THE COGNITIVE ADVANTAGE IN BILINGUALISM: ATTENTION AND WORKING MEMORY.

by

CAROLINE MARCOUX

B.A. (Hon.), McGill University, 2002

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
in
THE FACULTY OF GRADUATE STUDIES
(School of Audiology and Speech Sciences)

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

September 2004

© Caroline Marcoux, 2004
In presenting this thesis in partial fulfillment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Caroline Marcoux  30/09/2004
Name of Author (please print)  Date (dd/mm/yyyy)

Title of Thesis:  The Cognitive Advantage in Bilingualism: Attention and Working Memory

Degree:  Master of Science  Year:  2004
Department of   School of Audiology and Speech Sciences
The University of British Columbia
Vancouver, BC  Canada
Abstract

This study investigated the effect of bilingualism on the ability to perform on task tapping into executive functions. In particular the ability of 31 French-English bilingual children (age 8-10 years) to perform on inhibition and working memory tasks was compared to that of a group of French monolingual peers. All children completed a task requiring inhibitory skills. In this task, children must ignore spatial cues and select a response that corresponds only to the stimulus color. As well, all children completed two working memory tasks that involved both storage and processing of information. An auditory-verbal working memory task required children to categorize words by size of the referent before recalling an auditorally presented list of words. In a visuo-spatial working memory task children were instructed to remember the location and categorize shapes presented in a 4 x 4 grid. The bilingual children outperformed their monolingual peers on all three tasks. In addition, the bilingual children whose two languages were more balanced performed better than the bilingual children who were dominant in one of their languages on the inhibition task. The results of this study suggest that bilingual children are at an advantage when performing on tasks requiring inhibitory and working memory abilities. Possible mechanisms underlying the observed bilingual advantage are discussed.
Table of Contents

Abstract ........................................................................................................................................... ii

Table of Contents ............................................................................................................................ iii

List of Tables ..................................................................................................................................... vii

Acknowledgements ........................................................................................................................ viii

1 Review of the Literature ............................................................................................................... 1

1.1 The Bilingual Advantage ....................................................................................................... 1

1.2 The Bilingual Advantage and Memory .................................................................................. 10

1.3 Baddeley’s Model of Working Memory .................................................................................. 10

1.4 Just and Carpenter’s Limited Capacity Framework ............................................................... 12

1.5 Developmental Changes in Working Memory ..................................................................... 13

1.5.1 Increase in knowledge ....................................................................................................... 13

1.5.2 Changes in processing strategies ....................................................................................... 14

1.5.3 Changes in processing speed ............................................................................................. 15

1.5.4 Changes in attention processes ......................................................................................... 18

1.5.4.1 Amount of Information ................................................................................................. 19

1.5.4.2 Attentional focus .......................................................................................................... 20

1.5.4.3 Inhibition ....................................................................................................................... 21

1.5.5 Summary of developmental changes in working memory .............................................. 21

1.6 Timeline of Developmental Changes in Working Memory .................................................. 22

1.7 The Development of Working Memory and Bilingualism ...................................................... 23

1.7.1 Knowledge ....................................................................................................................... 23

1.7.2 Control of attention .......................................................................................................... 24

1.7.3 Summary of the development of working memory and bilingualism ......................... 25
3.2 Inhibitory Task (Simon task) ................................................................. 42
3.3 Working Memory Tasks ........................................................................ 45
3.4 Correlating Language Performance with Inhibition and Working Memory .... 47
3.5 The Effect of Language Dominance on Inhibition and Working Memory...... 47
3.6 Correlating Inhibition, Working Memory Skills, and IQ ......................... 50
3.7 Summary of Major Findings .................................................................... 53

4 Discussion .................................................................................................... 54
4.1 Inhibition ................................................................................................. 54
4.2 Working Memory ...................................................................................... 56
  4.2.1 Summary of main findings ................................................................. 56
  4.2.2 Previous research ................................................................................ 56
    4.2.2.1 Knowledge based tasks ............................................................... 57
    4.2.2.2 Memory Tasks ............................................................................ 59
    4.2.2.3 Summary of main findings as related to the larger literature .......... 61
4.3 Mechanisms Underlying the Bilingual Cognitive Advantage .................. 61
  4.3.1 Language knowledge .......................................................................... 61
  4.3.2 Context of bilingual development ...................................................... 63
  4.3.3 One or many underlying mechanisms? ............................................... 65
  4.3.4 Preliminary summary .......................................................................... 66
4.4 General Intelligence and the Bilingual Advantage .................................. 66
  4.4.1 Empirical evidence ............................................................................ 66
  4.4.2 Bilingual advantage within group ...................................................... 67
  4.4.3 Component Vs. complex tasks .......................................................... 67
  4.4.4 Summary: General intelligence and the bilingual advantage .............. 69
List of Tables

Table 2.1 Number of Error Trial RTs (% accuracy) and Number of trimmed trials (% of data excluded by trimming) for each group in each condition.................................42
Table 2.2 Mean (SD) RT in the Simon task for monolingual (M) and bilingual (B) children..................................................................................................................43
Table 2.3 Mean (SD) Number Correct in the Working Memory (WM) tasks for monolingual (M) and bilingual (B) children.................................................................45
Table 2.4 Mean (SD) z-scores in the Working Memory (WM) tasks for monolingual (M) and bilingual (B) children.................................................................45
Table 2.5 Mean (SD) z-scores in the Working Memory (WM) tasks for Balanced and Dominant Children.........................................................................................48
Table 2.6 Correlations between the Simon task and the Working Memory (WM) tasks.........................................................................................................................49
Table 2.7 Mean (SD) z-scores in the Working Memory (WM) tasks for IQ=matched monolingual (IQM) and bilingual (IQB) groups..................................................52
Acknowledgements

I would like to thank my supervisor, Dr. Judith Johnston, for so generously sharing with me her unlimited knowledge, great experience, and after hour time! Thank you for using the four comforting words “too soon to panic” always at the right moment. I will be sure to remember those words in other important professional and life challenges.

Thank you to my committee members, Dr. Jeff Small and Dr. Stefka Marinova-Todd for numerous insightful suggestions and interesting discussions throughout this process.

Paola Colozzo, thank you for being such a wonderful colleague, mentor, and friend. I really enjoyed sharing with you the countless hours spent planning, testing, and discussing theoretical, clinical, and life matters.

Thank you to the principals, teachers, and children from the participating schools for being so flexible and enthusiastic about this project.

Special thanks to you, mom, who besides supporting me through all these years of hard work did an amazing job at setting the stage for us to go testing in Quebec. We could have never done it without you. Merci maman!

To my classmates and friends, thank you for being by my side, in tears and laughter during this roller coaster ride that is grad school and life!

Finally, Mike, thank you for being both my rock and my comfort blanket. Thank you for your boundless love, patience, and understanding. I could never have done it without you!
1 Review of the Literature

1.1 The Bilingual Advantage

The purpose of this research is to further examine the developmental relationship between cognitive abilities and bilingualism. A recent body of research suggests that bilingual children perform better than monolingual children on a wide range of cognitive tasks, including the tower task (Bialystok & Codd, 1997), the Dimensional Change Card Sort task (Bialystok, 1999; Bialystok & Martin, in press), and the Simon task (Bialystok, Martin, & Viswarathan, in press). At first glance, these tasks seem quite diverse. For example, in the tower task, pairs of block towers are constructed from either Lego blocks or Duplo blocks. The Duplo blocks are twice as big as the Lego blocks. Children are presented with a pair of towers and asked to identify which tower contains the most blocks. Different conditions are included in the task. In one condition, the highest tower is also the one containing the most blocks (corresponding). In another condition, the two towers have the same height, thus the one made of Lego blocks contains more blocks (Noncorresponding-equal). In the last condition, the Lego tower is perceptually shorter but contains a higher number of blocks than the Duplo tower (Noncorresponding-conflicting). On the Noncorresponding-conflicting condition, bilingual children correctly identified the tower containing the most blocks more often than monolingual children (Bialystok & Codd, 1997). In the Dimensional Change Card Sort task, children are asked to sort a set of cards according to a perceptual feature (e.g. color) and then to resort the same cards on the basis of a different feature (e.g. shape). Bilingual
children made fewer mistakes than their monolingual peers when resorting the cards on the basis of a different feature (Bialystok, 1999; Bialystok & Martin, in press). In the Simon task, the child sits in front of a computer screen and is instructed to press a red button (situated on one side of the keyboard) when he sees a red square appear on the screen and to press a blue button (situated on the other side of the keyboard) when he sees a blue square appear on the screen. In each trial, a blue or a red square appears on either side of the computer screen and the child is instructed to respond as fast as possible without making mistakes. On this task, bilingual children are found to respond faster than their monolingual peers without making more mistakes (Bialystok, Martin, & Viswarathan, in press). Differences in performance between monolingual and bilingual children in tasks such as the ones described above have led Bialystok and other researchers to talk about a “bilingual advantage”.

Despite the apparent diversity, Bialystok (2001) and Bialystok and Martin (in press) maintain that a common characteristic of these tasks is their high demand for attentional control. In fact, they argue that when the need for attentional control (inhibition/attention shifting) is eliminated, the bilingual advantage disappears. They contend that the bilingual advantage is explained by the fact that bilinguals have more experience at controlling attention because of the need to inhibit one language when the other is being used.

Bialystok’s explanation does not, however, seem to fit all of the findings. A bilingual advantage has also been observed in tasks where attentional control does not appear to be a primary requirement. In a longitudinal study by Hakuta (1987), bilingualism was found to account for a significant proportion of the variance on the Raven’s Coloured Progressive Matrices Test and the Spatial Relations subtests of
the Thurstone’s Primary Mental Abilities. The Raven’s Coloured Progressive Matrices Test consists of different figures containing a missing piece, the child is instructed to pick, out of a set of possibilities, the piece that best completes the figure. One Spatial Relations subtest of the Thurstone’s Primary Mental Abilities involves choosing from four alternative geometric figures, a figure that would complement a target figure to make up a square. In another subtest, children are asked to draw missing lines on a geometric figure to match a model figure (Hakuta, 1987).

These results suggest that a bilingual advantage may exist even in tasks which do not appear to make high demands on attentional control. Moreover, some researchers are questioning Bialystok and Martin’s (in press) claim that the bilingual advantage found in tasks such as the Dimensional Change Card Sort (DCCS) task primarily reflects attentional control abilities. For example, Zelazo, Müller, Frye, & Marcovitch (2003) suggest that other components of cognitive function may be involved in performing this task. In the DCCS task, Bialystok and Martin (in press) argue that it is the conflict between the pre-switch and the post-switch rules that renders the task difficult for preschool children to solve and that this element of conflict increases the demands for attentional control. Indeed, when this element of conflict is eliminated, preschool children can successfully accomplish the task and no bilingual advantage is observed. However, Zelazo, Müller, Frye, & Marcovitch (2003) suggest that poor performance on the DCCS task could be due to memory limitations. They state that the DCCS task “requires children to formulate explicit rules, maintain them in working memory, and then use them to guide their behaviour”(pp.47). They state that it is possible that “3- to 4-year-olds’ memory for
the rules is limited in a way that permits them to succeed in some situations (i.e. those without conflict) but not others (i.e. those with conflict)”p.96. Keeping in line with this argument, one could suggest that the bilingual advantage observed on this task is due to differences in working memory capacity between monolingual and bilingual children.

There are at least two possible resolutions to this apparent conflict. The first resolution comes by paying attention to a study by Miyake, Friedman, Emerson, Witzki, and Howarter, (2000), which offers a more differentiated model of executive functions. Miyake et al. (2000) investigated three different executive functions; that is, attention shifting, inhibition, and updating. They define Shifting as “the disengagement of an irrelevant task set and the subsequent active engagement of a relevant task set” (p.55). For them, individual differences in shifting ability is not simply a reflection of one’s ability to engage or disengage in appropriate task sets, but also involves the ability to perform a new operation when facing proactive interference. As for Inhibition, it is defined as “one’s ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary” (p.57). Note that this definition concerns the deliberate controlled process of inhibition rather than other types of inhibitory effects such as the ones that take place in connectionist networks and are not necessarily conscious. The third executive function targeted in this study is the ongoing revision and monitoring of working memory representations. Miyake, et al. (2000) use the term Updating to refer to this process and state that the “updating function requires monitoring and coding incoming information for relevance of the task at hand and then appropriately revising the items held in
working memory by replacing old, no longer relevant information with newer, more relevant information” (p. 57).

Miyake et al. (2000) were interested in understanding the extent to which these three executive functions were independent. They tested 137 college students on three sets of tasks (3 tasks in each set), each of which tapped into one of the target executive functions. For example, one task they used to tap into ‘shifting’ was the Plus-Minus task. In this task, subjects were provided with 3 lists of 30 two-digit numbers. They were instructed to add 3 to each number in the first list, subtract 3 to each number in the second list, and alternate between adding and subtracting 3 to the numbers in the third list. The time to complete each list was recorded. The time required to complete the third list was compared to the average time required to complete lists one and two and a shift cost was calculated to serve as the dependent measure. One of the tasks used to tap into the ‘updating’ function was the Keep Track Task. In this task, subjects were shown three or four target categories at the bottom of a computer screen (e.g. animals, colours, countries, distances, metals, and relatives). Fifteen words, including 2 or 3 words from each category were then presented serially in a random order. The participants were then asked to remember the last word presented in each category and to write those words down. One of the tasks used to tap into inhibition was the widely known Stroop task. In this task, the participants are instructed to name the colour of a stimulus as quickly as possible. This task included three conditions; one consisted of a list of asterisks printed in different colours, one included colour words printed in a different colour (e.g. BLUE printed in red colour) and one with colour words printed in the same colour (e.g. BLUE printed in blue). The difference between Response Times (RT) between the
trials in which the word and the colour were incongruent and the trials with asterisks was used to measure inhibition.

Miyake et al. (2000) found low correlations between tasks used to measure different functions, and high correlations between tasks considered to tap the same executive function. They then used Confirmatory Factor Analysis (CFA) to determine which of three pre-determined models would best fit their data. Their rationale was that if the three target executive functions (i.e. shifting, updating, and inhibition) are in fact distinguishable, the best fitting model should be a three-factor model. On the other hand, if the three executive functions are merely three versions of the same cognitive capability, a one-factor model, one that assumes the unity of all functions, would best fit the data. A third possibility would be that two of the target functions are indistinguishable, in which case a two-factor model would best fit the data. Using this method, Miyake et al. (2000) established that the three target executive functions (shifting, inhibition, and updating) were clearly separable, but that they also showed some underlying commonalities. These findings were replicated by Lehto, Jujuvarvi, Kooistra, and Pulkkinen (2003) with 8 to 13 years old children.

Miyake et al. (2000) and Lehto et al. (2003) note the importance of considering both the diversity and the unity of functions when investigating executive processes. This advice suggests two possible resolutions to the debate about the nature of the bilingual advantage. First, in line with Miyake et al. (2000), it could be that all of the tasks at issue - the tower task, the DCCS, and the Simon task - actually tap into the common ground of executive function rather than one or another specific function. Alternatively, one could argue that the bilingual advantage
stems from two or more independent executive functions, e.g. attention shifting and memory updating, which may be required even in a single task. The definitions provided by Myake et al. (2000) do seem to indicate that the DDCS task makes heavy demands on attention shifting, and that the tower task and the Simon task make heavy demands on conscious inhibition. However, none of the tasks traditionally used in bilingual advantage research seems to make heavy demands on the ‘updating’ function so important for working memory.

This fact takes us to a related, yet importantly different approach by Zelazo, Müller, Frye, & Marcovitch (2003) who proposes that these tasks could reflect working memory capacities as well as executive functions such as inhibition, shifting, and updating. In order to successfully complete tasks such as the tower task or the Simon task children have to remember the task instructions (e.g. find the tower containing the higher number of blocks, press red button when I see red square/press blue button when I see blue square) and perform the task. Furthermore, the task instructions need to be applied to a succession of perceived items, requiring updating of information in working memory on each trial. Failure to remember the task instructions or apply them to the changing stimuli, could lead the child to respond according to perceptually salient cues (e.g. pick the higher tower or press the button situated on the same side as the stimulus cue). Thus, it is unclear whether attentional control (shifting and/or inhibition), memory, both processes, or some cognitive common ground is underlying the bilingual advantage observed in these studies. Memory seems to be an area deserving further exploration if we are to deepen our understanding of the processes underlying the bilingual advantage.
Three studies investigated the effect of bilingualism on memory. Two of these studies report a bilingual advantage on memory tasks, whereas one fails to find a difference. First, Whitaker, Rueda, & Prieto, (1985) who studied a group of seven and eight year old mentally retarded children, found that more proficient bilingual children performed better than less proficient bilingual children on a reconstruction memory task which consisted of copying an array of geometric forms from memory after a model is presented. More proficient bilinguals also outperformed less proficient bilinguals on a Circular Recall task, in which children had to repeat a series of words, starting with the last three items presented and ending with the first four items presented.

Kormi-Nouri, Moniri, & Nilsson, (2003) likewise reported a positive effect of bilingualism on both episodic and semantic memory in Swedish/Persian speaking children from 8 to 13 years of age when compared to monolingual children. There were two memory tasks, both administered in Swedish. The Episodic memory task consisted of recalling statements such as ‘read the book’ or ‘hug the doll’ after having performed the action using real objects or pretending to use objects. The semantic memory task consisted of a word fluency task where children had to write as many words as they could starting with the letter ‘s’ and the letter ‘b’ in two minutes. Bilingual children outperformed their monolingual peers on both these tasks. A Swedish vocabulary test was also administered to all children (monolingual and bilingual) and the groups did not differ on this measure.

And finally, a just published study by Gutierrez-Clellen, Colderon & Ellis Weismer (2004) compared the performance of a group of balanced bilinguals with a group of less-balanced bilinguals on two verbal working memory tasks. In the
Competing Language Processing Task (CLTP), children were asked to listen to sets of short sentences, judge their truth value and remember the last words of the sentences in each set. In the Dual Processing Comprehension Test (DPCT), children heard two sets of instructions given simultaneously by different speakers, one in each ear, and needed to attend to only one of them. The DPCT seems to focus more on attentional control, but the CLTP is a classic verbal working memory task based directly on the work of Daneman and Carpenter (1980). No group differences were found on either task.

These studies must be considered only preliminary due to methodological limitations, and the mixed findings should be evaluated accordingly. Neither Whitaker, Rueda, & Prieto, (1985) or Gutierrez-Clellen, Coderon & Ellis Weismer (2004) had a monolingual control group. The studies also were limited by weaknesses in their language proficiency measures. Kormi-Nouri, Moniri, & Nilsson, (2003) only measured bilingual proficiency through self-rating scales, and Gutierrez-Clellan, Coderon & Ellis Weismer (2004) evaluated proficiency by calculating grammatical error rates. This latter approach invalidly assumes a linear relationship between error rate and acquisition (Rispoli & Hadly, 2001). Two of the three studies, nevertheless, suggest that the bilingual advantage may extend to working memory tasks as well as those that tap into attentional control. No one would argue that sustained attention is not required to perform a memory task. However, the memory tasks described above do not seem to require the attention shifting or inhibitory abilities that Bialystok and her colleagues have argued are central to the bilingual advantage.
1.2 The Bilingual Advantage and Memory

The term 'memory' refers to a complex set of functions and capacities. They can be classified according to duration (i.e. short-term, long-term), content (declarative memory, including both semantic and episodic memory, and procedural memory), or processes (storage, recall, strategy) (Medin & Ross, 1996). One important focus of current memory research is 'working memory, that is, "a limited capacity system allowing the temporary storage of information necessary for such complex tasks as comprehension, learning, and reasoning." (Baddeley, 2000, p. 418).

Working memory is involved when information needs to be kept active while performing a cognitive task, and hence would seem to be important in most, if not all, of the tasks in which a bilingual advantage has been observed. One goal of the current study is to determine whether there is a demonstrable working memory advantage in young bilingual speakers. To set the stage for a description of the study, the following sections of this chapter will provide a brief look at one model of working memory and review key developmental findings.

1.3 Baddeley's Model of Working Memory

Baddeley and Hitch (1974) proposed one of the first models of working memory. Their model evolved from Atkinson and Shifrin’s (1974) earlier work on short-term memory. Since the first model proposed by Baddeley and Hitch (1974), extensive work has been done to clarify and expand the model (Baddeley, 1986; Baddeley, 1996, Baddeley, 1998, Baddeley, 2000, Baddeley, 2002, Baddeley and Hitch, 1994). The Baddeley (1986) model of working memory included three major components: Two slave systems, the phonological loop and the visuospatial...
sketchpad serve as the temporary memory stores for phonological and visuospatial information respectively. The phonological loop is believed to comprise two components, a phonological store and an articulatory rehearsal system. Baddeley, Gathercole, and Papagno (1998) have argued that the phonological loop is involved in children’s native language learning and adult second language learning. The visuospatial sketchpad component is less well understood and the nature of visuospatial rehearsal remains unclear (Baddeley, 2002).

The third constituent, the central executive, is the least specified of the components but it is believed to coordinate the actions of the two slave systems by controlling attentional resources. As well, the central executive is believed to be responsible for activating long-term memories and procedural schemes that are relevant to a particular task (Baddeley, 1996). Thus, the central executive is believed to be responsible for focusing available attentional capacity, dividing attention between tasks, and switching attention between tasks. It is important to note that within this working memory model, attention is viewed as a limited resource shared by the different processes (e.g. storage, processing, inhibition) required in the completion of virtually any task (e.g. computation, reasoning). This view of attention differs from the one endorsed by Bialystok and her colleagues as they view attention control (i.e. shifting or inhibition) as a function that is exercised in certain type of task (e.g. Dimensional Change Card Sort task, Simon task) but not other types (e.g. memory tasks). A fourth component, the episodic buffer, was recently introduced by Baddeley (2000). The episodic buffer developed subsequently to recent evidence that revealed the need for a storage system enabling the integration
of information from different sources. Baddeley (2000) describes this new component as follows:

The episodic buffer can be accessed by the central executive in the form of conscious awareness. The executive can, furthermore, influence the content of the store by attending to a given source of information, whether perceptual, from other components of working memory, or from LTM. As such, the buffer provides not only a mechanism for modelling the environment, but also for creating new cognitive representation, which in turn might facilitate problem solving (p. 421).

1.4 Just and Carpenter’s Limited Capacity Framework

As mentioned above, the role of the central executive in Baddeley and Hitch’s working memory model is to control attentional resources. However, the process by which attentional resources are distributed is underspecified. In particular, Baddeley does not indicate whether there is one pool of resources that is shared by all of the working memory components and processes or whether there are several. Just and Carpenter’s (1992) limited capacity framework for working memory does address this issue positing that storage and processing demands share a limited amount of resources. When the task demands are high (either because of storage or processing needs) more resources are needed. According to this framework, a limited capacity of resources is available. Thus if task demands exceed available resources, it will affect storage and/or processing abilities.

The present study will make use of the Baddeley and Hitch model, along with the Just and Carpenter perspective on shared resource, in designing the tasks and interpreting the outcomes. None of these theorists is a developmentalist and the models have not been constructed with developmental change in mind. We turn next to the developmental literature to help identify those aspects of working memory that change with age, and hence could be influenced by bilingual experience.
1.5 Developmental Changes in Working Memory

Cowan (1997) states that development changes in working memory could reflect many different factors (See also Diamond, 2002; Kail and Bisanz, 1982; and Pickering, 2001 for similar accounts). These factors include: increase in knowledge, changes in processing strategies, changes in processing speed, and changes in attentional processes. These factors will be reviewed in turn and evidence relating to each factor will be presented.

1.5.1 Increase in knowledge

First, increase in knowledge could support working memory in facilitating the grouping of elements to be remembered. This act of grouping elements together based on knowledge is often referred to as ‘chunking’ and is known to decrease the load on memory (Cowan, 1997). The effect of children’s knowledge on a working memory task was clearly demonstrated in a study by Chi (1978). In this study, children, who were experienced chess players, were compared to adults, who were novice chess players, in their ability to recall the location of pieces on a board. The children were better at recalling the location of pieces on the board, but only if the pattern formed by the pieces was one that could be observed in a game of chess. These results suggest that domain-specific knowledge is more important than general experience, or physical maturation in increasing working memory performance.

More evidence that knowledge influences working memory was found in a study by Gathercole, Frankish, Pickering, and Peaker (1999). They investigated 7 and 8 years old children’s ability to recall monosyllabic words and non-words
varying in phonotactic frequency. Children were presented with a list of words or non-words and were instructed to repeat the list as they heard it. They found that words were more easily recalled than non-words but that non-word recall showed superior accuracy for high over low probability non-words. Thus, it may be argued that increased speech and language experience may facilitate word recall. However, when they compared a high- and a low-language level group of the same age, Gathercole, Frankish, Pickering, and Peaker (1999) found that the high-language group performed better than the low language group on all conditions. This suggests that the superior performance of the high-language group did not solely rest on greater use of lexical or phonotactic knowledge to perform the task. Thus, domain-specific knowledge can support working memory by facilitating the grouping of the elements to be remembered. However, it is likely that other processes also contribute to a developmental increase in working memory performance.

1.5.2 Changes in processing strategies

Another factor that could influence developmental changes in working memory is change in processing strategies. For example, Pickering (2001) suggests that before the age of 8, children tend to encode pictures visually. After that, children start to use verbal strategies for remembering the same pictures. A study by Hitch, Halliday, Schaafstal, and Scharaagen, (1988) clearly illustrates this developmental change. A group of 5-year-old and a group of 10-year-old children completed an object recall task with three conditions, in which visual similarity and word length were systematically manipulated. Also, half of the children in the 5-year-old group were instructed to label the objects during presentation. The findings
revealed that children who labelled the objects performed better than those who did not, suggesting that phonological encoding improves recall. Also, only the younger group was affected by visual similarity of the objects. This suggests that 5-year-old children were using a visual encoding strategy. Finally, the older group was affected by the length of the objects’ labels, suggesting that they were encoding the objects phonologically. Thus, it is clear that change in strategy could explain the better performance of older children on some working memory tasks in which the items to be remembered are nameable. Cowen (1997) suggests that changes in processing strategies can take different forms; the knowledge of which strategy would be useful, the ability to use the strategy, the resources needed to implement a particular strategy, and the ability to use better versions of a strategy.

1.5.3 Changes in processing speed

Changes in processing speed could also contribute to developmental changes in working memory. Processing speed could increase due to maturation of brain tissue such as the completion of the myelin layer that serves as insulation for some nerve cells and speeds up the transmission of impulses (Cowan, 1997). A meta-analysis by Kail (1991) revealed that speed of processing increases dramatically during childhood and more slowly during adolescence. Some of the tasks that have been used to measure processing speed include the Number Comparison test and the Identical Picture test (Kail, 1992; Kail & Park, 1994). In the number comparison task, children are presented with pairs of 3 to 12 digit numbers. In half the pairs, the numbers in each pairs are identical, and in the other half they differ by one digit. The children are instructed to mark the pairs that differ by one digit. The identical
picture test consists of finding, among 4 distractor pictures, the picture identical to a target picture. The time taken to complete each task is used as the dependent variable. Kail and Hall (1994) argue that since this pattern of change is found across a wide range of perceptual and cognitive tasks, it suggests that a global mechanism is responsible for age-related change in speed of processing.

Baddeley (1986) suggests that as processing speed increases, items can be rehearsed faster (due to faster pronunciation rate), and more items can be refreshed in the phonological loop before they are lost from short-term storage. In a study by Case, Kurland, and Goldberg (1982), speed of processing was measured by asking 3 to 6 year old children to repeat single words as fast as possible in a microphone. Children were also asked to complete a short-term memory span task, which consisted of repeating lists of 3 to 7 words. A significant linear correlation was found between the mean speed of responding in the first task, and short-term memory span \( r = -0.74, p < 0.001 \) and remained significant when age was partialled out statistically \( r = -0.35, p < 0.02 \). Case et al. (1982) concluded that these results clearly showed that a strong relationship exists between speed of processing and short-term memory span. Using causal modeling, Kail (1992) and Kail and Park (1994) found that as processing time improves with age, words can be pronounced faster, producing more accurate recall. Thus, it could be argued that increase in processing speed may support working memory by permitting faster rehearsal and allowing more items to be refreshed in the phonological loop. No such rehearsal system has been specified for the visual sketchpad. However, a similar process could arguably be applied to visual-spatial working memory tasks.
Cowan (1997) argues that a different process than pronunciation speed could explain the correlation between increase in span and increase in processing speed. In one study, Cowan (1992) measured the timing of children’s (4 to 8 years old) correct repetitions of lists of words in a memory span task where children had to repeat the words in the same order they had heard them. He didn’t find differences in pronunciation time. However, he found that the length of pauses between the words was shorter in older children’s responses. Because longer pause times were also measured in longer lists of words, Cowen (1992) concluded that the pause time between words in the responses could be viewed as reflecting a memory search period where children go through the list to determine which word to pronounce next. Cowen (1997) argues that an increase in processing speed could help decrease the memory search time in a word-list repetition task. He explains that the process by which faster memory search can support working memory may be similar to the process by which faster pronunciation also supports working memory; “Information can be lost from short-term storage while either speech articulation processing or a rapid memory search are ongoing, and the faster these were to be conducted the less time there would be for short-term memory loss to take place” (p.180).

Similarly, Kail and Hall (1994) and Kail, Hall, and Caskey (1999) suggest that as processing speed increases with age, children can access words more rapidly, which in turn, increases their reading abilities. They found that children who were faster at object naming were also better in reading recognition and reading comprehension tasks. Additionally, Kail, Hall and Caskey, found that naming times were predicted by performance on general processing speed tasks rather than print exposure. This again suggests that increased speed in word access reflects a global
developmental change rather than task specific change, and further that maturational processes rather than specific experiences are underlying this type of change.

These results suggest that a global increase in processing speed may have an effect on other non-speeded tasks such as working memory tasks or reading comprehension. It can be argued that this effect takes place through mediating processes such as increase in articulation speed, or faster word access.

1.5.4 Changes in attention processes

Cowan (1997) also proposes that changes in the use of attention could contribute to developmental changes observed in working memory. He suggests that these changes in the use of attention could come about in three ways. First, there could be developmental changes in the amount of information that can be held in the focus of attention at any one time. Second, there could be changes in how efficiently attention is kept focused on the relevant task. And finally, changes could occur in the inhibitory functions of attention.

The idea of changes in the use of attention is related to Baddeley’s (1986) concept of central executive, which is believed to be in charge of the many facets of attention (e.g. attention focusing, attention shifting, division of attention) and of coordinating activities of the two slave systems (phonological loop and visuospatial sketchpad). Also, Cowan’s concept of the “amount of information that can be held in the focus of attention” seems closely linked to Just and Carpenter’s (1992) “amount of available resources”. If Cowan’s hypothesis on the development in use of attention is analysed through Just and Carpenter’s (1992) framework of limited capacity, improved performance on working memory tasks based on changes in use
of attention could be due to increase in processing efficiency, liberating attentional resources to be used for storage.

1.5.4.1 Amount of Information

Case, Kurland, and Goldberg (1982) argue that during development, total processing space (storage space and operating space combined) (i.e. total amount of resources) remains constant but that as operating (i.e. processing) becomes more efficient it requires less operating space (i.e. resources). Consequently, more space (i.e. resources) is available for storage. Similarly, Kail and Bizand (1982) suggested that the amount of available resources may increase with age due to automatization. The automatization hypothesis suggests that the amount of available attentional resources increase as processing becomes more automatic. Drawing upon computational connectionism, it could be argued that the process of automatization occurs through strengthening of relations, which would increase processing efficiency and free attentional resources for storage (Kail and Bizand, 1982).

According to this view, older children would benefit from an increase in capacity that could be used to store or process information as well as increase focus on a task or to inhibit possible interference from irrelevant information.

Case, Kurland, & Golberg (1982) used a counting span task, a working memory task involving both memory and processing, to investigate this idea. In this task, children were instructed to count the number of items on a series of cards and then recall the series of card totals. Older children obtained a higher counting span. Case, Kurland, & Golberg (1982) concluded that the better performance observed in the older children could be explained by the fact that they used less resources for
counting, leaving more capacity for the storage of the totals. It could be argued that older children use less resource for counting because they have more counting experience, which created stronger relations related to counting. Consequently, one can conclude that more efficient processing can occur through experience with a particular task, which in turn affects the ability to perform successfully on a working memory task involving both storage and processing components.

1.5.4.2 Attentional focus

Cowan (1997) suggested that developmental changes in working memory can occur because older children are better at keeping their attention focused on the relevant task. Findings from the large literature on incidental learning have typically yielded results such as those reported by Maccoby and Hagen (1965). These researchers presented both intentional and incidental memory tasks. On each trial, the children were presented with a series of coloured cards with a picture of an animal or common object on each card. The child was instructed to remember the sequence of colours. After those trials were completed, an incidental memory task was administered. In this task, the child was asked to identify which pictures had been presented with which colour. This task was incidental because children had not been asked to remember the pictures at the beginning of the task. Maccoby and Hagen (1965) found that while performance on the intentional task increased with age, performance on the incidental task decreased. They concluded that older children were better at focusing their attention on the relevant aspects of the material to be remembered and to ignore distractions. Cowan (1997) argues that focus of attention is important to success in a working memory task because
information has to be kept in the focus of attention in order to be remembered or processed.

1.5.4.3 Inhibition

Related to this idea, is the third mechanism in which changes in attention could occur, that is, inhibition. Cowan (1997) suggests that in the study described above, in addition of keeping attention focused on the relevant elements of the task, children may have had to actively inhibit the urge to pay attention to the pictures on the cards. He argues that if irrelevant information is kept in working memory, less space is available for the storage and processing of relevant information. Finally, Cowan (1997) argues that more research is needed to determine whether this change in inhibitory abilities seen in development is specific or just one example of a more efficient control of the focus of attention through central executive functioning.

1.5.5 Summary of developmental changes in working memory

Many processes may play a role in the developmental changes observed in working memory. It is important to notice that within working memory we find some of the same executive functions discussed previously. Thus, attentional control (i.e. shifting and inhibition) and working memory can be viewed as belonging to two different levels, with the latter including the former. However, all components included under the working memory umbrella may not be engaged at all times. In fact, what is termed ‘working memory’ potentially involves different activities depending on the nature of the task at stake. For example, it could be argued that although the central executive is believed to be responsible for the
inhibition of irrelevant information, this activity is not necessarily involved if a particular task does not make heavy demands on inhibition. The fact that processes such as inhibition and shifting can be part of working memory may account for the overlaps in the memory and attention literature.

Also worth noting, is that the processes that may play a role in the developmental changes observed in working memory are interdependent. For example, increase in knowledge in a specific domain may strengthen relations between related concepts thus increasing processing efficiency, which would in turn increase the amount of available resources that can be used for storage. Finally, this increased storage capacity could be used to increase knowledge in a particular domain! Alternatively, increasing processing efficiency could increase the amount of available resources that could be used to experiment with a more advanced strategy, perhaps liberating further attentional resources that can be used to inhibit irrelevant information. Thus, it is clear that any or all of these processes could combine to support the developmental changes observed in working memory. We now turn to the timeline of these developmental changes. Then, hypotheses will be presented regarding how the processes described above could be influenced by bilingualism.

1.6 Timeline of Developmental Changes in Working Memory

Diamond (2002) states that improvements with age on simple memory tasks (without demands for manipulation of information or inhibition) are not seen after 7 years of age. However, improvements after 7 years of age and into adulthood are seen in speed of processing and ability to use strategies. Improvements are also
noticed in the ability to hold information in mind and work with it (i.e. working memory). For example, from age 7 to 13, forward digit span increases by 1.5 digits whereas backward digit span increases by 3 digits (Diamond, 2002). The ability to hold information in mind and exercise inhibition also increases during school years and through adulthood. Davidson, Cruess, Diamond, O’Craven & Savoy (1999) found that the ability to respond to the color of a stimulus while inhibiting position cues (see Simon task described below) increases linearly from 4 to 26 years of age (as cited in Diamond, 2002, p. 488). These developmental changes are paralleled in the development of the frontal cortex where the amount of white matter increases linearly from 4 to 13 years of age (Diamond, 2002). Thus, it seems that if developmental changes in working memory occur through school years, and if working memory is influenced by bilingualism, a possible bilingual advantage in this domain should be observable throughout those years.

1.7 The Development of Working Memory and Bilingualism

As reviewed above, many different processes could affect developmental changes in working memory, namely, increase in knowledge, changes in processing strategies, changes in processing speed, and changes in the use of attention. To date, two of these areas have been examined and identified as areas of potential strength in bilingual children.

1.7.1 Knowledge

As reviewed above, Cowen (1997) argues that increased knowledge could facilitate the integration of elements to be remembered, allowing more information
to be stored in ‘chunks’. Use of chunking strategies will decrease the amount of resources needed to remember a given amount of information. Landry (1978) proposes that the bilingual child progresses in an environment containing two linguistic codes, two cultures, and two worlds of experiences and needs to develop strategies to unify these experiences to create a unified perspective on the world. This dual experience environment could thus contribute to expand the bilingual children’s breadth of knowledge and promote the development of more broadly interconnected chunks of information.

1.7.2 Control of attention

Cowen (1997) also suggests that increase in control of attention could contribute to the changes in working memory observed throughout development. Diaz and Klinger (1991) used Vigotsky’s theory of thought and language to explain the possible bilingual advantage. They argue that the exposure to two languages leads to an objective awareness of language, which is observed in the bilingual’s advantage on metalinguistic tasks (Hakuta, 1987; Bialystok, 1988; Bialystok, 1992, Bialystok, 1999; Bialystok, 2001; Bialystok, Mjumder, & Martin, 2003). They propose that this awareness may include non-communicative functions of language (i.e. self-regulation, attention). If so, they state that this enhanced awareness could lead bilingual children to increase their use of language as a tool of thought resulting in better performance on verbal and non-verbal tasks.

Alternatively, Landry (1978) proposes that a bilingual environment could facilitate variable encoding with linguistic contexts acting as different contexts in which information is learned. That is, bilingual children may have more opportunity
to learn similar information in different languages, increasing the variable encoding possibilities. The encoding of information in multiple contexts is thought to improve recall of material (Landry, 1978). If analyzed through a connectionist framework, it could be hypothesized that bilingualism, in so far as redundant networks are established through each of the language sources, helps to strengthen relations between concepts and thus facilitates more efficient processing. As mentioned earlier, when processing is more efficient, more attentional resources are available for storage or other resource demanding tasks such as attention shifting or inhibition.

Also fitting this category is the argument by Bialystok (2001) and Bialystok and Martin (in press) who maintain that bilingual children have more experience at controlling attention because of the need to inhibit one language when the other is being used. This idea is in line with Green’s (1998) inhibitory control model of bilingual language production. It is unclear whether this ability is specific to inhibition or whether it suggests a more general improvement in attentional control.

1.7.3 Summary of the development of working memory and bilingualism

To summarize, if bilingual children are at an advantage in performing working memory tasks, four different mechanisms could explain this advantage. First, the dual context in which the bilingual children evolve could contribute to increasing their breath of knowledge, which in turn could facilitate integration of information to be remembered in a working memory task. Second, bilingual children, because of their increased metalinguistic awareness, could be more inclined to use language as a tool of thought. This could help them focus their attention on relevant components of a task. Alternatively, a bilingual environment
may increase the possibility for variable encoding, which could strengthen relations between concepts and render general processing more efficient. As processing is more efficient, it requires less resources and more resources are available for storage or other resource demanding tasks. Finally, the experience of having to inhibit one language when using another could have an effect on bilingual children's ability to keep irrelevant information out of the working memory space.

1.8 Methodological Limitations in Bilingual Advantage Studies

Methodological problems have contributed to the uncertainties surrounding the bilingual advantage. These have included the absence of a monolingual control group (Hakuta, 1987), the assessment of language abilities in only one language (Bialystok, 1999; Bialystok & Codd, 1997; Bialystok & Martin, in press; Kormi-Nouri, Moniri, & Nilsson, 2003), and the assessment of abilities using only a receptive vocabulary test (Bialystok, 1999; Bialystok, 1988; Bialystok & Martin, in press; Bialystok, Martin, & Viswanathan, in press; Kormi-Nouri, Moniri, & Nilsson, 2003).

These methodological limitations may obscure our understanding of the processes underlying the bilingual advantage in many ways. First, when no monolingual control group is included, children may be compared on their level of proficiency in L2. When the more proficient bilinguals are found to have a cognitive advantage, it is impossible to determine whether they became more proficient because they were more cognitively advanced in the first place or became more cognitively advanced due to their high level of proficiency in two languages. Use of a monolingual comparison group would avoid this interpretative problem.
Second, when language abilities are assessed in only one language, the bilingual children’s language abilities are not fully assessed. In fact, Pearson, Fernandez, & Oller (1993) state that “any language measure based on only one language will fail to credit the child with knowledge unique to the “other” language” (p. 114). This is due to the fact that although bilingual children often have many translation equivalents between their languages, some words are known in one language only. This is true even when children are assessed in their dominant language as most bilingual children have singlets (words with no known translation equivalent in the other language) even in their weaker language (Umbel, Pearson, Fernandez, Oller, & Molinet-Molina, 1992). Additionally, assessing bilingual children in only one of their languages makes it impossible to determine their relative proficiency in each language and the degree to which they are bilingual. This could result in a very heterogeneous group of bilingual children. Wei (2000) identified over 30 types of bilingualism. The description of the different types is beyond the scope of this paper but it suggests that careful description of the participant’s language abilities is essential in bilingual research.

Finally, only assessing language abilities using a receptive vocabulary test can lead to spurious group comparisons. Bilingual children will frequently score lower than age peers on a vocabulary test in either of their languages (Ben-Zeev, 1977; Bialystok, 1988; Bialystok, Martin, & Viswanathan, in press; Rosenblum and Pinker, 1983; Umbel, Pearson, Fernandez, Oller, & Molinet-Molina, 1992). This pattern can be explained by the fact that bilingual children’s language exposure time is split between two languages, and thus vocabulary (when only one of their language is assessed) may lag behind the vocabulary of age matched monolingual
children (Oller & Pearson, 2002; Pearson, Fernandez, Lewedeg, & Oller, 1997; Schaerlackens, Zink, & Verheyden, 1995). In contrast, grammar development is more robust to differences in time of exposure, and bilingual children are more likely to perform as well as their monolingual peers in this domain (Bialystok, 2001; Paradis & Genesee, 1996). This is especially true for older children, as grammatical knowledge involves a finite set of schemes. Although bilingual children may experience a delay in grammar development in the early stages of language learning, they are observed to catch up to their monolingual peers as they reach this ceiling in grammar development. Vocabulary development, on the other hand, is infinite and the difference in vocabulary size between monolinguals and bilinguals may persist throughout the school years and beyond.

The current study is designed to avoid these methodological problems and hence yield more interpretable results. First, a French monolingual control group as well as a French-English bilingual experimental group will be used. Secondly, both vocabulary and grammar abilities are assessed to evaluate language abilities. Finally, language abilities will be assessed using tests available in both English and French, thus allowing judgements of the relative proficiency of bilingual children in each of their languages.

1.9 The Current Project

Research to date suggests that a bilingual advantage exists on certain cognitive tasks. The goal of the present study is to further investigate the relationship between bilingualism and cognition by focusing on both auditory-verbal and visuo-spatial working memory processes. The hypothesis is that bilingualism
may accelerate working memory development through one or a combination of processes discussed above. It is hypothesised, based on Baddeley's (1986) model of working memory, that if resource demands are increased through storage or processing load, a bilingual advantage will emerge on a task that doesn't make high demands on attentional control (shifting and/or inhibition). As discussed above, working memory abilities develop through the school years. If this is so, a bilingual advantage should be observable throughout school years. If a difference were indeed found between monolingual and bilingual performance on this type of task, it would suggest the existence of a different or broader bilingual advantage than previously reported in the literature. Failing to find a difference would support Bialystok and her colleagues' contention that the most important aspect of the bilingual advantage is primarily based on attentional control.
2 Method

In order to investigate the relationship between bilingualism and cognition, this study compared the performance of French monolingual children and French-English bilingual children on three processing tasks, one looking at inhibitory abilities, the other two looking at working memory.

2.1 Description of Participants

Sixty-two children, aged 8;5 to 10;4, participated in this study. Thirty-one were French monolinguals and 31 were French-English bilinguals, and children in the two groups were matched for age and gender. An additional 5 French monolingual children were tested to optimize age matching, but were not included in the analysis. The bilingual (B) children were recruited through the French school board of British Columbia (Conseil scolaire francophone de la Colombie-Britannique) and were attending three schools located in the Vancouver area. All three schools use French as the exclusive language of instruction. 31 French-English bilingual children were included, ranging in age from 101 months (8 years, 5 months) to 122 months (10 Years, 2 months) ($M = 110$ months, $SD = 6.63$). The monolingual (M) children were recruited in Québec through the Victoriaville school board (Commission Scolaire de Victoriaville). A total of 31 French monolingual children were included, ranging in age from 103 months (8 years, 7 months) to 124 months (10 Years, 4 months) ($M = 112$ months, $SD = 6.64$). There was no significant difference in age between the two groups, $t (60) = 0.78$, $p > .05$. 
2.1.1 Operationalizing bilingualism and monolingualism

Parents of the participating children were asked to complete a language use questionnaire (see Appendix A). Parent report confirmed that the children included in the bilingual group used both French and English in daily communication and that if one language had been introduced after the other it had been before the age of 3 (5 in the case of one child). The children in the monolingual group lived in a strictly French community. However, nowadays, it is very unlikely to find monolingual participants who have no exposure to another language. Thus, the children included in the monolingual group in this study were occasionally exposed to English television and had been attending 1 hour/week English as a second language classes for a period of one year or less (as part of the regular curriculum). Parent report confirmed that the children’s exposure to another language was minimal and that none of the children included in the monolingual group could speak or understand English in a functional manner. Both teacher and parent’s report confirmed that the children included in this study had no language, learning, or hearing difficulties.

2.1.2 Descriptive measures

2.1.2.1 Test of Non-verbal Intelligence (TONI)

All children included in this study obtained non-verbal IQ scores of 84 or greater, as indicated by scores on the Test of Nonverbal Intelligence (TONI) (Brown, Sherbenou, & Johnsen, 1997); M (M = 101.61, SD = 12.17), B (M = 114.29, SD = 18.10). There was a significant group difference on TONI scores, t
(60) = -3.24, p < 0.05, with the bilingual children scoring significantly higher than the monolingual children on this task.

2.1.2.2 Échelle de Vocabulaire en Image Peabody (EVIP)

The EVIP is a standardized test of French receptive vocabulary (Canadian French adaptation of the Peabody-Picture Vocabulary Test-Revised (PPVT-R). This test was administered to all children to compare their French language ability. All children obtained French vocabulary standard scores of 82 or greater (i.e. > -1.2 SD), with the exception of one bilingual child who obtained a score of 72; M (M = 119.61, SD = 11.55), B (M = 108.10, SD = 16.08). There was a significant group difference on French receptive vocabulary scores, t (60) = 3.24, p < 0.05, with the monolingual group outperforming the bilingual group.

2.1.2.3 The Carrow-Woolfolk-Test de comprehension

The Carrow-Woolfolk-Test de comprehension is a French adaptation of the Test for Auditory Comprehension of Language - Revised (TACL-R). No norms are available for the age group of children in this study. The Phrase complexes (Elaborated Phrases and Sentences) subtest was administered to all children to compare their French language grammatical abilities. In this task, children listened to sentences and were asked to pick the corresponding picture out of a set of three pictures. The sentences were graded in grammatical complexity. Using total number correct as the dependent variable, a score out of 25 was compiled for each child, M (M = 19.77, SD = 2.42), B (M = 20.42, SD = 2.55). There was no significant difference between groups on this measure t (60) = -1.02, p > 0.05.
2.1.2.4 Peabody-Picture Vocabulary Test-Revised (PPVT-III)

The PPVT-III is a standardized test of English receptive vocabulary. This test was administered to the bilingual children in order to assess their English vocabulary level as well as their relative competency in their two languages. All children in the bilingual group scored 81 (i.e. -1.27 SD) or higher on the English receptive vocabulary test (M = 107.06, SD = 13.96).

2.1.2.5 Test for Auditory Comprehension of Language - Revised (TACL-III)

The TACL-III is a standardized test of English auditory language comprehension. The Elaborated Phrases and Sentences subtest was administered to the bilingual children to evaluate their competency in a receptive grammar task. In this task, children listened to sentences and were asked to pick the corresponding picture out of a set of three pictures. The sentences were graded in grammatical complexity. All children in the bilingual group scored 8 (i.e. -.67 SD) or above on this test (M = 11.19, SD = 1.53).

2.2 Experimental Tasks

All children completed one experimental attentional control task as well as two working memory tasks. These tasks were administered in French for all children. One working memory task tapped auditory-verbal working memory and the other focused on visual-spatial working memory. These three tasks were presented using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b) on a Dell Notebook with a screen size of 9” x 12”. All auditory information was presented using headphones at a volume level each child deemed comfortable.
2.2.1 Simon task

The Simon task (See Lu & Proctor, 1995, for a review) was used by Bialystok, Martin, & Viswanathan (in press) to investigate the effect of bilingualism on the control of attention across the lifespan. The version of the task used in this study was the one used by Bialystok, Martin, & Viswanathan (in press) to test 5 year-old children. Participants were instructed to press a red button (attached to the “1” key) when a red square appeared on the computer screen, and to press a blue button (attached to the “=” key) when a blue square appeared on the computer screen. The red button was situated on the left and the blue on the right of the keyboard and the squares appeared on either side of the screen one at a time. Congruent and incongruent trials were randomly presented. A congruent trial consisted of a red or blue square appearing on the same side as its respective button. An incongruent trial consisted of a red or blue square appearing on the opposite side of its respective button (see Appendix B for a figure representing an incongruent trial). After 4 practice trials encompassing all conditions (congruent red, incongruent red, congruent blue, incongruent blue) were presented, 36 (18 congruent-18 incongruent) test-trials were randomly presented and response times were recorded. If children did not respond within 5500 msec, the trial ended and the next one began. Bialystok, Martin, Viswanathan (in press) found a bilingual advantage when five year old children were administered this task. This task was used to attempt to replicate their results with slightly older children (8-10 year olds).
2.2.2 **Auditory processing task**

This task was originally designed by Moser (2003) as an adaptation of Montgomery’s (2000a) working memory task in his exploration of Baddeley’s (1986) model of working memory.

2.2.2.1 **Stimuli**

Twenty-seven words were used in the auditory-verbal working memory task. Thirteen of the words represented objects that would fit into a box (measuring 8 ½ x 3 ¾ x 4 ½) that was available to the child during the experiment (e.g. ‘pomme’ (apple), ‘brosse’ (brush), ‘montre’ (watch). Fourteen of the words chosen represented objects that would not fit into that box (e.g. ‘lit’ (bed), ‘chien’ (dog), ‘train’ (train).

The stimuli words chosen have an age of acquisition of 30 months or less, as measured by a French Canadian adaptation (Trudeau & Boudreault, unpublished data) of the MacArthur Communicative Development Inventory (Dale & Fenson, 1996). This early acquisition criterion was chosen for two reasons. First, it has been suggested that bilingual children, because they have to share their time between two different languages, may show a delay in vocabulary acquisition in one language (Oller & Pearson, 2002; Pearson, Fernandez, Lewedeg, & Oller, 1997; Schaerlackens, Zink, & Verheyden, 1995). Use of early-learned words reduced the likelihood that any group differences merely reflected differences in word familiarity. Secondly, Morrision, Ellis, and Quinlan (1992) found that words acquired early are retrieved from lexical memory more easily than words acquired later. Again, the use of early-learned words minimized the lexical retrieval costs for
children in both groups. For one word ‘suce’ (pacifier), the age of acquisition data was not available from this source but it was rated as being one of the first 250 words acquired by the Guide D’Intervention en Réadaptation Auditive (GIRAFE) (Bergeron & Henry, 1994). Other lexical factors such as imageability, name agreement, frequency, and neighborhood density are known to influence recall (Morrison, Chappell, & Ellis, 1997). However, French language data on these variables is not yet available for children, preventing their use in the choice of French stimulus words.

All words were recorded by an adult female native French-speaker using list intonation. Words were spoken directly into a head mounted microphone and recorded on HP N5270 computer using Cool Edit 2000 software (1999-2000) at a sampling rate of 44,400Hz. Each word was recorded 3 times and the best exemplar of each word was chosen by the two experimenters for inclusion in the word list. Once the word list was constructed, it was normalized to 50% of maximum amplitude so that all words had approximately the same intensity.

2.2.2.2 Pre-test

A preliminary activity ensured that children knew the words to be used in the task and could categorize the words’ referents as fitting or not fitting in a box available to them during the experiment. In this preliminary exercise, the children were given 27 line drawings (on 3 ½ x 3 ½ cards) representing the words to be used in the verbal processing task. Twenty-one pictures were taken from the Snodgrass
Vanderwart set, developed by Rossion and Portois (2001) and 6 pictures were taken from Boardmaker (computer software, Maeyer-Johnson Inc.). Appendix C provides samples of pictures from both sources. Each child was instructed to look at the pictures and think of the real objects they represented. The child was asked to name each picture and to decide whether the real object represented by the picture would fit in a turquoise box (8 ½ x 3 ¾ x 4 ½) available to him to manipulate. He was instructed to put the picture in the box if he believed that the object it represented could fit in the box and to put the picture outside the box if he believed it wouldn’t fit. In rare occasions during this exercise, children misclassified items (e.g. ‘pelle’ (shovel) or ‘nez’ (nose)). However, after brief discussion with the experimenter (about the kind of shovel they should think about or the fact that if they could take only their nose it would fit in the box) the children were satisfied with the classifications. On some occasions children used a synonym to name items (e.g. ‘baignoire’ for ‘bain’ (bath), ‘chimpanzé’ for ‘singe’ (monkey), or ‘chaussette’ for ‘bas’ (sock). In those cases, the experimenter explained that for the purpose of this game they would call it ‘X’. Children agreed promptly and used the given names thereafter. Once the cards were classified, the experimenter and the child reviewed the items for each category in turn, i.e. fitting or not fitting in the box, by naming each item as it would be heard in the auditory processing task, (i.e. without the articles).

1 Images provided courtesy of Michael J. Tarr (Brown University, Providence, RI). Downloaded from http://www.cog.brown.edu/~tarr/stumuli.html.
2.2.2.3 Test

In the auditory processing task, children listened, through headphones, to a series of words (3-7 words) and were asked to group the words by size of referent prior to repeating them. Each list of words was constructed so that no two words belonged to the same category, i.e. clothing, body part, food, household items, toy, animal, nature. On any given trial, half (or nearly half) the words referred to items that would fit in the box and half (or nearly half) referred to items that would not fit in the box. The order of words in each list was randomized, but once constructed, the same lists were presented to each child in the same order. Children were instructed to repeat all of the words referring to objects that would fit in the box while pointing to a turquoise box on the computer screen, and all of the words referring to objects that wouldn’t fit in the box while pointing to an X on the computer screen (See Appendix D for an illustration). The order of mention for the two categories was unconstrained. They could chose to repeat the objects fitting in the box first and the objects not fitting in the box second, or vice versa.

The children pressed the space bar to start a trial, and a bell warned them that the series would be presented. While the words were being presented, the computer screen was black. Once the series had been presented a turquoise box and an ‘X’ appeared on the computer screen and the children responded. Initially, the experimenter demonstrated the task by completing 2 trials containing a list of three words. Then each child completed 2 practice trials containing a list of 3 words to insure that they understood the instructions. If a child alternated between the box and the ‘X’ within a practice-trial they were reminded that they needed to recall all of
one kind of words before the other kind of words. All children demonstrated understanding of the task before the test-trials began.

Initially, each child completed 6 trials containing a series of 3 words. If the child was successful on 4 of those 6 trials, he was informed that more words would be presented in the series, and 6 trials containing a list of 4 words were presented. If the child was successful on 4 of those trials, the number of words increased to 5 for the 6 following trials. This pattern continued until a child was successful on fewer than 4 trials on any given level, or when a child reached the highest level (7 words). If a child was successful on less than 4 trials on a given level, two trials at the next level were presented. If the child was unsuccessful on these two trials, the task was discontinued. If the child was successful on one of these two trials, the remaining four trials at that level were presented. This precaution was taken to ensure that a child’s span was not underestimated. A child’s span was calculated as the highest level at which he performed successfully on at least 4 trials. The number of overall successful trials was also calculated.

2.2.3 Visual processing task

As was true for the auditory-verbal processing task, this task was used by Moser (2003), was based on ideas of Montgomery (2000a) in his exploration of Baddeley’s (1986) model of working memory.

2.2.3.1 Stimuli

The stimuli consisted of 3-dimensional green shapes presented within a 4X4 square grid, one item per cell. There were 9 different shapes in all, each chosen from
the 3D part-based object database\(^2\) of Tarr M.J. (2004) and judged to be difficult to provide a label for. Across trials, the number of grid cells filled with objects varied between 3 and 7. Placement within the grid was constrained to minimize overall familiar patterns such as filled rows, columns, diagonals, symmetrical organization, or four corners. These precautions were taken to minimize the possibility that children could use familiar patterns as a coding strategy. Kemps (1999) found that the complexity of a visual pattern can be affected by two factors: quantitative and structural. In this task, complexity was manipulated by increasing the number of items included in a grid (quantitative complexity). We attempted to keep structural complexity constant by avoiding patterns that could be easily recognized.

2.2.3.2 Test

Four trials were presented per span level (3-7). The task was discontinued when a child failed all items contained in a given span level. Two different shapes were used on each trial. The shapes were randomly chosen from a set of 9 different shapes each time the task was administered. Thus, all children were presented with randomly chosen shapes on each trial. Children were instructed to remember the location of the shapes, by type. The filled grid was presented for 3500msec, followed by a 500 ms. black screen interval. Then, a grid filled with question marks would appear accompanied by the two shapes that had just been presented in the previous grid. Appendixes E and F provide an example of an encoding screen and a retrieval screen used in this task. Children were required to point to one shape and to the location of all objects of that type before pointing to the other shape and the

\(^2\) Images provided courtesy of Michael J. Tarr (Brown University, Providence, RI). Downloaded from http://www.cog.brown.edu/~tarr/stimuli.html.
locations of all of the objects of that type. They could choose to start with either of the two shapes. A child’s span was calculated as the highest level at which she performed successfully on at least 3 trials. The number of overall successful trials was also calculated.

Initially, the experimenter demonstrated the task by completing 2 trials containing three shapes. Then each child completed 2 practice-trials containing 3 shapes to insure that they understood the instructions. If a child alternated between the type of shape when recalling their location, they were reminded that they needed to recall the location of all one type of shape before the other type. All children demonstrated understanding of the task before the test-trials began.

2.3 Order of Task Presentation

The tasks were administered in 2 or 3 sessions (3 for the bilingual children) within a two-week period. The tasks were presented in a constant order except for the working memory tasks; the Auditory-Verbal Working Memory task (AVWM) was presented first for half the children and the Visual-Spatial Working Memory task (VSWM) was presented first for the other half. The order of task presentation was the following: EVIP, Carrow, TONI, SIMON, AVWM or VSWM, PPVT, TACL. The two last tasks were only administered to the bilingual children.
3 Results

3.1 Analysis Strategy

The purpose of this study was to investigate executive functions and working memory in bilingual children. First, this study aimed to replicate Bialystok, Martin, & Viswanathan’s (in press) finding that bilingual children had faster RTs on the Simon task, a task focusing on inhibitory abilities. Second, this study aimed to investigate the possible relationships between bilingualism and working memory abilities in both the auditory-verbal and the visual-spatial modality. Finally, the study aimed to address possible associations between inhibitory skills and working memory skills.

In order to answer the first research question, performance of the two groups on each condition (congruent and incongruent trials) of the Simon task will be compared using an Analysis of Variance (ANOVA) procedure. To answer the second question, the performance of the two groups on both the auditory and visual working memory tasks will be compared using an ANOVA procedure. Since we cannot assume psychological equivalence of the two tasks, memory performance will be examined using z scores to allow for a comparison of performance in the two modes. Finally, correlational analysis will be used to examine the association between the inhibition task (Simon) and the working memory tasks.

3.2 Inhibitory Task (Simon task)

The first analysis was designed to assess the differences between monolingual children and bilingual children’s performance on a task focusing on
abilities to inhibit irrelevant information. Only the reaction times (RT) of correct responses were included in the analysis. Number of trials deleted due to error and percent accuracy are provided in Table 2.1, and are equivalent for children in the two groups. Before performing the analysis, the data were trimmed to remove extreme outliers. The Means (M) and Standard Deviations (SD) were calculated for RTs of each group in each condition i.e. congruent and incongruent trials. Any trial RT falling above or below 3 SD from the mean of the particular group and condition was excluded from the analysis. This procedure is often used in RT research (Miyake, Friedman, Emerson, Witzki, and Howarter, 2003) to remove the influence of RTs that are unusually short or long due to factors such as inattentiveness or environmental distraction. No trial RT was found to fall below 3 SD from the Mean. Table 2.1 shows the number of trial RTs more than 3 SD above the Mean that were eliminated due to trimming for each group in each condition. Again, no group differences are evident.

Table 2.1 Number of Error Trial RTs (% accuracy) and Number of trimmed trials (% of data excluded by trimming) for each group in each condition.

<table>
<thead>
<tr>
<th>Group</th>
<th>Error Trials (% accuracy)</th>
<th>Trimmed trials (% of data)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congruent</td>
<td>Incongruent</td>
</tr>
<tr>
<td>Monolingual</td>
<td>18 (96%)</td>
<td>55 (90%)</td>
</tr>
<tr>
<td>Bilingual</td>
<td>22 (96%)</td>
<td>55 (90%)</td>
</tr>
</tbody>
</table>
Means and standard deviations for the reaction times (RT) of each group on the two conditions of the Simon task, i.e. congruent and incongruent, appear in Table 2.2.

Table 2.2 Mean (SD) RT in the Simon task for monolingual (M) and bilingual (B) children.

<table>
<thead>
<tr>
<th>Group</th>
<th>Congruent M, (SD)</th>
<th>Incongruent M, (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolingual</td>
<td>656.74 (15.06)</td>
<td>699.75 (16.83)</td>
</tr>
<tr>
<td>n = 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>611.71 (15.06)</td>
<td>648.15 (16.83)</td>
</tr>
<tr>
<td>n = 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both Groups</td>
<td>634.22 (85.53)</td>
<td>673.95 (95.70)</td>
</tr>
<tr>
<td>N = 62</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These results indicate that the bilingual children had shorter RTs than the monolingual children in both the congruent and the incongruent conditions. Also, both groups obtained shorter RTs in the congruent condition compared to the incongruent condition. Statistical tests were conducted to test the reliability of these findings. Preliminary tests for homogeneity of variance (Levene, p > .05) indicated that this distribution assumption had been met. Therefore, differences between the B and M groups on the Simon task were analysed using a two-way mixed model ANOVA with one between subject factor (Group) and one within subjects factor (Condition).

The ANOVA yielded a main effect of group, $F = 5.19; df = 1, 60; p < 0.05$. Bilingual children obtained faster reaction times (performed better) than their monolingual peers. Cohen’s $d$ for this effect was .53, indicating a “medium” effect size (Cohen, 1988). There was also a significant main effect of condition, $F = 26.27$;
df = 1.60; p < 0.01. Cohen's d for this effect was .43, again indicating a 'medium' effect size (Cohen, 1988). Across groups, children performed better (faster RTs) in the congruent than in the incongruent condition. There was no significant interaction between group and condition, F = 0.18; df = 1.60; p > 0.05.

3.3 Working Memory Tasks

The next analysis investigated the working memory (WM) skills of bilingual children in comparison with their monolingual peers. Both span level and overall number of correct answers was calculated for each child on each WM task. However, half of the children did not reach the criterion for the lowest span level on one or the other of the memory tasks, creating floor effects that would limit the analysis. Therefore, the number of correct items rather than span level was used as the dependent variable in the analyses. This score showed considerable variance even among the children who failed to reach span criteria and reduced the floor effect. This was confirmed by statistical tests of the distribution of this variable (Shapiro-Wilk's W) which did not indicate deviation from normality for either task.

Although they are both measures of working memory, the auditory-verbal and the visual-spatial tasks are different in the nature of the items being remembered and manipulated. Thus, it is impossible to determine whether all aspects of each task are psychologically equivalent. For this reason Z-score equivalents of number of items correct were computed based on the distribution of scores across all participants. This transformation enabled a valid comparison of the children's performance across the two modalities i.e. the auditory-verbal and the visual-spatial tasks.
Means and standard deviations for the number correct and z-scores of each group on the two working memory tasks, i.e. auditory-verbal and visual spatial, appear in Table 2.3 and 2.4.

Table 2.3 Mean (SD) Number Correct in the Working Memory (WM) tasks for monolingual (M) and bilingual (B) children.

<table>
<thead>
<tr>
<th>Group</th>
<th>Auditory-Verbal WM M, (SD)</th>
<th>Visual-Spatial WM M, (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolingual</td>
<td>8.03 (2.81)</td>
<td>4.10 (2.89)</td>
</tr>
<tr>
<td>n = 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>9.97 (2.98)</td>
<td>6.81 (2.88)</td>
</tr>
<tr>
<td>n = 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both Groups</td>
<td>9.00 (3.04)</td>
<td>5.45 (3.17)</td>
</tr>
<tr>
<td>N = 62</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.4 Mean (SD) z-scores in the Working Memory (WM) tasks for monolingual (M) and bilingual (B) children.

<table>
<thead>
<tr>
<th>Group</th>
<th>Auditory-Verbal WM M, (SD)</th>
<th>Visual-Spatial WM M, (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolingual</td>
<td>-0.32 (0.93)</td>
<td>-0.43 (0.91)</td>
</tr>
<tr>
<td>n = 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>0.32 (0.98)</td>
<td>0.43 (0.91)</td>
</tr>
<tr>
<td>n = 31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both Groups</td>
<td>0.00 (1.00)</td>
<td>0.00 (1.00)</td>
</tr>
<tr>
<td>N = 62</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Inspection of the means reveal that the bilingual group obtained higher scores than their monolingual peers on both working memory tasks. Statistical tests were computed to test the reliability of these findings. Preliminary tests of homogeneity of variance (Levene, p > .05) indicated that this distribution assumption had been met. Therefore, differences between the B and the M groups on the working
memory tasks were analysed using a two-way mixed model ANOVA with one between subjects factor (Group) and one within subjects factor (Mode).

The ANOVA yielded a main effect of group, $F = 16.64; \text{df} = 1,60; p < 0.01$. In comparison with their M peers, B children obtained higher working memory scores. Cohen’s $d$ for this effect was .81, indicating a ‘large effect’ (Cohen, 1988). The use of the $z$-scores eliminated the possibility of a main effect of Mode and focuses the analysis on the interaction. No significant interaction between group and mode was present, $F = 0.52; \text{df} = 1,60; p > 0.05$.

### 3.4 Correlating Language Performance with Inhibition and Working Memory

In order to further explore the nature of the findings regarding inhibition and working memory skills, the correlations between these experimental tasks and language performance was investigated. The French receptive vocabulary measure (EVIP) and the French grammar measure (Carrow) were significantly correlated $r = 0.26$. Thus, a composite language score was created by averaging the scores earned on the French vocabulary (EVIP) and grammar (Carrow) tests. The resultant composite index of language proficiency did not predict performance on either the memory or the inhibition tasks. The correlation coefficients ranged from -.05 to -.11 for the inhibition task and from .11 to .23, for the memory tasks. None were statistically significant.

### 3.5 The Effect of Language Dominance on Inhibition and Working Memory

The next analysis investigated the inhibition (I) and working memory (WM) skills of bilingual children as they relate to their relative language proficiency in...
each language. The scores of the children in the bilingual group on the French and the English receptive vocabulary tests were compared to determine language dominance. Thirteen children could be considered balanced bilinguals as their scores on each test fell within one half standard deviation of one another. Eighteen children obtained scores falling beyond one half SD of one another suggesting that these children were dominant in either French or English (12 English dominant, 6 French dominant). From this data, two groups were created. The 13 children whose two vocabulary scores fell within one half SD of one another formed the Balanced Group. Out of the 18 other children, the 13 children whose two vocabulary scores were furthest apart from one another were chosen to form the Dominant Group. Of this group, 4 were French dominant and 9 were English dominant. The two groups did not significantly differ in age, t (24) = 1.76, p > .05. Also they did not significantly differ on their performance on the Test of Non-verbal Intelligence (TONI), t (24) = 0.75, p > .05.

To investigate the effect of relative language proficiency on inhibition skills, composite scores, including the RTs for both the congruent and the incongruent trials from the Simon task, were created by adding the two scores together. Using these composite scores the two groups were compared on their overall performance on the Simon task. The balanced group obtained a Mean RT of 1182 ms (SD 158.17) and the dominant group obtained a Mean RT of 1335 ms (SD 206.99). Inspection of the means reveals that the balanced children had shorter RTs (performed better) than the dominant children on the Simon task. A Statistical test was conducted to test the reliability of this finding. A T-test demonstrated that the Mean RTs of the two groups were significantly different, T (24) = 2.12, p < 0.05. The balanced children
obtained faster reaction times (performed better) than their dominant peers. Cohen's $d$ for this effect was 0.84, indicating a "large" effect size (Cohen, 1988).

The balanced and the dominant groups were also compared on their performance on the working memory task. As in a previous analysis, Z-scores were used to compare the groups on these two working memory tasks. Means and standard deviations for the z-scores of each group on the two working memory tasks, i.e. auditory-verbal and visual spatial appear in Table 2.5.

Table 2.5 Mean (SD) z-scores in the Working Memory (WM) tasks for Balanced and Dominant Children.

<table>
<thead>
<tr>
<th>Group</th>
<th>Auditory-Verbal WM $M$, (SD)</th>
<th>Visual-Spatial WM $M$, (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balanced n= 13</td>
<td>0.60 (0.87)</td>
<td>0.70 (1.00)</td>
</tr>
<tr>
<td>Dominant n= 13</td>
<td>0.38 (1.61)</td>
<td>0.40 (0.90)</td>
</tr>
<tr>
<td>Both Groups N = 26</td>
<td>0.00 (1.00)</td>
<td>0.00 (1.00)</td>
</tr>
</tbody>
</table>

Inspection of the means reveals that the balanced group obtained higher scores than their dominant peers on both working memory tasks. Statistical tests were computed to test the reliability of these findings. Preliminary tests of homogeneity of variance (Levene, $p > .05$) indicated that this distribution assumption had been met. Therefore, differences between the balanced and the dominant groups on the working memory tasks were analysed using a two-way mixed model ANOVA with one between subjects factor (Group) and one within subjects factor (Mode).
The ANOVA yielded no main effect of group, $F = 0.73; \text{df} = 1,24; p > 0.05$. Although the trend suggests that the balanced bilinguals performed better than the dominant bilinguals, no significant difference was found between the two groups. The use of the z-scores eliminated the possibility of a main effect of Mode and focuses the analysis on the interaction. No significant interaction between group and mode was present, $F = 0.02; \text{df} = 1,24; p > 0.05$.

3.6 Correlating Inhibition, Working Memory Skills, and IQ

The final set of analyses investigated the correlations among the various experimental measures, and between these measures and IQ. The correlations among the experimental measures were calculated as one indication of the independence of different aspects of executive function. Table 2.6 reports the Pearson product moment correlations between inhibition (I), as measured by the Simon task, and Working Memory (WM), as measured by the two working memory tasks.

Table 2.6 Correlations between the Simon task (RTs) and the Working Memory (WM) tasks (raw scores)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Simon (congruent)</th>
<th>Simon (Incongruent)</th>
<th>WM (Aud-Verb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simon (Incongruent)</td>
<td>*0.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WM (Aud-Verb.)</td>
<td>-0.12</td>
<td>-0.18</td>
<td></td>
</tr>
<tr>
<td>WM (Visual-Spatial)</td>
<td>-0.17</td>
<td>-0.23</td>
<td>*0.31</td>
</tr>
</tbody>
</table>

* = significant correlation ($p < 0.05$)

Inspection of the correlations suggests that there is virtually no relationship between Inhibition and Working Memory scores. However, there is a significant
correlation between the two conditions of the Simon task as well as a significant
correlation, albeit weak, between the two working memory tasks.

Finally, since the preliminary analyses had indicated group differences in
TONI (nonverbal) IQ scores, further post hoc analyses were conducted to determine
the degree to which this difference could explain group differences on the
experimental tasks. A theory-based argument against such explanations will be
presented in Chapter 4, but an empirical test of the possibility will serve as a context
for later argumentation. Correlations between TONI scores and performance on
either condition of the Simon task ranged from .06 to -.09, making further analysis
unnecessary. Correlations between TONI scores and the working memory tasks
ranged from .40 to .42, and were reliable at the p< .05 level.

In order to explore the role of non-verbal IQ in explaining working memory
results, the groups were equated on TONI performance by removing from the
analysis the subjects who obtained the lowest and highest scores (< 85, >128). This
procedure essentially created somewhat smaller groups of monolingual (IQM) and
bilingual (IQB) children matched on non-verbal intelligence (TONI scores,
Monolingual: $M = 102, SD = 8.11$; Bilingual: $M = 106.5, SD = 9.38$). There was no
significant difference between these groups on non-verbal IQ performance, $t (47) = -
1.8, p > 0.05$. The working memory data were then re-analysed using these new
equated groups.

Means and standard deviations for the z-scores of each equated group on the
two working memory tasks, i.e. auditory-verbal and visual spatial appear in Table
2.7
Table 2.7 Mean (SD) z-scores in the Working Memory (WM) tasks for IQ-matched monolingual (IQM) and bilingual (IQB) groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Auditory-Verbal WM M, (SD)</th>
<th>Visual-Spatial WM M, (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQM n = 27</td>
<td>-0.37 (0.16)</td>
<td>-0.41 (0.17)</td>
</tr>
<tr>
<td>IQB n = 22</td>
<td>0.16 (0.18)</td>
<td>0.44 (0.19)</td>
</tr>
<tr>
<td>Both Groups N = 49</td>
<td>0.00 (1.00)</td>
<td>0.00 (1.00)</td>
</tr>
</tbody>
</table>

Inspection of the means reveal that the bilingual group (IQB) obtained higher scores than the equated monolingual group (IQM) on both working memory tasks. Statistical tests were computed to test the reliability of these findings. Preliminary tests of homogeneity of variance (Levene, p > 0.05) indicated that this distribution assumption had been met. Therefore, differences between the IQB and the IQM groups on the working memory tasks were analysed using a two-way mixed model ANOVA with one between subjects factor (Group) and one within subjects factor (Mode).

The ANOVA yielded a main effect of group, F = 14.39; df = 1,49; p < 0.001. In comparison with the IQM group, the IQB group obtained higher working memory scores. The use of the z-scores eliminated the possibility of a main effect of Mode and focuses the analysis on the interaction. No significant interaction between group and mode was present, F = 0.81; df = 1,47; p > 0.05.
3.7 Summary of Major Findings

1) French-English bilingual children responded with faster reaction times than their monolingual French age peers on the Simon task, generally interpreted as a test of inhibition, or attentional control.

2) French-English bilingual children earned higher scores than their monolingual French age peers in both an auditory-verbal and a visual-spatial working memory task that required manipulation of stored information.

3) French language proficiency was not significantly correlated with performance on any of the experimental tasks (Simon, AWM, VWM).

4) Performance on the measure of inhibition (Simon task) and on the measures of working memory (AWM, VWM) were not correlated.
4 Discussion

The purpose of the current study was to compare the ability of bilingual children and their monolingual peers to perform tasks tapping into executive functions and working memory. Previous research had suggested that a bilingual 'cognitive advantage' exists, especially in tasks that focus primarily on attentional control. This study aimed to explore the possibility that the bilingual advantage extends to working memory, a domain in which there has been little prior work.

First, in order to replicate previous findings, a task believed to tap mainly into inhibitory abilities was used. Second, bilingual and monolingual children's performance was compared on two working memory tasks (one verbal-auditory task, one visual spatial task). In addition, the relationship between inhibition and working memory was explored. In the following discussion, the primary results of this study are discussed with reference to the current research literature on this subject. Finally, possible mechanisms underlying the bilingual cognitive advantage are presented and considerations for future research are discussed.

4.1 Inhibition

The first goal of this study was to replicate Bialystok, Martin, and Viswanathan's findings (in press) that bilingual children performed better than monolingual children on the Simon task. Recall that in this task children must ignore spatial cues and select the response button that corresponds only to the stimulus colour. Bialystok, Martin, and Viswanathan (in press) argue that because congruent and incongruent trials alternate randomly, this task requires constant
attentional control, especially inhibition. This interpretation is supported by the work of Miyake, et al (2000) whose Inhibition cluster included a similar Stroop-like task.

The current study yielded similar results to those obtained by Bialystok et al. (in press). Children in the Bilingual group responded more quickly than children in the Monolingual group on both the congruent and the incongruent trials of the Simon task. One could argue that if inhibition is underlying the bilingual advantage on this task, the advantage should be observed on the incongruent trials only. However, as discussed above, Bialystok et al. (in press) suggested that because the trials are randomly presented, the task in its entirety places high demands on attentional control. In order to ascertain that the bilingual advantage could not be explained by response speed regardless of inhibitory demands, Bialystok et al. (in press) replicated their findings using a control task. In this control task, the red and blue squares always appeared in the middle of the screen eliminating the high inhibitory demands. No difference in response speed was found between the monolingual and the bilingual groups on this control task. These results suggest that the bilingual advantage observed on the Simon task cannot be solely explained by speed of response but is rather related to inhibitory abilities.

Thus, the results of this study are in line with previous research reporting a bilingual advantage in tasks that primarily require attentional control. As well as confirming the existence of such advantage, this replication indicates comparability of the present sample with those reported elsewhere and validates further comparisons.
4.2 Working Memory

4.2.1 Summary of main findings

The second goal of this study was to explore monolingual and bilingual children's ability to perform on working memory tasks. The data indicate that bilingual children have an advantage over monolingual children when performing both auditory-verbal and visual-spatial working memory tasks.

4.2.2 Previous research

The results of the present study lend weight to the growing body of research that suggests that a bilingual advantage can be observed even in tasks where attentional control is not a primary requirement (Hakuta, 1987; Kormi-Nouri, Moniri, & Nilson, 2003; Whitaker, Rueda & Prieto, 1985). As mentioned in Chapter 1, prior studies of working memory had methodological limitations that invited further investigation. The present data suggests that despite their imperfect design, the results from those studies that found a working memory advantage in bilingual children were pointing in the right direction. Further research will be needed, but there does appear to be a bilingual cognitive advantage that extends beyond inhibition and, at the least, includes other working memory functions. This seems to counter Byalistok and her colleagues' conclusion that the observed bilingual advantage was based only on attentional control abilities. They came to this conclusion when they failed to detect a bilingual advantage in tasks that did not have a high demand for attention switching or inhibition. The apparent conflict between their data and the current findings suggests the need for a more detailed task
analysis. The next section will examine the different cognitive tasks that have been included in bilingual advantage studies - both the tasks that yielded a bilingual cognitive advantage and those that did not. In each case, the processes involved in completing the task will be identified in an attempt to resolve conflicting claims and determine the extent of the bilingual advantage.

4.2.2.1 Knowledge based tasks

Bialystok and Codd (1997) found no bilingual advantage in a task that required an understanding of cardinality. In their Sharing task, 4 and 5 year-old children were instructed to share an even number of items (i.e. candies, blocks, toy animals) between two stuffed animals. They were assisted in the process of dividing the items by being asked to give one to each animal in turn. Once the items were evenly shared, the child was asked whether both animals had the same amount. Then the child was asked to count the amount of items one animal had. After the child counted one pile and told the experimenter the number, the experimenter hid the other pile to prevent the child from counting and asked the child to say how many items the other animal had. Bialystok and Codd (1997) stated that because there were no distractions incorporated in this task and no misleading perceptual cues, analysis abilities rather than control abilities were being measured. To perform well on this task, children had to understand basic principles of cardinality, and deduce that if the items were evenly shared, the two animals must have the same number of items. Unlike tasks in which a bilingual advantage has been observed, this task would seem to make minimal demands on memory or attention. Rather it
measured the child’s knowledge of a particular quantity concept and its application in a reasoning task.

Similarly, in a study by Bialystok and Majumder (1998) no bilingual advantage was observed on a task that required knowledge of the concept of proportions. The task used in this study was a version of the Noelting Juice Task. In this task, children are presented with two displays, each containing a jug, a number of glasses of orange juice and a number of glasses of water. The children are then asked to imagine that the water and the orange juice in the glasses in each display were poured into their respective jug. They are then asked to determine which jug would have a stronger orange taste or whether they would taste the same. Bialystok and Mjumder (1998) acknowledge that some level of control is required for this task as children need to focus on the proportion of orange juice to water rather than look at the absolute number of glasses of orange juice or water. However, they argue that the ability to solve this task is ultimately determined by the child’s mental representation of proportion. Since the task measures the child’s knowledge of a particular concept as well as the ability to process information, Bialystok and Mjumder (1998) conclude that the task is a measure of analysis rather than control.

The results from these two studies suggest that there is no bilingual advantage on tasks that primarily measure the extent of knowledge of a particular concept (e.g. cardinality or proportions). This suggests that although the bilingual advantage extends beyond attentional control, it doesn’t encompass all of cognition.
4.2.2.2 Memory Tasks

To date, tasks primarily tapping into memory abilities have been included in at least five studies investigating the bilingual cognitive advantage, with mixed results. A closer look at the nature of the memory tasks suggests that it is possible to differentiate them into two categories. That is, tasks primarily requiring storage of information versus tasks requiring manipulation of information in addition to storage.

An example of a memory task that primarily requires the storage of information can be seen in a study by Bialystok (1999). In a Visually Cued Recall Task, a series of posters, each containing 12 different pictures of familiar objects, were presented to the child. The experimenter then made a toy cat point to specific pictures on a poster and the experimenter named each selected object. When the cat finished pointing, the child was asked to point to the objects the cat pointed to. The child could recall the objects in any order. The number of correct items recalled was used as dependent variable. Because children had to recall items without computation, this task can be viewed as a storage task. Another memory task of the storage type was included in a study by Bialystok and Martin (in press). In their Forward Digit Span task, children are presented with a series of digits and are required to repeat the string back in the same order as they heard it. Bialystok (1999) and Bialystok and Martin (in press) found no difference between monolingual and bilingual children on these memory tasks, suggesting that no bilingual advantage exists when the memory demands are limited to the storage of information.
Other investigators have used memory tasks that require manipulation of information as well as storage. The most recent of these studies, Gutierrez-Clellan, Calderon and Ellis Weismer (2004) failed to find group differences on the Competing Language Processing Task. In this task children are required to decide if the information conveyed by a sentence is true or false, while also remembering the last word. As noted in Chapter One, findings from this study are compromised by the absence of a monolingual control group, and by the use of inappropriate language measures. The remaining two studies did find a bilingual advantage on memory tasks. For example, in a study by Kormi-Nouri, Moniri & Nilsson (2003), children had to complete a word fluency task. In this task, children had to generate as many words as possible starting with a particular letter and write them down. This required not only that, they keep the target letter in working memory, but also that they use this information to evaluate the suitability of various candidate words as they search through their lexicon. A second example of a memory task with requirements beyond storage is found in a study by Whitaker, Rueda, & Prieto (1985). In a Circular Recall task, children had to repeat a series of words, starting with the last three items presented and ending with the first four items presented. In this task, children had to reorganize the stimuli before recalling the sequence. Both of these studies report a working memory advantage associated with bilingualism, although again this conclusion can be questioned due to methodological weaknesses.

Despite design weaknesses, it seems important to note that the studies that do report a bilingual cognitive advantage in memory tasks (Kormi-Nouri, Moniri & Nilsson, 2003; Whitaker, Rueda, & Prieto, 1985) have used memory tasks that involve manipulation of the information in addition to storage. This is also true of
the memory tasks in the current study. Moreover, the current study corrects the design limitations of the earlier work by including a monolingual control group and more thorough and appropriate language measures. Taken together, these results therefore suggest that a bilingual advantage does exist in working memory tasks requiring the participant to manipulate as well as store information.

4.2.2.3 Summary of main findings as related to the larger literature

Review of the literature suggests that there is no bilingual advantage in tasks that measure the knowledge of a particular concept (e.g. cardinality or proportions) or on tasks primarily tapping into storage of information. These are the sorts of tasks that led Bialystok and her colleagues to conclude that the bilingual cognitive advantage stems from differences in attentional control. However, another set of findings now including those from the present study indicate that a bilingual cognitive advantage is observable not only on tasks tapping primarily into inhibition, but also on working memory tasks as long as these tasks require both manipulation and storage of information. In the next section, different hypotheses regarding the mechanisms underlying the bilingual cognitive advantage will be explored.

4.3 Mechanisms Underlying the Bilingual Cognitive Advantage

4.3.1 Language knowledge

The most obvious differentiating factor between monolingual and bilingual children is their language background. Thus, the first question is, could this advantage be a direct product of language knowledge? In bilingual research, language skills have been measured in two different ways. First, the language proficiency in one language can be measured for both the bilingual and the
monolingual participants. Second, for the bilingual group, the relative proficiency in each language can be determined. These two sorts of measures are logically independent and could have different relationships to other skills. For example, the absolute amount of French that is known could be a poor predictor of cognitive task performance, while at the same time, the degree to which this knowledge of French differs from a child’s knowledge of English could be a good predictor.

Indeed, such are the findings in the current study. Overall language proficiency in French (the language shared by all participants and in which the tasks were administered) did not predict performance on either the memory or the inhibition tasks. On the other hand, the results show that more balanced bilinguals performed better on the inhibition task than children dominant in one of their languages. Taken together, these facts suggest that the degree of equivalence of proficiency in the two languages, rather than any particular level of proficiency is important in predicting performance on the tasks used in this study.

The fact that more balanced bilinguals perform better on the inhibition tasks is in line with Bialystok’s hypothesis that the experience of having to inhibit one language when using another could have an effect on bilingual children’s ability to control attention. It seems likely that the more balanced the languages, the more inhibition of one language when using the other in needed. Thus, it could be argued that the more balanced a bilingual child is, the more experience he/she has with inhibition, and the better he/she is on tasks tapping primarily into attentional control. Note here that the language effect being hypothesized is not one that stems from knowing any particular words or grammatical patterns, but from the processing requirements of knowing two languages in equal degree.
An alternative approach to explaining the relationship between language and the cognitive advantage is found in the literature on metalinguistic awareness. There is a well-documented bilingual advantage in metalinguistic awareness (Hakuta, 1987; Bialystok, 1988; Bialystok, 1992, Bialystok, 1999; Bialystok, 2001; Bialystok, Mjumder, & Martin, 2003). Diaz and Klinger (1991) propose that this awareness may include non-communicative functions of language (i.e. self-regulation, attention) and state that this enhanced awareness leads bilingual children to increase their use of language as a tool of thought resulting in better performance on verbal and non-verbal tasks. This explanation is compatible with the current findings, but more research is needed to investigate whether bilingual children are in fact more inclined to use language as a tool of thought than their monolingual peers. If they are, it could affect their performance on a wide range of cognitive tasks.

4.3.2 Context of bilingual development

Landry (1978) proposes that bilingual children not only learn two different languages but also progress in an environment containing two cultures, and two worlds of experiences. As mentioned in chapter one, the dual context in which the bilingual children evolve could increase their breadth of knowledge. Cowan (1997) suggests that one factor influencing developmental changes in working memory is increase in knowledge because it can facilitate integration of information to be remembered in a working memory task. If growing up in a bilingual world in fact contributes to the ability to integrate the information to be remembered, this could explain a bilingual advantage on working memory tasks. Although the tasks in the present study were likely to be novel for all children (i.e. deciding if a particular
object would fit in a box, and remembering the location of different shapes in a grid), it is conceivable that enriched representations of the objects involved in the Auditory Working Memory task could improve performance. It is less clear how an increase in breadth of knowledge would have affected performance on the Visual Working Memory task.

The dual experiential context in which they evolve could affect bilingual children's performance in yet another way. As discussed in Chapter One, Landry (1978) proposed that a bilingual environment may increase the possibility for variable encoding. Variable encoding (i.e. learning information in multiple contexts) has been linked to better recall of information (Landry, 1978). Landry (1978) argues that bilingual children have the opportunity to learn similar information in different languages, increasing the variable encoding possibilities. If analyzed through a connectionist framework, it could be hypothesised that bilingualism, because of the inherent overlap in representations, helps strengthen relations between concepts and thus renders general processing more efficient. As processing is more efficient, it requires less resource and leaves more resources available for storage or other resource demanding tasks. If bilingual children's advantage rests on improved general processing efficiency, it would explain their increased performance on both the inhibition and the working memory tasks, i.e. because less resource is used for processing, more is available for inhibition or storage of information.
4.3.3 One or many underlying mechanisms?

It is unclear which mechanism or combination of mechanisms underlies the bilingual advantage observed on inhibition and working memory tasks. As reviewed above, explanations based on inhibitory language processing, metalinguistic sophistication, enriched representation, and processing efficiency are all plausible. Moreover, there could be a single mechanism affecting bilingual performance on both tasks or there could be different mechanisms affecting performance on each task separately. A clear answer to this question is presently unavailable.

What is clear is that virtually no correlation was found between the working memory tasks and the inhibition task in the present study, which suggests that inhibition and working memory are separable concepts. Nevertheless, the fact that both inhibition and working memory are enhanced in bilingualism suggests that these two functions are also related in some way. What is the shared component underlying these functions? Again, there is presently no clear answer to this question. Note, however, that most of the candidate explanations point to aspects of executive functions. Over the past decade, there have been increasing calls for differentiation of executive functions (e.g. Baddeley, 1996; Baddeley, 1998, Baddeley, 2002). And, as reviewed in Chapter One, the findings of Miyake et al. (2000) as well as Lehto et al. (2003), provide empirical support for both the commonality and the diversity in executive functioning. The present study adds further developmental data to this picture.
4.3.4 Preliminary summary

The results from the present study as well as the larger literature on the subject suggests that one source for the bilingual cognitive advantage arises from improvements in inhibition and working memory. Before reaching a final conclusion, however, one further alternate explanation for the results obtained in this study must be considered.

4.4 General Intelligence and the Bilingual Advantage

The results of the present study show that bilingual children, besides having an advantage in inhibition and working memory, also outperformed their monolingual peers on the Test of Non-verbal Intelligence (TONI). Although Bialystok and Martin (in press) did not obtain similar results regarding IQ and bilingualism, this type of result is not uncommon in the literature. Hakuta (1987) found that more proficient bilinguals performed better than less proficient bilinguals on the Raven's Coloured Progressive Matrices task as well as on the Spatial Relations subtests of the Thurstone’s Primary Mental Abilities. Likewise, Peal and Lambert (1962) found that French-English bilingual 10 years-old children outperformed monolingual peers on the Raven’s Coloured Progressive Matrices. Could differences in general intelligence explain the bilingual advantage on executive tasks? Three lines of evidence will be presented against this hypothesis.

4.4.1 Empirical evidence

The post-hoc analysis performed using groups equated on non-verbal IQ suggests that bilingual children outperform monolingual children on both working
memory tasks when performance on non-verbal IQ is controlled for. Therefore, the results of this study cannot be explained simply by reference to differences in non-verbal IQ.

4.4.2 Bilingual advantage within group

A second line of empirical evidence also argues against the idea that general intelligence can explain the bilingual advantage. Recall the results from the exploration of language dominance. Although the balanced and the dominant bilingual children did not significantly differ on TONI scores, the balanced bilinguals performed significantly better than the children dominant in one language on the inhibition task. Thus, a difference in IQ does not need to be present for an advantage in inhibition to be observable.

4.4.3 Component Vs. complex tasks

The final line of argument against explanations based on differences in general nonverbal intelligence is logical, rather than empirical in nature. It begins with task analysis.

Kane and Engle (2002) argue that intelligence tests can be divided according to which type of intelligence they primarily measure, that is crystallized (Gc) versus fluid intelligence (Gf). Crystallized intelligence can be viewed as learned information and Fluid intelligence can be viewed as reasoning abilities. They state that the Raven's Progressive Matrices have very high fluid intelligence loading but that the Wechler Adult Intelligence Scale Revised (WAIS-R) does not. Duncan,
Burgess, and Emslic (1995) found that frontal lobe patients score within normal on Gc tests but perform poorly on Gf tests (As cited in Kane and Engle, 2002).

The Test Of Nonverbal Intelligence (TONI) used in the current study strongly resembles the Ravens and can be presumed to likewise focus on fluid intelligence. This distinction between fluid and crystallized intelligence does not completely resolve conflicting results regarding the bilingual advantage and general intelligence tests, since Bialystok and Martin (in press) find no group differences between bilingual and monolingual children on the Ravens Progressive Matrices. Theirs is the minority finding, however, and the Kane and Engle’s (2002) distinction does raise the possibility that the bilingual advantage will only be seen in tests of fluid intelligence. Even if this were true, however, would it make sense to argue differences in fluid intelligence explain the findings in the present study?

Examination of the nature of the tasks included in non-verbal IQ tests reveal that those tasks are complex and require a number of different component abilities. The TONI and the Raven’s Coloured Progressive Matrices, are very similar in their cognitive demands. They both require the child to analyse a figure or a list of figures containing a missing piece, and pick, out of a set of possibilities, the piece that best completes the figure. On each trial within the task, children need to discover the relationship between the elements and pick the figure that best fits this relationship. In addition to requiring knowledge of, for example, geometric and order concepts, Peal and Lambert (1962) argue that this analysis of relationship cannot be done without ongoing cognitive reorganization.

This concept of cognitive reorganization seems to imply the need for working memory. It could be argued that the ability to discover the relationship
between different elements, and keep this relationship in mind while selecting the
correct answer from the choice pool relies on working memory processes.
Additionally, it could be argued that because the relationship between the elements
changes on each trial included in the test, the ability to update the information
available in working memory is of primary importance in these tests. Finally, it is
possible that to be successful in these tests, children have to have the ability to
inhibit irrelevant relationships and irrelevant choices through the choice pool. Thus,
it could be argued that a performing on a complex task such as the TONI or the
Raven’s require ability in different components such as working memory and
inhibition. This dependency on the complexity of the components would seem to be
a more logical view than one which posits the opposite relationship, i.e. that success
on an attention or memory task somehow requires complex reasoning abilities.

4.4.4 Summary: General intelligence and the bilingual advantage

The three lines of arguments above indicate that the bilingual advantage
observed in this study cannot be explained by differences in non-verbal intelligence.
First, the multiple regression analysis suggests that that working memory skills
influence the ability to perform on a non-verbal IQ test rather than vice versa.
Second, the within group difference on inhibitory ability, demonstrates that a
difference in IQ doesn’t need to be present for a bilingual advantage to be observed.
Finally, it is more logical to believe that performance on complex reasoning tasks
such as ones included in IQ tests rely on component abilities such as inhibition and
working memory rather than vice versa.
4.5 Final Conclusion: The Extent of the Bilingual Advantage

The purpose of the current research was to investigate the relationship between bilingualism, executive functions, and working memory. Findings indicated that the French-English bilingual school children in this study outperformed their monolingual French age peers on the Simon Task, an Auditory Working Memory Task and a Visual Working Memory Task. On both empirical and logical grounds, it seems unlikely that these results are explained by differences in general intelligence. Instead, they seem to point to a bilingual cognitive advantage that extends to two major areas, attentional control and working memory. The mechanisms underlying this advantage remain uncertain, but plausible candidates include inhibitory language processing, metalinguistic sophistication, enriched representation, and processing efficiency.

The remaining sections of this discussion will focus on the methodological strengths and limitations related to this study, as well as the implications of the present findings for education. Finally, future directions for research will be outlined.

4.6 Methodological Strengths and Limitations

4.6.1 Strengths

One strength in the methodology of this study was that because the working memory tasks had been previously used in research (Moser, 2003), the age-related difficulty of the tasks was known. This is important because research by Bialystok and Martin (in press) suggests that the general difficulty of a test could affect its effectiveness in revealing a bilingual advantage. Bialystok and Martin (in press)
systematically manipulated the difficulty of a computerized Dimensional Change Card Sort (DDCS) task and found a bilingual advantage only in the two moderately difficult conditions. No bilingual advantage was found in the easiest and the most difficult conditions. Bialystok and Martin (in press) classified children as passing or failing each task based on a criterion of 8/10 correct responses. Overall, 67% of the children passed the easiest condition, 49% passed the second condition, 45% passed the third condition, and 34% passed the most difficult condition. These results suggest that if a task is too easy or too difficult for children at a certain age, no bilingual advantage will be observed even if the task taps into functions that believed to be at an advantage in bilingualism. Careful planning regarding the tasks level of difficulty will be very important in further studies investigating the bilingual advantage.

Another strength of this study was that the bilingual children were carefully chosen to meet rigorous criteria and that both vocabulary and grammatical ability data were collected in both languages. These data permitted the careful description of the participants, empirical tests of the role of language knowledge, and the comparison of the children within the bilingual group. It is difficult to measure the full importance of taking these precautions, but it seems likely that they also played a role in the clear outcomes of this study.

4.6.2 Limitations

One limitation of this study is that no data was collected regarding Social Economic Status (SES) or parental educational background. However, the children participating in this study were all recruited from schools situated in middle-class
neighborhoods. Another limitation of this study concerns the generalization of the findings. The bilingual children were recruited from an unusual school setting, where instruction is conducted in the minority language of a community. Also, the two languages learned by the bilingual children can be seen as two equally valued languages. This situation is not representative of most bilingual children in North America. The bilingual situation in North-America more often involves immigrant children being educated in the majority language of their host country, and languages that are not equally valued. Further research is needed to determine whether the results of this study can be extended to other bilingual environments.

4.7 Future Directions

This study contributed to our understanding of the relationship between bilingualism, executive functions, and working memory. However, further research is needed to elucidate mysteries in at least three areas related to the cognitive advantage in bilingualism. First, the mechanisms underlying the bilingual advantage remain unclear. Future research should focus on the processes by which cognitive tasks are solved. For example, the use of language as a tool of thought should be investigated in order to determine whether increased self-talk affects performance on cognitive tasks, and whether bilingualism in fact contributes to an increased use of this tool. Second, further research is needed to investigate the possibility that the bilingual advantage extends to yet other executive functions such as organizing, or planning abilities. Finally, the bilingual cognitive advantage research needs to extend to other age groups in order to determine whether this advantage persists throughout the life-span or is limited to the childhood years.
References


Boardmaker [Computer software]. Maeyer-Johnson Inc.


Appendix A: Parent questionnaire on language use

Home language use Questionnaire

The Cognitive Advantage in Bilingualism: A Processing Perspective

Child’s name: ___________________________ Date of Birth: __________

1. Which language(s) has your child been learning since birth? ___________________________

2. Is your child exposed to any other language? __________ Which? __________
   Where? _______________________________________________________________________
   When? _______________________________________________________________________
   How often? ____________________________________________________________________

3. Which language(s) is/are spoken in your home? ___________________________
   by whom? _____________________________________________________________________

4. Does your child have any siblings? _____________________________________________________________________

5. Which language does your child use with his siblings? ___________________________________________________________________

6. Has your child ever received treatment for any speech, hearing, or learning problems?
   If so, please specify. _______________________________________________________________________

7. Has your child been learning both English and French? __________________________

* If you answer YES, please complete the questions on the reverse of this page.
  (if you answer no to this question, you may skip the rest of the questions)
8. Which language was acquired first?

9. When was the second language introduced?
   In which context?

10. Does your child use both languages at home?

11. Please give a rough estimate of how much of each language your child uses at home
   (e.g. English 30% French 70%)?

   Please give us an estimate of French and English spoken using % (see example below)
   In this example, the mother uses French 60% of the time when talking to her child.

<table>
<thead>
<tr>
<th>Speaker</th>
<th>to whom</th>
<th>French</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E.g. Mother</em></td>
<td>Child</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>Mother</td>
<td>Child</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child</td>
<td>Mother</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father</td>
<td>Child</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child</td>
<td>Father</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other adult (if applicable)</td>
<td>Child</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child</td>
<td>Other adult (if applicable)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12. Who is the adult (above) spending most time with the child?

13. Which language is used by the adults in the house when talking to each other?

14. Is the pattern of language use different on weekends?

15. Has this pattern of home language use remained similar since the child’s birth or has it changed?

16. Do you and your child mostly watch TV and listen to the radio in French or in English?
Appendix B: Simon Task: Incongruent Trial Example

Computer Screen

Red Square

Red button

Blue button

Keyboard
Appendix C: Sample pictures for the pre-test categorization activity.

Snodgrass and Vanderwart like pictures developed by Rossion and Portois (2001)

Boardmaker Pictures
Appendix E: Visual-Spatial Working Memory Task: Encoding Screen (Span 3)
Appendix F: Visual-Spatial Working Memory Task: Response Screen

<table>
<thead>
<tr>
<th>?</th>
<th>?</th>
<th>?</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

---

88