conducted separately for the two groups.

The English Group

Latencies

Median response latencies (from correct trials only) were calculated for each participant by response language, problem format, operation, and problem size. These median latencies were analyzed in a 2 (response language: English, French) x 3 (format: digits, English words, French words) x 2 (operation: addition, multiplication) x 2 (problem

size: small, large) repeated measures ANOVA. The results of this analysis of variance for the English group are summarized in Table 3.

The results of the English group supported all of the hypothesized main effects. Response times were significantly faster when participants responded in their first language (English) versus their second language (1254 ms vs. 1570 ms). Participants responded faster to problems presented in digits than to problems presented in English words and French words (1172 ms, 1454 ms, and 1610 ms, respectively). This result showing that digit problems are responded to more quickly than word problems is consistent with the findings of many studies, including Campbell (1994), Blankenberger and Vorberg (1997), and Noël and Seron (1997). Campbell and Clark's (1992) suggestion that word-format problems probably involve longer encoding times compared to digit problems because they require a wider visual angle and are less familiar looking could be applicable here. Further, McCloskey's abstract-modular model could be used to explain this by suggesting that the English verbal and French verbal comprehension systems are not as 'tuned' and as fast as the Arabic number comprehension system.

Response times were significantly faster for addition problems than multiplication problems (1320 ms vs. 1504 ms), and response times were shorter for small problems than for large problems (1245 ms vs. 1580 ms). This effect of operation is consistent with studies that have shown that response times for addition problems are fast than response times for multiplication problems (e.g., LeFevre, Bisanz & Mrkonjic, 1988). Perhaps retrieving an answer for an addition problem is relatively automatic, and possesses a lower need for attention compared to the retrieval of an answer for a multiplication problem.

There is also strong agreement in arithmetic research that problem difficulty and response time increase in relation to problem size (LeFevre, Sadesky, & Bisanz, 1996; McCloskey, Harley, & Sokol, 1991).

The results of the English group also supported the hypothesized interaction between response language and format (see Figure 6). The increase in response times from English words to French words was larger when the response language was English than when the response language was French (note the steeper slope of the English word line versus the French word line in Figure 6). Therefore, French words required longer response latencies than English words, and French response times were longer than English response times, however these effects are moderated when input and output languages match.

Further, a significant interaction between response language and problem size was found. The increase in response times from small problems to large problems was greater when the response language was French than when the response language was English (see Figure 7). Format and problem size also interacted significantly (see Figure 8). Differences in response times between small problems and large problems were greater for problems presented in English words than for problems presented in French word format.

None of these interactions can be explained by McCloskey's model, as the abstract-modular model posits that processing in each of the number comprehension system, calculation system, and number production system is independent of the processing in any other system (i.e., no interactions should occur). It is difficult to apply Dehaene's Triple-Code theory to these interactions as well, as all arithmetic processes are theorized to use

the auditory verbal code for processing; therefore, it is unclear what would be occurring in terms of the Triple-Code theory.

There were no two-way interactions found between response language and operation, format and operation, or operation and problem size. Of key interest here is the lack of support for the interaction between format and operation. Campbell (1994) found strong support for this interaction, however the French language response condition and the French word formats did not exist in his study. Therefore, further discussion about the comparison of these findings with those of Campbell (1994) for this interaction will be left until a later section, in which only those data equivalent to that of Campbell (1994) were analyzed. Finally, there were no three-way interactions found in the results of the English group, including the hypothesized interaction among response language, operation and format.

See Figure 9 for a complete graphical representation plotting format, operation, and problem size in each of the response languages. Also see Table 4 for the reaction times and standard deviations for each condition.

English Group – Errors

Percentage. Percentage of errors were analysed in a 2 (response language: English, French) x 3 (format: digits, English words, French words) x 2 (operation: addition, multiplication) x 2 (problem size: small, large) repeated measures ANOVA. Overall, the error rate for the English group was 10%. This is fairly high for simple arithmetic problems, however is comparable with the error rate of 7% found in Campbell (1994), and is probably largely due to the participants being told to answer the questions as quickly as

possible, as Campbell (1994) also suggested. A direct comparison between the present data and the findings of Campbell (1994) will be more closely examined in a later section. The results of the analysis of variance for the English group in this study are summarized in Table 3.

As predicted, there was a significantly higher error rate when responses were made in French (the second language) than when responses were made in English (13% vs. 10%). This finding is likely attributed to the finding that the English group were not highly proficient with French, and as a group, rarely used French (i.e., less than 10% of the time). An effect of format was also found with the English group. Digit problems (8%) were similar to English word problems (10%). However, English word problems had a lower error rate than French word problems (10% vs. 16%). These findings only partially support previous research that digits will have lower error rates than words (e.g., McCloskey et al., 1992). Although digits had lower error rates than French words, the error rates were similar between digits and English words. McCloskey et al. (1992) would propose that the increase in error rate for French word problems versus English word problems and digit problems could be attributed to the longer encoding times required. Similarly, according to Dehaene's model, the visual Arabic code is used more for numerical operation than the auditory verbal code, and further that English words are processed more frequently with the auditory verbal code than are French words. Also, as participants attempt to 'speed' to the answer as instructed, increased time encoding would lead to a higher probability of making an error. French words, for these English subjects, would require that much more encoding time, and this would account for the much higher

error rate seen with the French word format. Operation had an effect on the error rate too, with responses to addition problems resulting in fewer errors than responses to multiplication problems (10% vs. 13%). This is consistent with Campbell (1994); further, certain types of errors are more common with addition problems than with multiplication problems (to be discussed in a later section). Similarly, participants made fewer errors on small problems than on large problems (7% vs. 16%). All of these effects are consistent with the hypotheses.

Further, a two-way interaction between operation and problem size was found. The increase in error rate between small and large problems with addition (8% to 12%) was much less than the increase between small and large problems with multiplication (6% to 20%). Last, a significant three-way interaction was found among response language, format and problem size. Although the problem size effect for French words was similar across English and French response trials, the problem size effect for English words was much higher on French responses than on English responses. See Figure 10 for an illustration of these findings.

Types of Errors. All of the errors made by the English group were coded into one of seven categories of errors. See Table 6 for a breakdown of the numbers of each type and percentages of each type of error for the English group. Operation errors, when the wrong arithmetic operation is performed on a problem (e.g., $3 \times 3 = 6$), accounted for 6% of the 691 errors. Naming errors, when one or both operands in the question is named as part of the answer (e.g., $4 \times 4 = 44$), contributed to only 3% of the total. Operand-Intrusion Related errors, when one of the operands is named as part of an incorrect answer within the

same time-table (e.g., $8 \times 4 = 24$), were 17%, whereas Operand-Intrusion Unrelated errors (same, but not within the same-table, e.g., $8 \times 7 = 81$) accounted for 10% of the total errors. Other related errors, when the answer belongs to another time-table related problem, made up 25% of the errors, and non-specific errors (unclassifiable) were the highest cause of error at 35%. The final category was slightly different, and did not fit into any of the six main categories of error coding. There were 33 Language-interference errors (5% of the total); trials on which the participant answered the question in the wrong language. Of these 33 errors, 29 (88%) were made responding in English instead of French.

The first page of Table 7 provides a breakdown of each error type by response language, format, operation, and problem size for the English group. In order to look at the effects of language on the types of errors, both in terms of output (response language) and input (word format), 2 x 2 chi-square analyses were performed on each error type. The two factors in each chi-square test were response language and word format (note that 'word format' refers to English and French word formats only – with the digit format removed).

Operation errors. The proportion of operation errors within each response condition was virtually identical (6%). Further, proportions of operation errors were similar in each of the format conditions (between 5% and 8%). A 2 x 2 chi-square was conducted on the operation errors, with the digit format removed, and no interaction was found between response language and word format. When operation errors were compared across problem size, proportions were higher for small problems than for large problems

(14% vs. 3%). Similarly, operation errors accounted for a larger percentage of addition problems than multiplication problems (9% vs. 4%).

Naming errors. The numbers of naming errors were very small, accounting for less than 3% of the errors made by the English group. Due to these small numbers, caution should be taken interpreting the results of results here. For example, although the proportion of naming errors made while responding in English was double that of the French responses (4% vs. 2%), the numbers are too low to make valid conclusions. The chi-square analysis between response language and format was not significant for naming errors. Please refer to the first page of Table 7 for more statistics on naming errors.

Operand-Intrusion (Related) errors. Similar proportions of related operand-intrusion errors were found in each response language (~17%). Further, the proportion in each of the formats was virtually identical (~17%). A chi-square analysis revealed no interaction between response language and format for operand-intrusion errors. The proportion of this type of error was also consistent between small and large problems (~17%). However, although only 3% of the errors made during addition problems were related operand-intrusion errors, nearly 28% of multiplication errors fell into this category.

Operand-Intrusion (Unrelated) errors. There were similar proportions of unrelated operand-intrusion errors made when responding in English than in French (9% vs. 10%), however the proportion was higher when the presentation format was French words rather than English words or digits (12% vs. 8% vs. 7%). An interaction was found using a 2 x 2 chi-square between response language and word format, $X^2 = (1, N=56) = 3.72$. Fewer than a third of the errors were made when problems were presented in English words rather

than in French words, and only 4 unrelated operand-intrusion errors were made when responding in English to problems presented in English words. All conditions involving French (either as a word format, as a response language, or both) had 4-5 times more unrelated operand-intrusion errors than the English word, English response condition. Therefore, the second language appears to have greatly affected the number of operand-intrusion errors made by the English group, both as a word format (input) and as a response language (output).

Other related errors. Identical proportions of other related errors were made in each of the response languages (~24%). The proportions of other related errors were also similar in each format (~24%). A chi-square analysis of word format and response language was not significant. Other related errors accounted for more of the multiplication problems than for the addition problems (28% vs. 20%), and more of the small problems than the large problems (28% vs. 23%).

Non-specific errors. Non-specific errors accounted for a similar proportion of English response errors as French response errors (38% vs. 33%). Similarly, the proportion of non-specific errors was consistent across digit, English word and French word formats (~35%). A chi-square analysis did not find an interaction between word format and response language. A higher percentage of errors on large problems were non-specific than small problems (39% vs. 28%). The largest notable difference is that non-specific errors accounted for over half of the addition problem errors versus less than one quarter of the multiplication problem errors.

Language Interference errors. As with the naming errors, the numbers of this type of error were relatively small, accounting for less than 5% of the group's total errors. Therefore, caution is again advised when interpreting the results. However, there were some interesting differences found. Almost 8% of the errors made responding in French were language-interference errors (i.e., participants responded in English when they should have responded in French). Chi-square results, although non-significant, revealed that the largest number of these errors were made when the presentation was English words. It would appear that these errors are the result of a failure to translate the response at the output stage into the second language, probably due to time pressure.

Summary – Types of errors. Differences in types of errors were found in addition versus multiplication for almost all types of errors. Higher proportions in addition versus multiplication problems were found with operation, naming, and non-specific errors, while multiplication problems were linked more to related operand-intrusion, and other related errors. There were also differences found between small and large problem sizes in proportions of operation errors (higher with small problems), and non-specific errors (higher with large problems). However, with the exception of a significant interaction found with unrelated operand-intrusion errors, the proportions of each type of error were relatively similar across response language and format conditions. It was suggested in the introduction that error patterns would be similar between language conditions if participants were translating. With the English group, there do not appear to be any striking differences in error patterns between English and French word formats (input) or between English and French response languages (output). Thus, translation appears to be

occurring both at the input and output stages of processing. This will be discussed further in the General Discussion.

The French Group

Latencies

Median response latencies (from correct trials only) were calculated for each participant by response language, problem format, operation, and problem size. These median latencies were analyzed in a 2 (response language: English, French) x 3 (format: digits, English words, French words) x 2 (operation: addition, multiplication) x 2 (problem size: small, large) repeated measures ANOVA. The results of this ANOVA are summarized in Table 3.

The results of the French group provided support for some of the hypothesized main effects. Participants responded fastest to problems presented in digits, and slower to problems presented in English words and French words (means of 887 ms, 1206 ms, and 1307 ms, respectively). However, these findings only partially supported the hypothesis. Response times were faster for digits than both English words and French words, consistent with research finding digits faster than number words (e.g., Campbell, 1994; Noël et al., 1997). However, latencies between English and French word formats were similar, and French word problems were expected to result in lower latencies than English word problems. This finding is consistent with self-reports in which the French group reported using English a higher percentage of the time than French (57% vs. 43%).

Response times were significantly faster for addition problems than multiplication problems (1041 ms vs. 1226 ms), and response times were shorter for small problems than for large problems (1029 ms vs. 1238 ms). These effects concur with the hypotheses of the study. However, there was no main effect found for response language, as was hypothesized; participants' response times were not significantly different when responding in French than when responding in English. Again, this is likely attributable to the finding that the French group uses their second language, English, more frequently than they use French, and are likely just as familiar, if not more, with English than French.

The results of the French group did not support the hypothesis for a two-way interaction between response language and problem format. There were no two-way interactions found between response language and operation, format and operation, response language and problem size, or format and problem size. These findings would therefore not rule out McCloskey's Abstract Modular model nor Dehaene's Triple-Code Theory. In particular, the lack of support for the format by operation interaction found by Campbell (1994) suggests that language (both response and format) may be interfering with this interaction; this will be examined more closely in a later section comparing the present data to Campbell (1994) more directly. However, a significant interaction between operation and problem size was found; the increase in response times with small problems to large problems was significantly less with addition trials than with multiplication trials (note the steeper slope for multiplication in Figure 11). This interaction was not found with the English group as was expected, but it is consistent with previous research (e.g., Campbell, 1994).

Finally, there were no three-way interactions found for the French group, including no interaction between response language, operation and format. This finding was contrary to what was hypothesized, as was the case with the English group. See Figure 12 for a complete graphical representation plotting format, operation, and problem size in each of the response languages. Also see Table 4 for the reaction times and standard deviations for each condition.

French Group - Errors

Percentage. Percentage of errors were analysed in a 2 (response language: English, French) x 3 (format: digits, English words, French words) x 2 (operation: addition, multiplication) x 2 (problem size: small, large) repeated measures ANOVA. The results of this analysis of variance are summarized in Table 3. Overall, the error rate for the French group was 7%. Due to the high level of mathematical proficiency found with the French group, many of the errors are likely due to the speed of responding. The results of the analysis of variance are summarized in Table 3.

The error rates for English and French response languages were virtually identical (~8%). Hence, there was no effect of response language found. This finding may be due to the fact that although French is a first language for this group, English is actually used more, on average, by this group than is French (see Table 1). There was an effect of format found such that digit problems had a lower error rate (6%) than did English word problems (9%) and French word problems (10%). Consistent with the hypothesis and with previous research, fewer errors were found on digit problems compared with word problems (Campbell, 1994; Noël et al., 1997). However, the hypothesis that a difference would also

exist between the error rates of English word problems and French word problems was not supported. Operation also had an effect on the error rate, with responses to addition problems resulting in fewer errors than responses to multiplication problems (7% vs. 10%). Similarly, a significant effect of problem size was found with the French group. Participants made fewer errors on small problems than on large problems (6% vs. 11%).

However, there were no two-way or three-way interactions found with the error rates of the French group.

Types of Errors. As with the English group, all of the errors made by the French group were coded into one of seven categories. See Table 6 for a breakdown of the numbers of each type and percentages of each type of error for the French group. Operation errors accounted for 7% of the 492 errors, naming errors contributed to only 3%, operand-intrusion related errors were the cause of 17% of the errors, operand-intrusion unrelated errors for 7%, other related errors made up 25% of the errors, and non-specific errors were the highest cause of error at 30%. An interesting finding is that the remaining 10% of the errors were language-interference errors – questions answered in the wrong language. Of these language-interference errors, 84% occurred when the response language *should have been* English (i.e., they answered in French when they should have answered in English), and 16% occurred when the response language was French.

The second page of Table 7 provides a breakdown of each error type by response language, format, operation, and problem size for the French group. In order to look at the effects of language on the types of errors, both in terms of output (response language) and input (word format), 2 x 2 chi-square analyses were performed on each error type. The two

factors in each chi-square test were response language and word format (with the digit format removed).

Operation errors. The proportion of French response errors that were operation errors was more than it was for English response errors (10% vs. 5%). However, the French group only made a total of 37 operation errors (7% of the total errors made by the French group). Therefore, it is not advised to use these results as a basis for conclusions. There were, however, similar numbers of operation errors made within each of the three formats: digits, English words and French words (11, 14, and 12 respectively). A 2 x 2 chi-square was performed on response language versus word format, and no interaction was found. There was also no apparent pattern worth noting from the chi-square table. When proportions of operation errors were compared across problem size, it was found that a higher percentage were made with small problem trials than with large problem trials (19% vs. 2%). Similarly, a higher percentage of errors made on addition problems were accounted for by operation errors than on multiplication problems (12% vs. 4%).

Naming errors. As with the English group, the number of naming errors made by the French group was very small, accounting for only 3% of the total number of errors. Therefore, caution must be taken when attempting to draw any conclusions from this data. Numbers of naming errors were similar between English and French response languages, addition and multiplication problems, and between small and large problems. The only notable difference was that there was only one naming error made on digit problems compared with eight made on English word problems and six made on French word problems. A chi-square between response language and word format was non-significant.

Operand-Intrusion (Related) errors. The proportion of English response errors that were related operand-intrusion errors was less than the proportion of French response errors (15% vs. 19%). Further, the proportion of errors that were related operand-intrusion errors within the English word format was less than in the French word format (16% vs. 19%). A 2 x 2 chi-square was performed on response language versus word format, and a significant interaction was found, $X^2 = (1, N=67) = 4.04$. A closer look at the chi-square table revealed that the two most prevalent conditions for related operand-intrusion errors were English word, English response, and French word, French response. Also, the pattern that the language of the word format is most disruptive when the response language is the same indicates that the French group is probably not translating, in agreement with what they had indicated (see Figure 5). Other findings worth noting were that a higher proportion of multiplication errors versus addition errors were related operand-intrusion (23% vs. 7%), and similar proportions were found between small problems and large problems (15% vs. 17%).

Operand-Intrusion (Unrelated) errors. Although the chi-square analysis was significant in finding an interaction between response language and word format for the *related* operand-intrusion errors, the same analysis was not significant for the *unrelated* operand-intrusion errors. Numbers made in English and French response languages were similar (16 vs. 22) as were numbers of unrelated operand-intrusion errors made in English word problems and French word problems (14 vs. 19). Also, the proportion of addition problem errors compared to the proportion of multiplication problems of this type was

similar (10% vs. 7%), as was the proportion between small and large problem size (9% vs. 6%).

Other related errors. Related errors made up an equal percentage of English response compared with French response errors (~25%), and a relatively equal percentage of the errors within each of the formats (30%, digits; 26%, English words; 22%, French words). No interaction was found between response language and word format, based on a chi-square analysis. The proportion of errors that were 'other related' was also similar between small and large problems (23% vs. 26%). However, this type of problem accounted for a third of multiplication problem errors versus only 13% of addition problem errors.

Non-specific errors. Non-specific errors accounted for the highest proportion of errors with the French group (30%). Half of these errors were made in English response trials and half were made in French response trials. Similarly, there were relatively equal numbers of this type of error made in digits, English word, and French word formats. However, almost half of the addition problem errors were non-specific versus less than one quarter of multiplication problem errors being non-specific. There were also more non-specific errors made with large problems than with small problems (118 vs. 28).

Language Interference errors. This type of error accounted for 10% of the errors made by the French group, and produced some interesting findings. The majority of language interference errors were made when the response language was English (i.e., participants responded in French when they should have responded in English). Further, 37 of the 50 language interference errors made by the French group occurred when

problems were presented in French words rather than English words (10 errors) or digits (only 3 errors). A 2 x 2 chi-square between response language and word format found a significant interaction occurring, $X^2 = (1, N=47) = 15.81$. Language interfered most when problems were presented in French word format and the participants were asked to respond in English. This condition accounted for three quarters of language interference errors with the French group. This may be due to the fact that numbers and simple arithmetic were learned in the French language with this group, and that responding to a French word problem in their second language was probably the least familiar of the conditions for them. Using the two languages equally for these individuals, answering problems in the same language in which they were presented did not cause interference in this type of error. Further, answering an English word problem in French was probably a more familiar experience for them living in a dominantly English city, and thus should cause less interference than answering a French word problem in English.

Summary – Types of errors. Operation errors, related-operand intrusion errors, other related errors, and non-specific errors were found in different proportions between addition and multiplication problems. There were larger proportions of operation errors found with small problems than with large problems, and the reverse for non-specific errors. Of interest to this study, however, are any differences in patterns that were found with language as a factor. Language affected the pattern of related operand-intrusion errors; more errors were found in the English word, English response and the French word, French response conditions than in opposite word format and language response conditions. Because the language of presentation has a larger effect on the number of

related intrusion errors when the response language is the same, it would appear that the French group is not translating. This would concur with the suggestion that these individuals are less likely to translate due to their relatively equal proficiencies in the English and French languages, coupled with their relatively equal amount of use of the two languages.

Campbell (1994) Comparison – data subset

English Group, English Response, 2 Formats only

In order to compare the present findings with the findings of Campbell (1994), one of the proposed goals of this research, it was deemed necessary to examine those data of the present experiment that were most similar to those collected by Campbell (1994). For comparison purposes, the English group (n=16) responding only in English to digit problems and English word problems were analysed in a 2 (Format: digits, English words) x 2 (Operation: addition, multiplication) x 2 (Problem Size: small, large) repeated measures ANOVA was conducted on median response times. See Table 5 for the results of this analysis of variance. See Figure 13 for an illustration of these results. Findings support the effects of format, operation, and problem size, consistent with the data of Campbell (1994). For comparative purposes, also see Figure 13 for an illustration of the actual results of Campbell (1994).

Latencies

Consistent with Campbell (1994), response times were faster when problems were presented as digits (1028 ms) than as English words (1264 ms). Response times were

significantly slower for multiplication problems (1198 ms) than for addition problems (1093 ms). This finding also concurs with the results of Campbell (1994). Participants were significantly slower to respond to large problems (1292 ms) than to small problems (999 ms), as Campbell (1994) had found.

In contrast to Campbell (1994), no interaction was found between format and operation. Further, the two-way interactions between format and problem size, and between operation and problem size, were not significant, nor was the hypothesized three-way interaction between format, operation and problem size. Upon comparison of the present data with the results of Campbell (1994) in Figure 13, it is evident that although small problems appear to be answered with similar response times to those found by Campbell (1994), larger problems are responded to more slowly in the comparison data. In particular, the large addition problems for digits in the present experiment have higher reaction times than the same problems in the Campbell (1994) study. One suggestion to make here would be that one of the reasons for not finding the interactions that were found by Campbell (1994) is that the participants involved in this experiment that have contributed to the comparison data are of lower skill level than those involved in the Campbell (1994) study. Further research is suggested here to examine this suggestion.

Errors

Percentage. Percentage of errors were analysed in a 2 (format: digits, English words) x 2 (operation: addition, multiplication) x 2 (problem size: small, large) repeated measures ANOVA. The results of this analysis of variance are summarized in Table 5.

The overall error rate for this data set was approximately 3%, which was surprisingly low due to the fact that the error rate for the English group as a whole was 10%. This comparative subset also has a much lower error rate than found in the Campbell (1994) study (7%). Therefore, removing the French language response condition and the French word problem format from the English group data set in order to fairly compare with the findings of Campbell (1994) removed a large percentage of the overall error rate. This finding may be due to many factors, including the infrequent use of French for these subjects. Whatever the case may be, it is obvious that the addition of the French word format and response languages to the design of Campbell (1994) dramatically affected the performance of the English group in this study.

Types of Errors. See Table 6 for a breakdown of the numbers of each type and percentages of each type of error for the comparison data subset. Operation errors accounted for 7% of the 159 errors, naming errors for 1%, operand-intrusion related errors for 18%, operand-intrusion unrelated errors for 5%, other related errors for 28%, and non-specific errors for 40%.

Table 6 also includes the percentages of each type of error from the study by Campbell (1994). To compare these with Campbell (1994), it is important to point out that Campbell (1994) did not separate related and unrelated operand-intrusion errors as was done in the present study. Further, he grouped other related errors and non-specific errors into the category *other* errors. Last, because Campbell (1994) only used English words and English responses, there would not have been any language interference errors. The

present data was also examined in the same groupings that Campbell (1994) used for comparative purposes.

Campbell (1994) also found that each error type had a different operation (addition, multiplication) X format (digits, English words) interaction. To test for this, a 2 x 2 chi-square between operation and format was performed on each error type.

Operation errors. In comparison with Campbell (1994), operation errors accounted for a smaller proportion of the errors (7% vs. 11%). Further, no interaction was found between operation (addition, multiplication) and format (digit, English word), as Campbell (1994) had found. However, it is also important to note here that the present finding is based on only 11 operation errors made by only 16 participants, whereas the findings of Campbell (1994) were based on 291 operation errors made by 64 participants. Therefore, caution should be taken when interpreting these results.

Naming errors. Naming errors were much less prevalent in this study than in the Campbell (1994) study (1% vs. 7%). However, with only two naming errors (both made with English word problems) contributing to the errors in this subset of data, there was insufficient data to test for an interaction between operation and format.

Operand-Intrusion (Related and Unrelated) errors. When these two types of errors were combined in the present study, the proportion they contributed to the total number of errors in this data subset was similar to that found in the Campbell (1994) study (23% vs. 27%). However, contrary to the findings of Campbell (1994), no interaction was found between operation and format when these two types of errors were combined. Further, no interaction was found between operation and format when related operand-intrusion errors

were tested separately, and no interaction was found when unrelated operand-intrusion errors were tested on their own. Once again, however, caution should be taken in interpreting these results, due to the much lower numbers of errors involved in the analyses, and the lower numbers of participants in this data subset compared with the Campbell (1994) study (16 vs. 64).

Other errors. Other errors (including other related errors and non-specific errors, but excluding language interference errors) accounted for a higher percentage of the errors in the present experiment than in the Campbell (1994) study (69% vs. 55%). No operation X format interaction was found with 'other errors' in the present experiment, nor was there an operation X format interaction found with *other related errors* or *non-specific errors* when analyzed separately.

Summary – Types of errors. Although there were no operation X format interactions found with any of the types of errors with this data subset, as Campbell (1994) had found, it is important to stress the need for caution when making conclusions with these results. Sixty-four participants were involved in the study conducted by Campbell (1994), compared with only 16 participants included in this data subset. Further, participants in the Campbell (1994) study received 576 trials versus participants in the present study receiving approximately 288 trials (with the French word trials removed). With more trials for each participant, the opportunity for error was higher, and this also contributed to the higher numbers of each type of error found by Campbell (1994).

General Discussion

In the current study, the relation between English-French bilingualism and simple arithmetic was examined by comparing the response latencies, error rates, and types of errors made by two groups of subjects. Due to differences found between the English group and the French group, data from the two groups were analyzed independently. Also, a comparative subset of the data from the English group was compared against the findings of Campbell (1994). The English group demonstrated the hypothesized effects of response language, format, operation and problem size, both in reaction times and error rates. Several interactions were also found with the English group. In general, problems involving the second language (either French word format or French response language) were associated with longer response times and larger numbers of errors for the English group. The French group also demonstrated the hypothesized effects of format, operation, and problem size, however they did not show an effect of response language. One interaction between operation and problem size was found with the French group. Overall, the French group performed similarly on problems involving their second language as on problems involving French, and neither reaction times or error rates were differentially affected by English versus French word input or by English versus French response languages. Although some of the results from each group were predicted by one of the three models previously discussed, many of results from the present experiment can not be explained by McCloskey's abstract-modular model, Dehaene's triple-code theory, or Campbell and Clark's encoding-complex view of number processing. None of the three

models include the effects of knowledge of different languages on number processing and mathematics.

In an attempt to explain some of the findings of each of the two groups of participants, a model was constructed. The model is used to examine whether language has an effect only on the input and output of mathematical problems, or whether language also affects the “in-between” processing stage. In other words, the model examines whether internal processing is seen as language-independent or language-specific. The present study replicated previous findings that word problems produce longer latencies and more errors than digit problems (e.g., Campbell, 1994; Noel, Fias, & Brysbaert, 1997). Therefore, this model is focused on English and French input (word formats), English and French output (response languages), and the intervening processes. Because the English and French groups appear to be distinct subsamples from the bilingual population, the model was adapted for each group (see Figure 14).

The English group, although bilingual, was found to be dominant in the English language. A very high proportion of the participants in this group reported that they translated French word problems into their first language before solving them. The data are consistent with the self-reports in that translation appears to occur at the input stage. The findings related to error type analyses support this view. As hypothesized, patterns of errors were not found to be different between English word and French word formats. Presumably, if translation was not occurring, patterns of errors would be different for the two formats due to linguistic differences. Second, the longer latencies and increased error rates found with the French word format over the English word format are consistent with

the hypothesis that response rates and errors would be higher with second language problems. The English group therefore supports the findings of Frenck-Mestre and Vaid (1993); that individuals process simple arithmetic in the language in which it was learned. In Figure 14 (top panel), the model for the English group shows input translation occurring with the French word format before being entering the process stage; this extra task in the pathway corresponds to the increased latencies and error rates. Therefore, input in both English word format and French word format are encoded into the process stage from the English word format.

The model also shows that not only was translation occurring at the input level with the English group, but at the output level as well. An effect of response language was found with the English group. The data also suggests that all output coming from the process stage is in English, and is then translated into French when the response requires it to be; error rates and response latencies were higher for problems responded to in French than in English. The model illustrates this by showing the extra task that translation causes from the process stage to the French output compared with the path of English output (see Figure 14). Thus far, it has been determined that English-French bilingualism affects the input and the output of number processing for the English group. But does it affect the processing that occurs in between? The interactions found with the English group should also be examined.

A response language by problem size interaction revealed that the problem size effect was larger for French responses than for English responses. As the English group uses the French language infrequently and French words for smaller numbers are likely

more ingrained in memory, the higher number responses to large problems are probably that much more difficult. Therefore, this interaction is likely due to increased problems with translation at the output stage. This point is supported by the finding that response times to digit problems were much slower when the response language was French than when the response language was English.

A response language by format interaction was also found with the English group. With this interaction, the two main effects of word format (French words require longer response times than English words) and response language (French responses are slower than English responses) are moderated when input and output languages match. Further research would need to be done to investigate this interaction in more detail, however this interaction could still be explained by occurrences within the input and output stages only, and not in the processing stage. One suggestion would be that although the English group does not regularly use French, receiving a problem in French word format surfaces knowledge of the French language into short-term memory, and thus prepares members of the English group to better to make a response in French. The French response pathway in the model, therefore, may be shortened when the word format is also French. Seeing a problem in English, however, the language that they use more naturally and frequently, would not prepare them for a French response.

A third interaction to investigate using this model is the format by problem size interaction that was found with the English group. This interaction demonstrating a larger problem size effect for English words than French words could be interpreted in two ways. Either small problems are much easier when presented in English than in French, or large

problems are similarly difficult in English words to French words. Due to the lower frequency of use with French in general, the former is probably more likely. Small English word problems are likely relatively automatic for the English group, whereas all French word problems (small or large) require encoding time in order to process. Consistent with the model's view that language is independent of number processing with the English group, this interaction could be explained as a poorer encoding system for French word number processing compared with a better output system for French responses. This theory can also be extended to explain the three-way interaction found between response language, format and problem size. The increase in problem size from English to French responses found with French words was less than that found with English words. The poorer encoding system for French words was not so dependent on response language as the more automatic and frequently-used encoding system for English words. This model can therefore continue to support the view that internal processing is language-independent, and that translation steps at both the input and output levels are contributing to the findings with the English group.

A last finding to explain with this model for the English group was the interaction found with unrelated operand-intrusion errors. It was hypothesized that should any differences between languages be found with types of errors, this occurrence of translation should be questioned. However, the interaction that was found between word format and response language with unrelated operand-intrusion errors occurred because of a very low number of this type of error in the English word, English response condition. This finding could therefore be due simply to the more natural, familiar, and automatic nature of this

condition (the shortest pathway in the English model) versus the other three, all of which involve the relatively infrequently used French language. The English word, English response condition would allow for the fewest places in the model for errors to occur, unlike all other conditions which involve at least one task of translation.

The model for the French group is constructed differently (see Figure 14, bottom panel). The French group was found to be a more balanced group of bilinguals. The majority of this group reported that they did not translate English word problems into French before solving them. Further, this group actually use their second language more frequently than their first language. No effect of word format was found; response times and error rates were similar with English word problems and French word problems. The French group therefore does not support the findings of Frenck-Mestre and Vaid (1993); problems presented in the second language were not responded to more slowly. This is shown in the model by the equal lengths of the arrows at the input level in the model. Therefore, the model for the French group suggests that English word input and French word input are encoded for number processing separately, or that either type of input can be used to activate the relevant internal representations.

Similarly, no effect of response language was found with the French group, indicating that no translation was occurring at the output stage. Further, no interactions were found involving either word format or response language, on either reaction time analyses or error rate analyses. Thus far, this model also supports that view that number-processing is language-independent. It would appear that the two languages are used to

encode the problem separately into the processing system, and are then again used with relatively equal skill to verbalize the coded result.

However, analyses of the different types of errors revealed a significant interaction between word format and response language for related operand-intrusion errors. This type of error was most prevalent when input and output languages (word format and response languages) were the same. The fact that these errors are *related* operand-intrusion errors raises a question. Should it not be expected that no pattern would exist between input and output with related errors if number-processing is indeed independent of language? The fact that the operand intrudes most frequently when the output language is identical to the input language suggests that the language of the problem is somehow carried through the number-processing system (Campbell, 1994, 1997). In other words, if the language of the problem was encoded to a calculation code at the input stage, whether to digits or an abstract code, and then encoded into the appropriate response category after coming out of the process stage (as the model depicts), there should not be an interaction between word format and response language found with related errors. This finding is particularly interesting, and it's challenge to the view language-independent view of number processing would be well suited as the topic of future research in this area.

One last point of interest with the French group were the language interference errors. Most of these errors occurred when participants were presented with a French word problem and asked to respond in English. This finding supports the hypothesis for the internal representation of language termed *interlanguage* by Selinker (1972), cited in O'Malley & Chamot (1990). Interlanguage is believed to be an intermediary form of a

second language that often contains parts of both the native and the target language. The model would explain this as a failure to encode the output properly after processing occurs. However, this finding also challenges the view that number processing is language-independent, as it is another example of the input word format carrying through the process stage to the output.

Can mathematical problems be solved in word format? Further, can mathematics be *performed* and processed in different languages, rather than in only one abstract code? It is interesting to find that the possible answers to these questions can really only be examined with a balanced group of bilingual participants. If only the English group had been tested in the present experiment, these questions may never have arisen. Although the English group supports the theory that individuals process simple arithmetic in the language they learned it (Frenck-Mestre & Vaid, 1993), the French group does not support this theory. These questions would be worthwhile topics for future research.

It is important to point out several limitations to the present study. The unfortunate finding that the English group was significantly different from the French group in many aspects resulted in having to analyse the groups separately, thus reducing the N by one half. The data from sixteen participants can not really validly be compared to the data from the sixty-four participants involved in the Campbell (1994) study. A suggestion for future studies of this nature would be to match the groups of participants that are allowed to be a part of the study on levels of mathematical proficiency, and second language proficiency. It is important to point out that mathematical proficiency could bias results of similar experiments also. The significantly lower level of mathematical proficiency of the

English group in the present experiment may have been a major contributor to the significance of some of the findings. For example, if the English group had been more proficient in mathematics, the effects of operation and problem size may not have been as strong, or perhaps the individuals would have been able to attend more to their second language skills if they didn't need to focus on their mathematical skills as much. It would be useful to conduct another experiment with bilinguals similar to the English group (i.e., lower frequencies of second language use), but with higher mathematical proficiencies to reduce the effects of mathematical proficiency and focus more on issues such as translation. Further, in order to examine the questions raised by the French group in the present study, all participants should be from a balanced group of bilinguals who use both languages frequently and a relatively equal amount of the time. Taking these controls would allow for between-group analyses and would likely open up a whole new level of findings that would reveal more about the relation between English-French bilingualism and simple arithmetic.

However, as this topic is a relatively new one to the field, and there are many implications of finding a relation between language and mathematics, the present study was successful in raising some issues for future research. In particular, this study examined whether internal processing of arithmetic is language-specific or language-independent. This problem remains unsolved, as arguments were made in the present study for each side.

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Table 1

Comparison between the English Group and the French Group on various measures

	English Group		French Group	
	Mean	SD	Mean	SD
Mean Age (in years)	21.7	(2.3)	21.9	(2.0)
“French Kit” Score (Mathematical Proficiency) *	64.4	(27.6)	84.7	(22.5)
PPVT-III Score (2 nd Language Proficiency)	97.5	(20.6)	106.2	(11.7)
% first language use **	90.1	(7.1)	43.3	(14.8)
% second language use **	9.9	(7.1)	56.7	(14.8)
% indicating use of translation (post-test) **	87.5	-	37.5	-
% indicating no use of translation (post-test) **	12.5	-	56.3	-
	Pearson's r		Pearson's r	
Correlation: Mathematical Proficiency and RT	- .63**		- .51*	
Correlation: Math. Proficiency and Error Rate	- .46		- .27	
Correlation: 2 nd Language Proficiency and RT	- .64**		- .21	
Correlation: 2 nd Lang. Proficiency and Error Rate	- .71**		- .57*	

Significance Difference found between groups:

* $p < .05$ ** $p < .01$

Table 2 - Summary of Questionnaire Data – Means or Frequencies (Selected Questions)

Question	English Group		French Group	
	Mean	SD	Mean	SD
Procedure Use Section				
2. Overall, please estimate what proportion of the time you solve simple multiplication problems in ways <i>other than</i> by automatically remembering the answers?	2.6	0.8	2.1	0.9
3. Overall, please estimate what proportion of the time you solve simple addition problems in ways <i>other than</i> by automatically remembering the answers?	2.6	1.0	1.9	1.0
4. Overall, please estimate what proportion of the time you solve subtraction problems in ways <i>other than</i> by automatically remembering the answers?	3.1	0.9	2.2	0.9
5. Overall, please estimate what proportion of the time you solve division problems in ways other than by automatically remembering the answers?	2.7	0.9	2.3	0.9
Mathematics Section				
2. How would you rate your level of basic mathematical skill (e.g., skill at calculation)?	4.7	1.3	6.0	1.0
3. How would you rate your level of mathematical skill in more complex areas of mathematics (e.g., calculus, algebra)?	3.9	1.6	4.8	1.6
4. How would you rate your level of mathematical skill when you are required to use your second language rather than your first language?	3.5	1.5	5.1	1.3
5. Do you ever actively AVOID situations involving mathematics?	5.3	1.9	6.4	1.5
6. How often do you find that situations involving mathematics make you nervous?	5.1	1.9	6.2	1.6

(Table 2 Continued...)

Question	English Group		French Group			
Mathematics Section (Continued)	Mean	SD	Mean	SD		
7. How important do you feel that mathematics will be in the development of your career?	4.9	2.0	4.5	2.1		
8. How difficult was mathematics for you in high school?	5.1	1.2	4.4	2.1		
9. How difficult do you find doing mathematics in your second language?	4.3	1.4	5.3	1.8		
10. How much emphasis was placed on learning basic arithmetic (e.g., 3 + 4, 5 X 9) by your teachers in elementary school?	5.4	1.8	6.0	1.0		
11. How much emphasis was placed on rote learning (or memorizing) basic arithmetic facts by your teachers in elementary school?	5.6	2.0	5.6	1.3		
Language (Spoken) Section (Note: ③ = English, ① = French, ② = Other)	Frequency (%)		Frequency (%)			
	③	①	②	③	①	②
1. What languages do you speak?	100.0	100.0	25.0	100.0	100.0	31.3
2. Which do you consider your first language (i.e., most proficient speaking)?	93.8	-	6.2	25.0	75.0	-
3. Which language is your "mother-tongue" (lang. spoken when you learned to speak as a child)?	81.3	-	18.7	-	87.5	12.5
4. If you had to choose only one, in which language do you remember learning addition?	100.0	-	-	-	100.0	-
5. If you had to choose only one, in which language do you remember learning multiplication?	100.0	-	-	-	100.0	-
6. Which language do you typically use when talking about anything concerning numerical information?	100.0	-	-	81.3	18.7	-

(Table 2 Continued...)

Question	English Group		French Group	
	Mean	SD	Mean	SD
Language (Reading and Writing) – Continued				
1. How would you rate your level of basic reading skill (e.g., reading an instructional manual for information)?	6.2	0.7	5.7	1.5
2. How would you rate your skill in reading complex materials (e.g., reading a novel for an upper-year English course)?	5.7	1.1	4.9	1.4
3. How would you rate your spelling skills?	5.1	1.3	5.2	1.3
4. How would you rate your basic written communication skills (e.g., summarizing a set of notes for a friend or writing a letter)?	5.7	1.0	5.3	1.2
5. Overall, how would you rate your written language skill (e.g., writing a paper for a university course)?	5.4	1.0	5.2	1.4
6. Do you ever actively AVOID situations involving reading?	6.0	1.5	5.6	1.7
7. Do you ever actively AVOID situations requiring writing?	5.9	1.4	5.7	1.5
8. How often do you find that situations requiring that you "read for meaning" make you nervous?	5.6	1.3	5.3	1.9
9. How often do you find that situations involving writing make you nervous?	5.7	1.1	5.4	2.0
10. How important do you feel that language skills (reading and writing) will be in the development of your career?	6.9	0.3	6.3	1.1
11. How difficult was English for you in high school?	5.7	1.8	4.9	1.9

Table 3

Analyses of Variance for Latencies and Percent Errors – English and French Groups

<u>Source</u>	df	<u>F</u>		<u>F</u>	
		English Group		French Group	
		Latencies	% Errors	Latencies	% Errors
Response Language	1	10.95**	8.71**	.60	.27
MSE	15	875887.37	74.61	201899.29	51.39
Format	2	29.51**	5.33**	37.99**	7.52**
MSE	30	213716.89	424.16	162337.40	70.26
Operation	1	7.96*	6.33*	4.14*	7.94*
MSE	15	408785.35	163.58	787813.29	98.40
Problem Size	1	21.58**	19.33**	11.50**	33.75**
MSE	15	499909.77	419.16	361463.31	86.33
RespLang. X Format	2	3.36*	.44	3.17	2.82
MSE	30	30572.80	72.00	26194.98	39.27
RespLang X Operation	1	1.28	.96	.22	3.06
MSE	15	119911.07	79.18	194998.75	40.72
Format X Operation	2	.15	1.69	.60	1.75
MSE	30	116640.63	47.89	33679.56	26.41
RespLang X Format X Operation	2	2.62	.65	.35	1.25
MSE	30	43729.77	64.55	8232.62	21.13
RespLang X Probsize	1	8.32*	.20	1.70	.15
MSE	15	73435.73	57.04	53183.26	39.51

(Table 3 Continued...)

<u>Source</u>	<u>df</u>	<u>F</u>		<u>F</u>	
		English Group		French Group	
		Latencies	% Errors	Latencies	% Errors
Format X Probsize	2	4.87*	.67	1.06	.31
MSE	30	48365.45	51.37	59254.56	46.18
RespLang X Format X Probsize	2	.53	5.09*	.72	.12
MSE	30	33773.15	36.10	21087.28	48.54
Operation X Probsize	1	3.60	19.35**	4.42*	1.51
MSE	15	217277.81	107.93	99149.69	109.18
RespLang X Operation X Probsize	1	1.96	.58	1.03	.09
MSE	15	106586.20	32.75	83639.99	31.29
Format X Operation X Probsize	2	3.00	.15	.20	1.39
MSE	30	49318.44	41.20	27644.78	45.75
RespLang X Format X Oper. X Probsize	2	.28	.76	1.09	2.03
MSE	30	28223.51	51.39	10268.60	34.48

** $p < .01$ * $p < .05$

Table 4

Reaction Time Means and Standard Deviations for Each Condition

Condition	English Group (n = 16)		French Group (n = 16)	
	Mean RT	SD	Mean RT	SD
Response Language = English				
Small Problems				
Digits, Addition	834.6	198.5	705.9	207.5
Digits, Multiplication	923.4	326.2	827.2	321.3
English Words, Addition	1071.3	264.7	985.6	272.2
English Words, Multiplication	1168.2	383.0	1162.1	463.2
French Words, Addition	1323.3	391.7	1201.3	421.2
French Words, Multiplication	1438.9	494.0	1279.7	578.3
Large Problems				
Digits, Addition	1147.7	435.3	822.2	336.7
Digits, Multiplication	1204.8	524.2	1057.5	459.0
English Words, Addition	1318.9	460.6	1186.7	440.0
English Words, Multiplication	1496.7	667.4	1365.7	560.5
French Words, Addition	1398.1	456.0	1303.2	573.6
French Words, Multiplication	1726.2	658.5	1491.4	826.1
Response Language = French				
Small Problems				
Digits, Addition	1008.7	423.0	760.2	264.3
Digits, Multiplication	1165.4	538.1	869.9	453.6
English Words, Addition	1316.0	564.0	1014.7	322.0
English Words, Multiplication	1480.8	692.3	1146.9	506.0
French Words, Addition	1633.3	866.2	1158.6	399.8
French Words, Multiplication	1573.1	608.5	1241.3	655.3
Large Problems				
Digits, Addition	1383.4	750.1	880.9	326.6
Digits, Multiplication	1711.3	1199.8	1170.9	764.1
English Words, Addition	1709.6	747.4	1224.9	454.8
English Words, Multiplication	2073.3	1259.7	1564.6	1238.6
French Words, Addition	1699.1	656.2	1251.6	506.1
French Words, Multiplication	2090.9	1224.9	1531.3	1161.0

Table 5

Analyses of Variance for Latencies and Percent Errors – Campbell Comparison

<u>Source</u>	<u>df</u>	<u>F</u>	
		Latencies	% Errors
Format	1	28.41**	4.14*
MSE	15	62808.42	69.42
Operation	1	5.34*	17.31**
MSE	15	66238.17	40.38
Problem Size	1	23.74**	35.61**
MSE	15	115452.06	98.87
Format X Operation	1	1.76	1.53
MSE	15	18782.23	32.47
Format X Problem Size	1	.03	.19
MSE	15	23331.62	26.61
Operation X Problem Size	1	.33	8.73**
MSE	15	14822.07	50.06
Format X Operation X Problem Size	1	2.02	.61
MSE	15	12562.20	27.30

Table 6

Types of Errors for English Group, French Group, and Comparison subset of data

	English Group		French Group		Comparison subset		Campbell (1994) data %
	n	%	n	%	n	%	
Types of Errors							
Operation	41	5.9	37	7.5	11	7.0	10.7
Naming	18	2.6	15	3.0	2	1.3	7.3
Operand-Intrusion (Related)	118	17.1	82	16.7	28	17.8	26.5 ¹
Operand-Intrusion (Unrelated)	67	9.7	38	7.7	8	5.1	55.5 ²
Other related errors	169	24.5	124	25.2	45	28.7	
Non-specific Errors	245	35.5	146	29.7	63	40.1	
Language-Interference Errors	33	4.8	50	10.2	-		-
TOTAL ERRORS	691		492		157		

¹ Campbell (1994) included related and unrelated operand-intrusion errors under the same category: *Operand-Intrusion*² Campbell (1994) included other related errors and non-specific errors under the same category: *Other*

Table 7

English Group Error Types Summary -- By Response Language, Format, Operation, Problem Size, and Total

Variable	Operation		Naming		Related Op. Intrusion		Unrel. Op. Intrusion		Other Related		Non-specific		Language Interfere		Total
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	
Response Language	18	5.7	12	3.8	56	17.6	28	8.8	78	24.5	122	38.4	4	1.3	318
	23	6.2	6	1.6	62	16.6	39	10.5	91	24.4	123	33.0	29	7.8	373
Format	13	8.3	0	-	26	16.6	11	7.0	37	23.6	59	37.6	11	7.0	157
	13	6.2	5	2.4	35	16.6	17	8.1	53	25.1	75	35.5	13	6.2	211
French Words	15	4.6	13	4.0	57	17.6	39	12.1	79	24.5	111	34.4	9	2.8	323
Operation	27	9.1	14	4.7	9	3.0	27	9.1	60	20.1	153	51.3	8	2.7	298
	14	3.6	4	1.0	109	27.7	40	10.2	109	27.7	92	23.4	25	6.4	393
Problem Size	28	14.3	5	2.6	34	17.3	16	8.2	54	27.6	54	27.6	5	2.6	196
	13	2.6	13	2.6	84	17.0	51	10.3	115	23.2	191	38.6	28	5.7	495
TOTAL FOR GROUP	41	5.9	18	2.6	118	17.1	67	9.7	169	24.5	245	35.5	33	4.8	691

Table 7 (Continued...)

French Group Error Types Summary – By Response Language, Format, Operation, Problem Size, and Total

Variable	Operation		Naming		Related Op. Intrusion		Unrel. Op. Intrusion		Other Related		Non-specific		Language Interfere		Total
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	
Response Language															
	13	5.1	7	2.7	37	14.5	16	6.3	65	25.5	75	29.4	42	16.5	255
English	24	10.1	8	3.4	45	19.0	22	9.3	59	24.9	71	30.0	8	3.4	237
Format															
Digits	11	9.6	1	0.9	15	13.0	5	4.3	34	29.6	46	40.0	3	2.6	115
English Words	14	8.1	8	4.7	28	16.3	14	8.1	44	25.6	54	31.4	10	5.8	172
French Words	12	5.9	6	2.9	39	19.0	19	9.3	46	22.4	46	22.4	37	18.0	205
Operation															
Addition	24	12.1	9	4.5	14	7.1	19	9.6	26	13.1	91	46.0	15	7.6	198
Multiplication	13	4.4	6	2.0	68	23.1	19	6.5	98	33.3	55	18.7	35	11.9	294
Problem Size															
Small	31	19.0	7	4.3	25	15.3	9	5.5	38	23.3	28	17.2	25	15.3	163
Large	6	1.8	8	2.4	57	17.3	29	8.8	86	26.1	118	35.9	25	7.6	329
TOTAL FOR GROUP	37	7.5	15	3.0	82	16.7	38	7.7	124	25.2	146	29.7	50	10.2	492

Figure 1

McCloskey's Abstract-Modular Model

- Processing that occurs within each system is **INDEPENDENT** of the processing in any other system (i.e., No Interactions)

(McCloskey, Caramazza, & Basili, 1985; McCloskey, Harley, & Sokol, 1991;
McCloskey, & Macaruso, 1994; McCloskey, Maracuso, & Whetstone, 1992)

Figure 2

Dehaene's Triple-Code Theory

- For Virtually any numerical operation, only one of the 3 codes is responsible for processing.
- Input into the model is Translated by encoding processes into the code that matches the internal representation of the particular task.

(Dehaene, 1992; Dehaene & Cohen, 1995)

Figure 3

Campbell & Clark's Encoding-Complex View

- Mathematical Information may be represented in a variety of codes, any of which can be used in processing a mathematical task.
- Facilitates interactions between Comprehension/Encoding, Calculation, and Production

(Campbell, 1994; Campbell & Clark, 1998, 1992)

Pre-Test Translation Question
Asking How a 2nd-Language Math Problem is Handled
English and French Groups

Post-Test Translation Question
Asking How a 2nd-Language Math Problem is Handled
English and French Groups

Figure 6

English Group
Response Language X Format Interaction

Figure 7

English Group
Response Language X Problem Size Interaction

Figure 8

English Group
Format X Problem Size Interaction

Figure 9

English Group

Figure 10
Error Rates for English Group

Figure 11

French Group
Operation X Problem Size Interaction

Figure 12

French Group

Figure 13
Two formats (digits, English words), One response language (English)

Figure 14

The Present Model for the English Group

The Present Model for the French Group

Appendix A

Informed Consent Form – Letter that was given to each participant before participation.

Informed Consent Form

The purpose of an informed consent form is to insure that you understand the purpose of the study and the nature of your involvement. The informed consent must provide sufficient information such that you have the opportunity to determine whether you wish to participate in this study.

Title: Language and Mathematics: The Relation Between English-French Bilingualism and Simple Arithmetic

Research Personnel: The following people are involved in this research project and may be contacted at any time: Alex Stringer (Carleton: 520-2600 ext. 2696; e-mail: astringe@chat.carleton.ca) and Dr. Jo-Anne LeFevre (520-2600 ext. 2693). If you have any ethical concerns about this study, please contact Dr. M. Gick (Chair of the Ethics Committee: 520-2600 ext. 2664) or Dr. K. Matheson (Chair of the Department of Psychology: 520-2600 ext. 2648).

Purpose: The purpose of this study is to examine the relation between simple arithmetic (addition and multiplication) and English-French bilingualism (first versus second languages).

Requirements: You will be asked to solve simple addition and multiplication problems presented on the computer screen. You will answer either in English or in French, depending on how the problem is presented to you. Half of the problems will be presented as words (e.g., three + three, or deux + quatre) and half as digits (e.g., 3 + 3). You will also be required to do the following: answer a few questions verbally with the experimenter, do a paper-and-pencil arithmetic task, complete a questionnaire about your educational background, feelings, and beliefs about arithmetic as well as your mathematical skills, and a complete a brief language proficiency test in either English or French, to assess your proficiency in your second language.

Duration and Locale: The experimental session will last a maximum of two hours. Testing will take place in room A500 of the Loeb Building at Carleton University.

Anonymity/Confidentiality: The data collected in this experiment are confidential. All data are coded such that your name is not associated with the data. The coded data are made available only to the researchers associated with this project.

Right to Withdraw: You have the right to withdraw at any time without academic penalty.

Signatures: *I have read the above description of the study and understand the conditions of my participation. My signature indicates that I agree to participate in the experiment.*

Date: _____ Participant's Name: _____

Participant's Signature: _____

Researcher's Name: _____ Researcher's Signature: _____

Appendix B

Language of Computation – Pre-test and post-test verbal questions asked by the experimenter.

Language of Computation

Subject Number: _____ **Experiment Code:** _____

Date (MM/DD/YYYY): _____ **Time (optional):** _____

Verbal (Interview) Discussion Questions

Brief questions will be asked by the experimenter about language of computation in mathematics and the absence/presence of translation. Examples of these types of questions would be:

- "Do you do mathematics only in your first language?"
- "Would you say that your basic mathematical skills are equal in both English and French?"
- "Do you think people in general only solve math in one language?"
- "Are you comfortable solving simple arithmetic in your second language?"
- "How would you solve a simple arithmetic problem in your second language?"
- "Do you translate mathematical problems into your first language before solving them?"

Experimenter's Comments

Appendix C

Participant ordering of response language, operation, and block number – counterbalanced.

English Group**Response Language, Operation, Problem Set Number**

Participant #	ENGLISH		FRENCH	
	Addition	Multiplication	Addition	Multiplication
101	2	4	1	3
102	3	1	4	2
103	1	3	2	4
104	2	4	1	3
	Multiplication	Addition	Multiplication	Addition
105	1	3	2	4
106	2	4	1	3
107	3	1	4	2
108	2	4	1	3
	FRENCH		ENGLISH	
	Addition	Multiplication	Multiplication	Addition
109	2	4	3	1
110	3	1	2	4
111	1	3	4	2
112	2	4	3	1
	Multiplication	Addition	Addition	Multiplication
113	1	3	4	2
114	2	4	3	1
115	3	1	2	4
116	2	4	3	1

French Group**Response Language, Operation, Problem Set Number**

Participant #	FRENCH		ENGLISH	
	Addition	Multiplication	Addition	Multiplication
201	2	4	1	3
202	3	1	4	2
203	1	3	2	4
204	2	4	1	3
	Multiplication	Addition	Multiplication	Addition
205	1	3	2	4
206	2	4	1	3
207	3	1	4	2
208	2	4	1	3
	ENGLISH		FRENCH	
	Addition	Multiplication	Multiplication	Addition
209	2	4	3	1
210	3	1	2	4
211	1	3	4	2
212	2	4	3	1
	Multiplication	Addition	Addition	Multiplication
213	1	3	4	2
214	2	4	3	1
215	3	1	2	4
216	2	4	3	1

Appendix D

The “French-Kit” (French, Ekstrom & Price, 1963) mathematical proficiency test.

ADDITION TEST — N-1

This is a test to see how quickly and accurately you can add. It is not expected that you will finish all the problems in the time allowed.

You are to write your answers in the boxes below the problems. Several practice problems are given below with the first one correctly worked. Practice for speed on the others. This practice may help your score.

Practice Problems:

4	7	12	84	7	34	17	45	31	80
9	6	5	54	38	81	50	41	52	78
1	15	67	72	80	51	74	89	19	15
<input type="text" value="14"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

Your score on this test will be the number of problems that are added correctly. Work as rapidly as you can without sacrificing accuracy.

You will have 2 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Part 1 (2 minutes)

8	2	12	43	67	23	83	63	19	48
3	51	42	71	95	74	14	99	57	17
7	8	53	11	52	8	19	5	83	39
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

19	69	6	30	50	75	39	52	17	81
8	40	67	98	42	17	90	45	55	83
27	44	38	59	13	19	82	91	58	42
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

4	75	36	18	40	5	16	49	44	99
98	34	20	63	3	26	18	27	7	88
31	22	54	92	59	89	39	36	80	77
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

25	11	76	85	33	42	13	31	62	54
47	23	41	47	59	23	87	8	38	34
17	48	53	85	16	18	58	53	49	78
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

14	74	65	38	58	63	47	84	62	22
41	86	58	25	86	29	74	34	15	83
38	93	34	77	55	22	31	19	26	19
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

6	91	17	33	73	66	78	19	63	47
37	13	38	51	78	89	34	56	23	2
98	87	67	65	45	32	65	45	43	39
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

DO NOT TURN THE PAGE UNTIL ASKED TO DO SO.

STOP.

Part 2 (2 minutes)

76	69	34	48	77	53	18	94	38	42
38	93	33	45	24	49	61	5	58	34
71	85	51	99	44	77	22	37	88	76

6	46	57	55	46	85	28	92	14	48
23	53	53	31	37	34	73	34	65	29
44	37	35	13	99	8	44	63	83	77

83	50	67	72	48	62	31	11	98	37
9	34	78	98	1	31	35	74	87	32
13	42	45	62	98	23	48	68	39	62

73	9	49	23	36	56	17	43	17	41
52	27	61	7	32	60	49	15	97	57
61	83	14	69	88	17	51	38	82	78

13	88	67	96	90	77	62	59	97	84
26	45	47	78	50	34	73	19	57	79
58	9	62	14	26	61	23	56	31	8

82	80	55	96	6	91	9	77	86	77
12	39	10	68	85	21	88	24	11	84
65	4	41	29	37	49	43	38	48	59

DO NOT GO BACK TO PART 1 AND

DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO.

STOP.

SUBTRACTION AND MULTIPLICATION TEST — N-3

This is a test to see how quickly and accurately you can subtract and multiply. It is not expected that you will finish all the problems in the time allowed.

You are to write your answers in the boxes below the problems. Several practice problems are given below with the first one correctly worked. Practice for speed on the others. This practice may help your score.

If you wish, you may use the space between the lines or at the bottom of the page for scratchwork.

Practice Problems:

Subtract:

$\begin{array}{r} 98 \\ -75 \\ \hline 23 \end{array}$	$\begin{array}{r} 40 \\ -35 \\ \hline \end{array}$	$\begin{array}{r} 37 \\ -19 \\ \hline \end{array}$	$\begin{array}{r} 84 \\ -77 \\ \hline \end{array}$	$\begin{array}{r} 81 \\ -38 \\ \hline \end{array}$	$\begin{array}{r} 76 \\ -40 \\ \hline \end{array}$	$\begin{array}{r} 59 \\ -46 \\ \hline \end{array}$	$\begin{array}{r} 90 \\ -31 \\ \hline \end{array}$	$\begin{array}{r} 46 \\ -29 \\ \hline \end{array}$	$\begin{array}{r} 56 \\ -23 \\ \hline \end{array}$
---	--	--	--	--	--	--	--	--	--

Multiply:

$\begin{array}{r} 86 \\ \times 6 \\ \hline 516 \end{array}$	$\begin{array}{r} 67 \\ \times 4 \\ \hline \end{array}$	$\begin{array}{r} 30 \\ \times 3 \\ \hline \end{array}$	$\begin{array}{r} 81 \\ \times 8 \\ \hline \end{array}$	$\begin{array}{r} 42 \\ \times 5 \\ \hline \end{array}$	$\begin{array}{r} 37 \\ \times 8 \\ \hline \end{array}$	$\begin{array}{r} 81 \\ \times 4 \\ \hline \end{array}$	$\begin{array}{r} 86 \\ \times 3 \\ \hline \end{array}$	$\begin{array}{r} 43 \\ \times 6 \\ \hline \end{array}$	$\begin{array}{r} 69 \\ \times 7 \\ \hline \end{array}$
---	---	---	---	---	---	---	---	---	---

Your score on this test will be the number of problems solved correctly. Work as rapidly as you can without sacrificing accuracy.

You will have 2 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Part 1 (2 minutes)

89 -60	52 -48	60 -39	51 -28	85 -23	18 -11	49 -37	83 -57	42 -23	68 -47

73 x 8	41 x 5	69 x 3	29 x 9	16 x 8	63 x 8	60 x 4	52 x 4	85 x 6	36 x 7

52 -19	91 -23	60 -31	42 -31	94 -45	98 -64	50 -33	53 -19	61 -45	41 -27

52 x 9	98 x 3	41 x 8	19 x 6	15 x 4	49 x 2	71 x 9	30 x 8	48 x 7	81 x 5

39 -23	61 -37	29 -19	31 -14	54 -12	92 -65	60 -43	43 -27	70 -31	94 -24

45 x 9	32 x 6	79 x 2	37 x 8	19 x 9	52 x 6	17 x 5	47 x 2	39 x 3	78 x 7

DO NOT TURN THE PAGE UNTIL ASKED TO DO SO.

STOP.

Part 2 (2 minutes)

48 -19	42 -31	95 -65	81 -62	40 -31	51 -27	42 -18	97 -18	93 -45	74 -23
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

14 x 3	38 x 8	50 x 2	80 x 9	61 x 7	52 x 7	97 x 4	72 x 7	16 x 5	49 x 6
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

65 -39	36 -22	80 -46	51 -27	82 -31	91 -64	68 -59	75 -34	64 -24	42 -37
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

52 x 7	71 x 2	96 x 8	47 x 6	83 x 3	16 x 8	44 x 3	50 x 8	62 x 6	39 x 5
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

99 -45	61 -27	91 -60	82 -47	25 -19	73 -45	58 -32	57 -17	59 -42	31 -27
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

13 x 8	68 x 4	75 x 5	67 x 6	45 x 9	94 x 7	52 x 6	83 x 7	61 x 6	54 x 9
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

DO NOT GO BACK TO PART 1 AND

DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO.

STOP.

Appendix E

Questionnaire about the participant's general background, mathematics, and language abilities.

QUESTIONNAIRE

Subject Number: _____

Experiment Code: _____

Date (MM/DD/YYYY): _____

Time (optional): _____

Experimenter: _____

General Background

1. From which province did you receive your education (or country if not Canada)?

- Elementary: _____
- Secondary: _____
- Post-Secondary: _____

2. Date of Birth: ____/____/____ (DD/MM/YYYY)

3. Sex: ① Male ① Female

4. In which Canadian province were you born? _____

Procedure Use

There are many ways to solve simple arithmetic problems. For each of the problems below, please explain how you would **usually** solve it.

Problem	Explanation
1. 9×7	
2. $20 \div 4$	
3. $13 - 6$	
4. $8 + 7$	
5. $72 \div 8$	
6. 9×6	
7. $11 - 2$	
8. $9 + 5$	

1. How do you solve problems like 7×6 , 9×5 , 3×9 ? Do you switch the number around so that the smaller number is placed first? Do you always do this? When did you learn to do this?

[illegible]

Please answer the following questions by circling or darkening the closest response. Note that your first instinct is typically correct.

Never	Rarely	Sometimes	Often	Always
--------------	---------------	------------------	--------------	---------------

2. Overall, please estimate what proportion of the time you solve simple multiplication problems in ways <i>other than</i> by automatically remembering the answers?	①	②	③	④	⑤
3. Overall, please estimate what proportion of the time you solve simple addition problems in ways <i>other than</i> by automatically remembering the answers?	①	②	③	④	⑤
4. Overall, please estimate what proportion of the time you solve subtraction problems in ways <i>other than</i> by automatically remembering the answers?	①	②	③	④	⑤
5. Overall, please estimate what proportion of the time you solve division problems in ways <i>other than</i> by automatically remembering the answers?	①	②	③	④	⑤

Mathematics

Mathematics Education

Highest level math course taken in high school: _____

Grade in course: _____

Math or related courses in University/College: _____

Grade in course: _____

1. Do you remember using a calculator when doing simple arithmetic? If so, when did you start using a calculator?

Please answer the following questions by circling or darkening the closest response. Note that your first instinct is typically correct.

Very Low Skill	Moderate Skill					Very High Skill
----------------------	-------------------	--	--	--	--	-----------------------

2. How would you rate your level of basic mathematical skill (e.g., skill at calculation)?	①	②	③	④	⑤	⑥	⑦
3. How would you rate your level of mathematical skill in more complex areas of mathematics (e.g., calculus, algebra)?	①	②	③	④	⑤	⑥	⑦
4. How would you rate your level of mathematical skill when you are required to use your second language rather than your first language?	①	②	③	④	⑤	⑥	⑦

Always try to avoid	Sometimes try to avoid	Never try to avoid
---------------------	------------------------	--------------------

5. Do you ever actively AVOID situations involving mathematics?

① ② ③ ④ ⑤ ⑥ ⑦

Almost always	Sometimes	Almost never
---------------	-----------	--------------

6. How often do you find that situations involving mathematics make you nervous?

① ② ③ ④ ⑤ ⑥ ⑦

Not important	Moderately important	Very important
---------------	----------------------	----------------

7. How important do you feel that mathematics will be in the development of your career?

① ② ③ ④ ⑤ ⑥ ⑦

Extremely difficult	Moderately difficult	Not at all difficult
---------------------	----------------------	----------------------

8. How difficult was mathematics for you in high school?

① ② ③ ④ ⑤ ⑥ ⑦

9. How difficult do you find doing mathematics in your second language?

① ② ③ ④ ⑤ ⑥ ⑦

Little emphasis	Moderate emphasis	Strong emphasis
-----------------	-------------------	-----------------

10. How much emphasis was placed on learning basic arithmetic facts (e.g., $3 + 4$, 5×9) by your teachers in elementary school?

① ② ③ ④ ⑤ ⑥ ⑦

11. How much emphasis was placed on rote learning (or memorizing) basic arithmetic facts by your teachers in elementary school?

① ② ③ ④ ⑤ ⑥ ⑦

Language (Spoken)

1. What languages do you speak?

⑥ English ① French ② Other (please specify below)

2. Which do you consider your first language (i.e., most proficient speaking)?

⑥ English ① French ② Other (please specify below)

3. Which language is your "mother-tongue" (language spoken when you learned to speak as a child)?

⑥ English ① French ② Other (please specify below)

4. If you had to choose only one, in which language do you remember learning addition?

⑥ English ① French ② Other (please specify below)

5. If you had to choose only one, in which language do you remember learning multiplication?

⑥ English ① French ② Other (please specify below)

6. Which language do you typically use when talking about anything concerning numerical information?

⑥ English ① French ② Other (please specify below)

7. Please indicate what percentage of time you use your first language and second language:

1st language use: _____ % 2nd language use: _____ %

8. If you did French immersion in school, please answer the following questions:

- a) You were in French immersion from grades _____ to _____
- b) When did you start doing math in French? _____ (Grade level)
- c) When did you stop doing math in French? _____ (Grade level)

Language (Reading and Writing)

Language Education

Highest level language/English course taken in high school: _____

Grade in course: _____

Language/English related course in University/College: _____

Grade in course: _____

Please answer the following questions by circling or darkening the closest response. Note that your first instinct is typically correct.

Very Low Skill				Moderate Skill			Very High Skill
-------------------------------	--	--	--	---------------------------	--	--	--------------------------------

1. How would you rate your level of basic reading skill (e.g., reading an instructional manual for information)?	①	②	③	④	⑤	⑥	⑦
2. How would you rate your skill in reading complex materials (e.g., reading a novel for an upper-year English course)?	①	②	③	④	⑤	⑥	⑦
3. How would you rate your spelling skills?	①	②	③	④	⑤	⑥	⑦
4. How would you rate your basic written communication skills (e.g., summarizing a set of notes for a friend or writing a letter)?	①	②	③	④	⑤	⑥	⑦
5. Overall, how would you rate your written language skill (e.g., writing a paper for a university course)?	①	②	③	④	⑤	⑥	⑦

Always try to avoid	Sometimes try to avoid	Never try to avoid
---------------------	------------------------	--------------------

6. Do you ever actively AVOID situations involving reading? ① ② ③ ④ ⑤ ⑥ ⑦
7. Do you ever actively AVOID situations requiring writing? ① ② ③ ④ ⑤ ⑥ ⑦

Almost always	Sometimes	Almost never
---------------	-----------	--------------

8. How often do you find that situations requiring that you "read for meaning" make you nervous? ① ② ③ ④ ⑤ ⑥ ⑦
9. How often do you find that situations involving writing make you nervous? ① ② ③ ④ ⑤ ⑥ ⑦

Not important	Moderately important	Very important
---------------	----------------------	----------------

10. How important do you feel that language skills (reading and writing) will be in the development of your career? ① ② ③ ④ ⑤ ⑥ ⑦

Extremely difficult	Moderately difficult	Not at all difficult
---------------------	----------------------	----------------------

11. How difficult was English for you in high school? ① ② ③ ④ ⑤ ⑥ ⑦

Appendix F

Debriefing Letter outlining the purpose of the experiment – given to each participant.

Written Debriefing

Thank you for participating in this study. The main purpose of the experiment was to examine how the use of first and second languages (English and French) affects the mathematical performance (simple addition and multiplication) for bilingual subjects.

Studies in mathematics have shown that response latencies and error rates are affected by problem format (i.e., digits vs. words). Campbell (1994) found differences between simple arithmetic problems presented in digits and English words. The present experiment extended this study to include problems presented in the French language as well as the English language. Two bilingual groups of subjects were looked at. The first group spoke English as a first language and French as a second language, and the second group spoke French as a first language and English as a first language.

It was hypothesized that the results of Campbell (1994) would be replicated in each of the groups, and in both English and French within each group. The effects of problem format (digits vs. words), as described above, problem operation (addition vs. multiplication; multiplication was expected to produce higher response latencies and error rates), and problem size (small vs. large; large problems were expected to produce higher response latencies and error rates) were hypothesized. In addition, a response language by format interaction was hypothesized within each group; response times and rates of error were expected to be higher with problems presented in the second language than with those presented in the first language. Further, it was expected that many individuals would translate problems presented to them in their first language into their second language in order to solve the problem. The error patterns of each subject for their first and second languages will be compared to look for translation occurrence. Lastly, a language by format by operation interaction was hypothesized; the differences in response latencies and error rates for digits and words with operation (i.e., addition versus multiplication) will be greater for second language presentation problems than for first language presentation problems.

Once again, thank you for the time and effort you put into this research project.

Feel free to contact the research personnel at any time if you should have any questions or comments about the experiment: Alex Stringer (Carleton: 520-2600 ext. 2696; e-mail: astringe@chat.carleton.ca) and Dr. Jo-Anne LeFevre (520-2600 ext. 2693). If you have any ethical concerns about this study, please contact Dr. M. Gick (Chair of the Ethics Committee: 520-2600 ext. 2664) or Dr. K. Matheson (Chair of the Department of Psychology: 520-2600 ext. 2648).