SIMON AND PICTURE-WORD STROOP TASKS OF INHIBITION IN MONOLINGUAL AND BILINGUAL GRADE 2 CHILDREN.

by

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Abstract

This study investigated the effect of bilingualism on children's performance on two tasks of inhibition. English monolinguals (n =21) and successive Chinese-English bilinguals (n =21) in Grade 2 (ages 7-8) completed the Simon task and a picture-word Stroop task. Both tasks required the inhibition of perceptual attributes of the stimuli; certain conditions of the picture-word Stroop task also required inhibition of conceptual information. In the Simon task, children were required to ignore salient spatial cues and respond only to stimulus colour. As expected, both the monolingual and bilingual groups in this study showed faster RTs on the condition that did not involve a spatial conflict than the one that involved a spatial conflict. In contrast with previous research findings, however, a bilingual group advantage was not observed on this task. In the picture-word Stroop task, children had to name pictures with or without incongruent words written inside. The distracters in different conditions were hypothesized to access the semantic/conceptual level to varying degrees, in accordance with a connectionist model of language processing. Across all participants, real-word distracters were associated with lower accuracy and slower RTs than all other distracters. In general, RT interference varied with the nature of the distracter: words that accessed the semantic level more directly were associated with greater interference, and words that did not access the semantic level produced less interference. No monolingual-bilingual group differences were observed on this task. This study illustrates the feasibility of applying connectionist processing models to language tasks of inhibition. Implications of these results for current explanations of the bilingual inhibitory advantage are discussed.
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Introduction

The purpose of this research is to investigate cognitive inhibition in a group of monolinguals and bilinguals. Studies comparing inhibitory abilities of monolingual and bilingual groups across the life span will be reviewed, after a short overview of the developmental trajectory of inhibition in monolinguals. The current study will identify several issues raised by these previous studies, and will present a connectionist language-processing model that has the potential to clearly explain the levels of processing involved in various tasks of inhibition. This study's two inhibition tasks will be explained in detail, followed by a discussion of findings within the context of the bilingual inhibitory advantage.

Development of Inhibition

Children experience a constant barrage of perceptual information when interacting with the world. Fortunately, the human brain develops mechanisms for giving these percepts order and meaning. One possible framework by which to describe the cognitive organizational mechanisms that act on percepts is Bialystok's analysis and control dichotomy (Bialystok & Ryan, 1985; Bialystok, 1999; Bialystok, 2001). Under this model, analysis is the process of constructing mental representations which become increasingly explicit, detailed, and abstract throughout development. As analysis proceeds, knowledge comes to be organized as complex, abstract concepts, and mental representations can be retrieved independently of the context in which they were learned. The other cognitive mechanism, control, is the process by which attention is directed to the selected aspects of representations that will help a child solve a problem or reach a goal. As analysis and control mutually develop, a child learns to do increasingly complex tasks.
Children with well-developed control over their mental representations can accurately and efficiently select the perceptual information relevant to the goal of their task. Control becomes more difficult when irrelevant perceptual features of the stimulus draw attention away from the relevant ones; thus, inhibition of irrelevant information is a necessary part of attentional control (Bialystok, 2001). Zacks and Hasher (1994) describe inhibition as an attentional mechanism that regulates the contents of working memory in accordance with internal goal states. That is, when relevant and irrelevant information are co-activated in a task, the job of inhibitory processes is to keep irrelevant information from intruding into goal-directed behaviour. Similarly, Houghton and Tipper (1994) see the processes of selective attention, including inhibition, as mediating between perception of a stimulus and a goal or task response. In a review of the neurobiological correlates of selective attention, Driver and Frackowiak (2001) concluded that selective attention exerts an important influence on sensory processing, through anticipatory mechanisms and/or online responses to stimuli.

Many behavioural tasks have been used to track changes in inhibitory ability throughout the life span. Tasks measuring attentional inhibition vary greatly in stimuli, task goals, and level of difficulty, but they all have in common the presence of misleading information; usual attentional patterns must be changed or overcome in order to achieve the task goal (Bialystok, 2001).

Attentional inhibition, as a key aspect in the overall development of executive function (Brocki & Bohlin, 2004), appears to follow an inverted U-shaped trajectory when traced across the life span (Comalli, Wapner, and Werner, 1962; Dempster, 1992; Dagenbach & Carr, 1994; Zelazo, Craik, & Booth, 2004). Cross-sectional studies show that, in childhood, performance on tasks of inhibitory control increases linearly with age: the ability to inhibit irrelevant perceptual
information develops incrementally from early childhood into adolescence (e.g., Brocki & Bohlin, 2004; Leon-Carrion, Garcia-Orza, & Perez-Santamaria, 2004; review in Zelazo & Müller, 2002). Sex differences have not been observed on measures of inhibition (e.g., Welsh, Pennington, & Groisser, 1991). Inhibitory abilities of both sexes peak in young adulthood and then decline in older age, starting around the age of 60 (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004).

Inhibition in Monolinguals and Bilinguals

Not all children follow the same course in the development of their ability to inhibit irrelevant stimuli. The development of inhibition in bilingual children appears to diverge from that in monolingual children. On many tasks of inhibition, bilinguals perform better than monolinguals of the same age and background, especially when the information to be inhibited is very salient or complex (i.e., tasks that require high control) (Bialystok, 2001). In a series of studies (reviewed in Bialystok, 2001), researchers have ruled out the possibility that differences in task performance are attributable to superior analysis abilities in bilinguals. In one study, Bialystok (1986) found that increasing age is associated with better competency on tasks of analysis, while bilingualism is associated with better competency on tasks of control. Subsequent studies have shown that, as literacy skills increase over the years, both monolingual and bilingual children are able to do tasks requiring higher levels of analysis. Observed performance differences between monolinguals and bilinguals, however, are consistently related to control (Bialystok, 2001).

Studies that explicitly compare monolinguals and bilinguals on tasks of inhibition tend to emphasize the bilingual-monolingual difference, rather than how the magnitude of this difference changes with age, task, and participant background. The purpose of the following literature
review is to provide a framework for a more detailed understanding of factors affecting the bilingual inhibitory advantage. The studies are described in detail to highlight the variety of participants, stimuli, and response modes used in inhibition research. Because monolingual studies have shown that age and inhibitory abilities are linearly related in childhood, inhibition differences between language groups should be interpreted within a developmental framework. To this end, the following review of studies comparing monolinguals and bilinguals on tasks of inhibition has been organized by participants' age groups: preschool, school age, and adult.

Inhibition in preschool children
Researchers have observed the bilingual inhibitory advantage in children as young as three years of age. Bialystok and Codd (1997) tested 3-to 5-year-old children on the tower task. In this task, children were presented with two block towers and had to decide which one contained more blocks. The block towers were constructed either from Lego blocks or twice-as-big Duplo blocks. In one condition, the Lego tower was shorter but contained more blocks than the Duplo tower. Children had the greatest difficulty in this condition, in which perceptual information (i.e., tower height) conflicted with estimates of quantity (i.e., number of blocks). Bialystok and Codd explained that, in this context, children had to inhibit the salient perceptual information of tower height in order to achieve the goal of judging the quantity of blocks. In this condition, bilingual children identified the tower containing the most blocks significantly more often than monolinguals.

Another task often used to study inhibition in preschoolers is the Dimensional Change Card Sort task (Frye, Zelazo, & Palfai, 1995; Zelazo, Frye & Rapus, 1996). In the original version of this task, children were presented with a set of cards. Each of the cards featured one of two items, such as blue squares and red circles, which children had to place into containers
labeled with pictures that had the same perceptual dimensions as the sorting cards but in a
different combination. Thus, the blue squares and red circles were sorted into containers labeled
with a red square and a blue circle. In the first phase (pre-switch), children were asked to play
the 'colour game', which involved sorting the cards by colour. In the next phase (post-switch),
they were asked to play the 'shape game', which required re-sorting the cards by shape into the
same two containers. Preschool children typically sorted the cards accurately in the pre-switch
condition, whether it was the colour or the shape game, but made mistakes in the post-switch
condition. While there have been many theories about the reason for children's failure in the
post-switch phase of this task, Bialystok and Martin (2004) identified the critical difficulty in this
task as the ability to ignore an obsolete feature of the sorting cards; for example, the ability to
inhibit attention to shape in the colour game.

In this task, too, an early bilingual advantage has been observed. Bialystok (1999) and
Bialystok and Martin (2004) compared bilingual and monolingual children's performance on the
Dimensional Change Card Sort task. The bilingual children in these studies spoke either Chinese
or French at home, and English in the community and at daycare/school. At ages 3 and 4,
bilinguials performed more accurately than monolinguals on the post-switch phase of the
experiment. The advantage was also observed in a computerized version of this task with
children of 4 and 5 years old.

Results changed, however, when different stimuli were used. Bialystok and Martin (2004)
repeated this task with stimuli that did not differ on the perceptual dimensions of colour and
shape, but instead differed on conceptual (i.e., lexical-semantic) dimensions. The set of cards, for
example, pictured objects that were either toys that belonged outside the house, or things to wear
that belonged inside, and the sorting container featured a toy that belonged inside and a thing to
wear that belonged *outside*. The task required children to sort the cards into two groups on the basis of one conceptual feature (e.g., function: *toy* or *thing to wear*), and then to re-sort them according to the other conceptual feature (e.g., location: things that go *inside* or *outside*). As in the original version of the Dimensional Change Card Sort task, children had to inhibit an obsolete stimulus feature in the post-switch phase. In 4- and 5-year-old children, the bilingual advantage over monolinguals was not observed on this new version of the task. The researchers concluded that bilinguals' advantage in inhibition does not hold when the dimension to be inhibited is a conceptual one rather than a perceptual one (Bialystok & Martin, 2004).

Bilingual preschoolers' inhibitory advantage has also been observed in tasks where the speed of responses is measured. Another commonly-used task of inhibition, the Simon task (Simon & Rudell, 1967; reviewed in Lu & Proctor, 1995), is a computer task based on spatial compatibility between stimulus and response. Participants are instructed to press a designated key on one side of the keyboard (e.g., left) when a red square appears on the screen and a key on the other side of the keyboard (e.g., right) when a blue square appears. Congruent trials are those in which the square appears on the same side (left or right) as its designated key. Incongruent trials are those in which the square and its designated key are on opposite sides. Measures of speed and accuracy show that participants generally demonstrate a longer reaction time (RT) and lower accuracy on incongruent trials than congruent trials. Simon task interference, calculated as the difference in RT between incongruent and congruent trials, is known as the Simon effect. A smaller Simon effect is usually attributed to a participant's ability to prevent a misleading spatial cue from interfering with a response.

In one study involving 5-year-old children, as well as three adult age groups (Bialystok, Martin, & Viswanathan, 2005), a bilingual advantage was found on both congruent and
incongruent trials of the Simon task. This pattern occurred in the 5-year-old group, the 30- to 60-year-old group, and the group over 60 years. The bilingual RT advantage on the incongruent trials was consistent with the inhibitory advantage observed in other studies. The faster RTs of bilinguals even on the congruent trials, however, were surprising; they were attributed to bilinguals' better ability to constantly manage attention in a task where incongruent and congruent trials are randomly presented.

Taken together, these tasks show a bilingual inhibitory advantage that emerges in the preschool years. This advantage was demonstrated in a variety of inhibitory tasks but was not found on a task that required inhibition of the conceptual information that was associated with a perceptual stimulus. Therefore, the bilingual advantage may depend on the kind of information being inhibited; the advantage may not extend to tasks requiring inhibition of conceptual (lexical-semantic) features that go beyond perceptual characteristics of stimuli.

However, the explanation given by Bialystok and Martin (2004) brings up a theoretical problem: why bilinguals would perform equivalently to monolinguals on tasks of conceptual inhibition but outperform monolinguals on tasks of perceptual inhibition. Researchers (Green, 1998; Kroll & De Groot, 1997) have argued that the reason the bilingual inhibitory advantage arises is because bilinguals constantly inhibit attention to representations in one language when functioning in the other language. If the bilingual advantage emerges from this constant practice inhibiting the irrelevant language (i.e., conceptual) information, it remains unclear how this should lead to an advantage only when inhibiting perceptual information. So far, an adequate explanation has not been advanced in the literature.
Inhibition in school-aged children

Despite evidence that the development of inhibition continues in the school years (see Zelazo & Müller's 2002 review), there are few studies comparing monolinguals and bilinguals in this age group; however, the existing studies indicate that, in school-aged children, the bilingual inhibitory advantage persists. As part of a larger study on the bilingual cognitive advantage, Marcoux (2004) compared bilinguals and monolinguals in Grades 3 and 4 (ages 8-10) on the Simon task. The bilinguals in the study used both French and English in daily communication and had been learning the two languages since before the age of three. These bilinguals responded more quickly than monolinguals on both congruent and incongruent trials of the Simon task, consistent with the findings of Bialystok, Martin, and Viswanathan (2005) with preschoolers and adults. Marcoux (2004) invoked Bialystok, Martin, and Viswanathan's (2005) explanation of results: a task with such rapidly-changing attentional demands exerts a greater burden upon the control processes of monolinguals than bilinguals.

In a slightly younger age group, a very different task also pointed to a bilingual advantage in the area of inhibition. A perceptual task studied by Bialystok and Shapero (2005) presented Grade 1 children (approximately 6 years old) with ambiguous images and judged their ability to interpret the images in both ways (e.g., a black vase or two face-to-face people). Bilinguals, who spoke various languages at home and English at school and in the community, were significantly better at identifying the alternative image than monolinguals. The authors hypothesized that, in this task, the first interpretation of the image must be suppressed in order to achieve a new interpretation.

Testing groups of children on multiple tasks of inhibition can give researchers valuable information about the extent to which these different tasks depend on the same set of skills. Bialystok and Shapero (2005) tested a group of 5½-year-old children on the ambiguous figures
task and two more inhibition tasks: the opposite worlds task and the Dimensional Change Card Sort task. In the opposite worlds task, children saw a barn scene with pictures of cows and pigs lining a road. First, they were asked to trace the road, naming each animal they encountered; next, they were asked to trace the route again, reversing the names of the animals (i.e., calling pigs cows and vice versa). In the Dimensional Change Card Sort task, since children at this age have nearly perfect accuracy, the researchers measured RT instead. Bilinguals outperformed monolinguals on the ambiguous figures and opposite worlds tasks, but not on the Dimensional Change Card Sort task. In a regression analysis, however, performance on the post-switch phase of the card sort task was related to the ability to see alternative images. Results of this study showed that not all tasks of inhibition had the same ability to demonstrate a bilingual advantage, probably because they involved slightly different skill sets and/or levels of difficulty.

One aspect of these results presents a conflict with previous research. The opposite worlds task in Bialystok & Shapero (2005) is a task of conceptual inhibition, since it requires taking the perceptual information (e.g., a picture of a pig), connecting it with lexical-semantic information (the label pig) and inhibiting that information in order to reach the task goal (calling the picture cow). Bilinguals demonstrated an advantage over monolinguals on this task. Recall that Bialystok & Martin (2004) found slightly-younger bilingual children did not show an advantage on a task of conceptual inhibition. In light of this contradictory evidence, it remains unclear whether the requirement to inhibit conceptual information affects the bilingual inhibitory advantage. This issue will be further explored in the current study.

These studies with school-aged children generally demonstrated bilingual superiority on tasks where inhibition was hypothesized to be the critical skill. When researchers used the Dimensional Change Card Sort task, however, on which bilinguals showed an advantage earlier
in development (3 to 5 years old), they found that the 5½-year-old bilinguals did not outperform monolinguals (Bialystok & Shapero, 2005). Perhaps, as inhibitory skills gradually develop in both monolinguals and bilinguals, certain tasks lose their ability to show superior performance of one group or the other. Thus, demonstration of the bilingual inhibitory advantage at a given age appears to depend on the difficulty of the task for that age group.

Inhibition in adults

Tasks of inhibitory control also show a bilingual advantage in various stages of adulthood. Bialystok, Craik, Klein, and Viswanathan (2004) studied Simon task performance of monolingual and bilingual adults who were around either 40 or 70 years old; the bilingual participants spoke both languages every day. Bilinguals in both age groups exhibited a smaller Simon effect than monolinguals. Moreover, as inhibitory abilities of all participants began to decline with age (i.e., in the 70-year-old group), the bilingual advantage over monolinguals became greater. The authors suggested that, for these older adults, bilingualism attenuates the decline in executive functions that is characteristic of normal aging.

Bilinguals' inhibitory advantage is slightly less clear in early adulthood. The cross-sectional study by Bialystok, Martin, and Viswanathan (2005) described above, which tested inhibition in monolinguals and bilinguals of different ages across the life span, included a group of young adults (ages 20-30). The researchers found that there was no difference in Simon task performance between monolinguals and bilinguals in young adulthood, suggesting that inhibitory abilities reach a maximum at that age and that bilingualism offers no further boost to
performance. In the other age groups of the study (one preschool group and two groups of older adults), bilingual performance did surpass that of the monolinguals.

A magneto-encephalography (MEG) imaging study (Bialystok, Craik, et al., 2005) investigated young adults (ages 22-36) in two bilingual groups and one monolingual group. At this stage of adulthood, no differences should be observed between groups on the Simon task. The bilingual Cantonese-English group, however, outperformed both the bilingual French-English group and the monolingual English group on both congruent and incongruent trials of the Simon task. The latter two groups did not differ. The authors attributed the Cantonese-English speakers' superior performance to sampling variability.

Despite the lack of a bilingual advantage on the Simon task at this age, other tasks of inhibition are sensitive enough to detect monolingual-bilingual group differences in young adults. The Stroop task (Stroop, 1935) is a popular task of inhibition that has been extensively studied in monolingual populations (see review in MacLeod, 1991). In Stroop's original experiment, participants named colours as fast as possible in two conditions: (a) colour patches, and (b) colour words written in incongruent ink colours (e.g., red written in blue ink). He compared the RT for naming colour patches to that of naming the ink colours of the incongruent words and found that RT increased significantly in the second condition, where participants had to ignore the incongruent colour words. The increase in RT attributable to the presence of the distracting colour word is known as the Stroop effect. Among the reasons for the Stroop test's popularity as a measure of inhibition is its methodological elegance: the set of responses is consistent regardless of the experimental condition. Since participants must produce the same output in all

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1 A complementary explanation of these results is that the Simon task poses equal difficulty to monolinguals and bilinguals in young adulthood; in other words, the task fails to be sensitive enough to demonstrate a bilingual advantage.
conditions (e.g., saying the same colour names aloud in the same sequence), any increase in RT in the presence of a distracter can be attributed to attempts to inhibit it (MacLeod, 1991).

When the Stroop task was used to compare monolinguals and bilinguals, Bialystok (2006a) found that both younger (20- to 21-year-old) and older (67- to 68-year-old) adult bilinguals experienced less interference (i.e., a smaller Stroop effect) than age-matched monolinguals. The observation of a bilingual advantage in young adulthood on the Stroop task, but not always on the Simon task, reinforces the idea that different tasks are differentially-sensitive measures of inhibition. The Stroop study’s results show that bilingual and monolingual group differences are detectable in young adult populations given an adequately sensitive measure.

In general, the results from studies with adults indicate that for the period in young adulthood when inhibitory abilities are sharpest, performance differences between monolinguals and bilinguals do not appear on certain tasks. On other tasks, the bilingual advantage persists. Later in life, a definite bilingual advantage re-emerges as bilingualism offsets normal age-related decline in the executive functions, including inhibition.

The above studies indicate that the advantage of bilinguals over monolinguals on tasks of inhibition is relatively consistent over the life span. Bilingualism is associated with superior performance on these tasks in preschool, in the early school years, and (less obviously) in young adulthood. The bilingual advantage over monolinguals increases again in older age. At all ages, the bilingual inhibitory advantage appears to depend somewhat on the difficulty of the task used to measure it; tasks of inhibition that are too easy or too hard for a certain age group may fail to detect the advantage. Furthermore, so far there is conflicting evidence for the bilingual inhibitory advantage on tasks that depend on conceptual, in addition to perceptual, processing.
Issues raised by previous studies

The foregoing literature review indicates that bilinguals show a robust advantage on tasks where inhibition of a perceptual stimulus feature is required. Research with preschoolers and school-aged children, however, has not pinpointed what effect (if any) conceptual inhibition has on children's ability to inhibit; it is also unclear whether conceptual inhibition affects the bilingual inhibitory advantage. In Bialystok and Martin's (2004) task, described above, bilinguals did better than monolinguals when the task required children to inhibit a perceptual stimulus feature, but the bilingual advantage was not observed when children had to interpret the perceptual features and then inhibit a conceptual feature of the stimulus. Because these two tasks of inhibition were identical except for the stimuli and the thing being inhibited, the necessity for conceptual inhibition appeared to affect the presence of the bilingual advantage. However, bilinguals and monolinguals do not show equivalent performance on all tasks of conceptual inhibition, since Bialystok & Shapero (2005) did find a bilingual advantage on the opposite worlds task, which also required inhibition of conceptual features of the stimulus. The current study aimed to investigate this issue further.

Bilingual and monolingual children in this study completed a task of perceptual inhibition, along with a language inhibition task in which selected conditions involved conceptual inhibition.

In previous research on inhibition, conceptual processing is a vaguely-defined notion. According to Bialystok and Martin (2004), their task of conceptual inhibition required children to make multiple semantic associations with the stimulus object, and then inhibit all but one set of these associations (either function or location) in order to achieve the task goal. Although this is a plausible explanation, a model of cognitive processing is necessary to explain the meanings of conceptual and semantic. Such a model allows more precise definitions of the different skills
required for each inhibitory task, facilitating comparisons of performance on one task to those on another task.

Figure 1 shows a simple connectionist model that can be applied to Bialystok and Martin's (2004) task. The way in which a visual representation of an object (i.e., a picture) gives rise to semantics can be described using this framework. Connectionist models posit different levels of cognitive representation, such as the semantic level of Figure 1, that are (a) driven by activation, and (b) interconnected with other levels of representation. Activation often begins with a perceptual stimulus and proceeds to higher levels of representation; between-level activation is virtually always bidirectional.

![Figure 1. Simplified model of picture processing.](image)

*Note. Arrows represent possible directions of activation.*

Figure 1 illustrates how the visually-perceived stimulus could have activated semantic concepts in the conceptual condition of Bialystok and Martin's (2004) task. The child saw a picture of a teddy bear, for example, which activated certain semantic concepts (e.g., toy, belongs indoors), which in turn activated related words (because activation was bidirectional) and related concepts. Of all the activated semantic concepts, only one of these conceptual
representations was relevant to the task goal; the others needed to be inhibited. Bialystok and Martin (2004) found that children performed equally on this task of conceptual inhibition regardless of language background. Bialystok & Shapero’s (2005) opposite worlds task involved the same form of stimulus (i.e., picture) and required inhibition at the same level of representation (i.e., semantics), although in this latter task children gave verbal responses rather than motor (sorting) responses. Despite the similarity in task requirements, bilinguals showed different performance; there was a bilingual advantage observed on the opposite worlds task.

The task of inhibition devised in the current study explores the apparent contradiction regarding tasks of conceptual inhibition. This task manipulates the extent to which conceptual inhibition is needed to achieve the task goals. A connectionist model is used to hypothesize behavioural outcomes. From a connectionist perspective, two hypotheses are made: (a) children should experience more difficulty inhibiting a perceptual representation if the percept accesses the semantic level, and (b) given two percepts associated with the semantic level, children should find it more difficult to inhibit the percept that accesses semantics by a more direct route. Results of the current study should help determine whether these hypotheses are valid for all children; also, by comparing the performance of monolinguals and bilinguals, this study will contribute to knowledge of how the requirement of conceptual processing affects the bilingual advantage.

Another important issue raised by previous research is whether a single mechanism of inhibition can account for performance on all tasks that require participants to overcome a usual attentional pattern. An implicit assumption of the above research is that a single inhibitory (control) ability is at work. Clearly, across the life span there are tasks in which bilinguals show a better ability to filter out perceptual information that is irrelevant to the task goal or action. However, in all of the above evidence there are many factors that vary: the language background
of the bilinguals, the task stimulus, the thing inhibited, the type of response (motor versus verbal), and the measures (speed versus accuracy). How a single mechanism of inhibition could account for the performance of these various participants on such different tasks remains unclear. A secondary purpose of the current study, therefore, is to address this question. If there is truly one mechanism of inhibition, a child tested on multiple tasks of inhibition should have strongly correlated scores across tasks (assuming the tasks are of equal difficulty). The current study will attempt to correlate children's scores on the two tasks of inhibition in order to shed light on this issue.

Theoretical basis of the current study
This study tested the same two groups of participants on two different tasks of inhibition. Inhibition of perceptual information was measured via the Simon task, in which the participant must initiate a motor response based on stimulus colour. This much-studied task has been deemed appropriate for a variety of age groups (Bialystok, Craik, Klein, & Viswanathan, 2004). Previous studies of the Simon task have found a bilingual RT advantage at various points in the life span (e.g., Bialystok, Martin, & Viswanathan, 2005), including in third and fourth grades (Marcoux, 2004), but the task has not yet been used to compare monolinguals and bilinguals in Grade 2.

This study also required an inhibition task that varied the extent to which conceptual inhibition was involved. One common variant of the Stroop task allows many manipulations of the relationship between target and distracter: the picture-word version (Hentschel, 1973). The stimuli in this inhibition task are pictures with or without superimposed print. Picture naming in the picture-word Stroop task, similar to the colour Stroop task, is hindered when an incongruent word is presented inside the picture (e.g., the word cow inside a picture of a fish; see Rosinski,
Golinkoff & Kukish, 1975). The picture-word format allows the target and distracter to be related in different ways: distracters can be varied on perceptual dimensions and/or conceptual dimensions. A target picture of a dog, for example, can be paired with a distracter word such as bell that, in different conditions, varies on perceptual dimensions such as font size. Alternatively, distracters could vary in the way they relate to the picture of the dog conceptually, as in cat versus brown. The picture-word Stroop task poses an appropriate level of challenge for bilingual and monolingual second graders since Grade 2 children have successfully completed similar tasks in monolingual studies (e.g., Ehri, 1976; Rosinski, Golinkoff, & Kukish, 1975).

This current study's inhibition task called for children to name pictures with incongruent words written inside. For the reasons outlined above, task construction required varying the amount of semantic processing associated with the percept (i.e., the written distracter word) while keeping the perceptual characteristics of the distracter as constant as possible. Previous studies have addressed this issue by using different kinds of written word forms. A study by Rosinski, Golinkoff, and Kukish (1975) investigated the performance of second graders, sixth graders, and adults (all monolinguals) on a picture-word Stroop experiment using distracters that were either real words or CVC nonsense words\(^2\). The authors argued that distracters in the two conditions were perceptually similar but had "differential semantic loadings" (Rosinski et al., 1975, p. 252). Since interference in all groups was found to be greater for the real-word distracters than the nonsense-word distracters, they concluded that semantics caused the interference.

In a series of experiments with adults, Rayner and Posnansky (1978) investigated ways in which words can activate meanings; in other words, ways in which an orthographic percept gives rise to a concept. In their direct-semantic-access model, a reader is able to access meaning from

\(^2\) These are nonsense words in the form of consonant, vowel, consonant.
a printed word directly and rapidly. In two other models, meaningfulness is mediated by something else: in the visual-features stage model, the reader re-codes the visual (orthographic) features of the stimulus word into a known word before accessing meaning, and in the phonemic-recoding stage model, the stimulus word is converted into a phonological or articulatory code before meaning is extracted. The researchers tested these models by constructing stimulus words that matched (or failed to match) a real word, either visually or phonologically.

Because both of the above studies were published before the current connectionist models of language processing were popular, neither of them approached their subject from a processing perspective. Although the theoretical reasoning of Rosinski et al. (1975) and Rayner and Posnansky (1978) was based mainly on intuition, their ideas can be successfully re-cast using a current language-processing model. Figure 2 (based on similar schemas by Small, 2006, Harm & Seidenberg, 2004, and Plaut, 1999) is a connectionist framework that illustrates how perceptual aspects of a written word are processed and eventually associated with meaning.
Figure 2 shows how a visually-perceived written word (*visual representation*) becomes associated with semantics. A written stimulus that is recognized as a real word activates the *orthographic form* level, followed by the *orthographic lemma*, which is a lexical representation distinct from all others; the lemma in turn activates a set of semantic concepts. This route is the most direct manner by which conceptual processing can take place.

The task in the current study required naming a picture with a distracter word inside. Recall that this study was concerned with how written-word distracters were connected to semantics. Figure 2 shows that there are multiple paths by which a written-word distracter can lead to semantics. Using Rayner and Posnansky's (1978) models as a guide, at least three
different written word forms can be devised, each of them being processed in a unique way: (a) the well-formed word *cake*, for example, could activate its semantic features by taking the *direct* route through the orthographic lemma level, as described above; (b) the word *keyk*, which cannot activate semantics through the orthographic lemma level (because it is not an orthographically-recognizable English word), could first be re-coded into its phonological form (via the hidden unit layer) and then, through the phonological lemma level, be associated with the semantic features of *cake*; and (c) the word *cnle*, which is an unpronounceable non-word, could not be recognized as a real English word orthographically or phonologically, and therefore could be blocked from activating the semantic level. In the current study's picture-word Stroop task, these three kinds of words were used as distracters and their effect on interference was investigated. These distracters' processing routes were called, respectively, the *direct* route, the *phonological* route, and the *visual* route. Only the *direct* and *phonological* routes involved access to the semantic level.

Research with this kind of language inhibition task has found that, in general, the more meaningful the distracters, the more interference they cause (MacLeod, 1991). If the connectionist model of Figure 2 is valid in its application to this task, distracters that access the semantic level, and those that do so more directly or efficiently, should be more difficult to inhibit. For both monolinguals and bilinguals with knowledge of English, the *direct* and *phonological* conditions have semantic-level associations and thus should have the potential to cause a great deal of interference. A distracter like *cake* should proceed via the *direct* route and produce the greatest interference; *keyk*, via the *phonological* route, should produce less interference (because its route is less direct), and *cnle*, via the *visual* route (without any semantic associations), should produce even less interference.
Because this study included Chinese-English bilinguals, one additional condition involved the use of a Chinese-word distracter. For bilingual participants who are literate in Chinese, a well-formed Chinese word should activate the semantic level of processing and, as such, should cause substantial interference. Because meaningfulness affects interference in general (MacLeod, 1991), the Chinese distracters should cause more interference for these bilinguals than the visual distracter condition, which did not involve access to meaning (semantics). Chinese-word distracters, however, should cause less interference than the direct and phonological conditions. This is because studies of the Stroop effect in bilinguals have found that between-language interference (e.g., that which arises from a Chinese distracter and an English response) is significantly less than within-language interference (MacLeod, 1991). Since all responses in the current task are in English, the Chinese-word distracter condition is a between-language condition. As such, this condition should be associated with less interference than the two semantically-associated English distracter conditions.

For the monolinguals, the condition involving a Chinese word distracter should cause very little interference; Chinese distracters should produce few, if any, semantic associations. Neither the Chinese distracters nor the visual condition distracters have any meaning for the monolinguals. Between these two conditions, however, the visual condition distracters are expected to cause more interference. Since distracters in the visual condition are written in Roman letters, they are likely more familiar to the monolingual children than Chinese characters. Familiarity is a factor that could increase the salience of the distracter for the monolinguals; the

---

3 The Chinese words should not activate the semantic (conceptual) level for the monolinguals; however, these distracters could cause some interference because they are possibly recognized as allowable words in another language.
more salient a distracter, the more interference it produces (Arieh & Algom, 2002). Given two types of distractors that do not involve the semantic level, the one that is more familiar (and therefore more salient) should cause more interference. This leads to the prediction that monolinguals will experience greater interference on the visual condition than the Chinese condition.

To summarize, this study adapted a language task of inhibition to be able to investigate whether conceptual processing (and the directness by which it takes place) influenced RT interference in picture-naming, and ultimately whether this experimental manipulation affected the performance of monolinguals compared to bilinguals. Although distracter words varied perceptually, certain dimensions (such as the font size and number of letters) were held constant. Distracter words from condition to condition were perceived and processed differently as outlined above.

This study should be distinguished from many past and recent ones (with monolingual participants) that have manipulated semantic relationships per se between targets and distracters. In these studies, unlike the current one, all distracter words were orthographically well-formed. In general, these studies of semantics have found that the interference-causing potential of a word depends on its semantic closeness with target concepts (e.g., Mahon, Costa, Peterson, Varga, & Caramazza, 2007); for example, when naming the picture bed, the word sleep is more difficult to inhibit than the word shoot. Semantically-close distracters are associated with target responses that are both slower and less accurate. These target-distracter semantic relationships, however, were held constant in the current study; the pictures and words used to construct stimulus items were nouns from various semantic categories and were randomly paired.
Hypotheses of the current study
The Simon task of this study was intended to check whether previous findings of the bilingual advantage, shown in preschool children (Bialystok, Martin, & Viswanathan, 2005) and in children aged 8-10 (Marcoux, 2004), were replicated in a different age group. On the Simon task, accuracy should be greater for congruent trials overall; both congruent and incongruent trials are hypothesized to be associated with faster RTs in bilinguals than monolinguals (Marcoux, 2004). The bilinguals should show a smaller Simon effect than the monolinguals because of their apparently robust advantage on tasks of perceptual inhibition.

The picture-word Stroop task aimed to investigate the effects of conceptual inhibition on the bilingual advantage. In general, all participants were expected to experience more RT interference with more meaningful stimuli. For the monolinguals, the greatest interference should be associated with the direct condition (with real-word distracters) and the phonological condition, respectively, and then the visual condition and the Chinese condition. The bilinguals were expected to experience the greatest interference in the direct condition, followed by the phonological condition, the Chinese condition, and the visual condition. The manipulations in these conditions were hypothesized not to affect accuracy, since accuracy in other picture-word Stroop studies was related to semantic manipulations between distracter and target items per se (Mahon, Costa, Peterson, Varga, & Caramazza, 2007). In this task, all of the conditions involve inhibition of perceptual information (i.e., a distracter word) but only two of the conditions require conceptual inhibition. Thus, if bilinguals and monolinguals show equivalent performance on all of the conditions, there would be no evidence that conceptual processing affects the bilingual advantage. If bilinguals show an advantage only on the condition that does not involve conceptual processing (i.e. the visual condition), there would be evidence that the bilingual advantage is limited to tasks of perceptual inhibition. Finally, if bilinguals show an advantage on
all conditions, results would support the idea that the bilingual advantage persists in a variety of conditions, regardless of whether conceptual inhibition is involved.
Method

Participants

The study included 42 children in Grade 2 (Mean age 7;11), divided equally between two groups: bilingual and monolingual. The age and sex of participants in these groups are shown in Table 1. Children in the bilingual group were speakers of English and Chinese, and those in the monolingual group spoke only English.

Participants came from the same neighborhoods, and were recruited through the Vancouver and Richmond School Districts. All children attended schools in which the exclusive language of instruction was English. Teachers and parents helped the researchers select participants who had no history of problems in language, learning, or attention.

Grade 2 children were studied in this experiment for several reasons. According to Cummins' (1976, 2000) threshold hypothesis, the cognitive consequences of bilingualism depend partly on the level of proficiency in the two languages. Children that speak a minority language at home and learn English at school may not show a bilingual advantage in Kindergarten, for example, because it is too early in their English-learning experience. Only bilinguals at a higher threshold of proficiency in both languages would potentially show a bilingual advantage. In other words, bilinguals must be balanced in their two languages. By the end of Grade 2, children have had about three years of English exposure at school and, because their English proficiency should be relatively high, they would have the potential to show the cognitive benefits of speaking multiple languages.

The assumptions regarding stimulus processing in the current study also necessitate a minimum level of reading proficiency, achievable only by Grade 2. According to the standards of the American Speech-Language-Hearing Association (for monolingual children, at least),
children tested near the end of second grade should be competent decoders of unfamiliar words and be able to identify a large number of words automatically by sight ("Your Child's Communication," 2007). Children younger than Grade 2 may not have the decoding and sight reading skills required to make the current study's picture-word Stroop test valid. Moreover, bilingual children who speak a minority language at home should have literacy skills equivalent to their monolingual peers by Grade 2. A longitudinal study by Lesaux and Siegel (2003) showed that, by this age, bilinguals are equally proficient readers and writers in English compared to monolingual peers, even though their oral proficiency may lag behind.

Chinese-English speakers were chosen because several authors have pointed out that, to obtain valid results in research related to the bilingual advantage, children must come from environments in which their skills in multiple languages are valued (Genesee, Paradis, & Crago, 2004). Chinese speakers in Greater Vancouver comprise the largest non-majority ethno-linguistic group: about 47% of the non-majority population is Chinese ("Visible Minority," 2007). As a result, there are opportunities to hear and use the Chinese language on a regular basis through community groups, mass media, and business interactions. In fact, 10 of the 21 Chinese-English children in this study participated in extra-curricular Chinese classes. These factors contribute to an environment that supports the Chinese language and leaves open the possibility of observing the positive cognitive effects of bilingualism.
Table 1

Age and Sex of Participants in Monolingual and Bilingual Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean age</th>
<th>Age range</th>
<th>No. of Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolingual</td>
<td>8;1</td>
<td>7;5-8;5</td>
<td>14</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>7;10</td>
<td>7;5-8;4</td>
<td>11</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The monolingual group in this study spoke English at home and at school. Those participants that had some exposure to other languages (for example, one participant who heard Greek 2% of the time among family, and another who attended a weekly Chinese class) were not able to use those languages functionally.

The bilingual children spoke Mandarin at home and English at school, except two participants who came from Cantonese-speaking households. All bilinguals' Chinese proficiency was rated by their parents as high, both before and after entrance into Kindergarten. Participants varied somewhat in their exposure to English before Kindergarten, but all bilingual participants' English language proficiency was rated as having improved since they entered school, with the exception of two participants who had high levels of English and Chinese proficiency even in the preschool years. While some previous studies (e.g., Marcoux, 2004) have operationalized bilingual participants as those who began acquiring two languages before age three, the majority of the bilingual participants in this study were not proficient in English (their second language) before Kindergarten. In other words, they were successive bilinguals, different from those in previous studies.
Several other children were tested in the study but did not fit the language profile of either group: one was a monolingual Spanish speaker who had completed only two months of school in Canada, and the other had a Vietnamese-, Chinese-, and English-speaking household but only functioned in English. These two children were excluded from the analyses. Another four Chinese-speaking children were excluded because they had lived in Canada for less than two years. The parents of these four children rated their English proficiency lower than their Chinese, indicating that these bilinguals' language abilities were not balanced.

Tasks and Procedures
Children completed an individual 20-minute testing session with the experimenter. All instructions and responses were in English. Children were given a sight word reading task, a word decoding task, and the two tasks of inhibitory control: the Simon task and the picture-word Stroop task. Prior to testing, a language background questionnaire was completed by each child's parent or caregiver.

Reading tasks
A sight word reading task and a word decoding task were administered to assess children's English reading proficiency. Previous research (e.g., Cox et al., 1997) cautions that, in a Stroop-type task where words are used as distracters, participants must have the basic capacity to process the words if interference results are to be valid. When real words are used as distracters, the capacity to process the words necessitates the ability to read; participants with a very low reading proficiency may find the words easy to ignore. Participants in this study were tested on measures of sight reading and decoding to establish that they had the reading sub-skills deemed necessary for processing the various distracters of the picture-word Stroop task: real
words and those that sounded like real words when decoded\textsuperscript{4}. The content of these two tests are detailed in Appendix A.

The sight word reading task was the reading subtest of the standardized Wide Range Achievement Test – 3 (WRAT-3) (Jastak & Wilkinson, 1993). Children were asked to read aloud a list of successively-harder words from a test card; the experimenter awarded one point for every correct word. Children in the study were allowed to stop after they failed to read correctly three consecutive words. Because all children were functioning in an English academic environment, it was important to establish that they were reading English at an age-appropriate level. The children's raw scores were converted into standard scores to ensure that they were in the average or above-average range. The bilingual group's standard scores provide only a rough measure of age-appropriateness, however, since bilingual children like the ones in this study were not included in the WRAT-3's norm group.

The word decoding task was a list of 14 nonsense words selected from the decoding subtest of the Phonological Awareness Profile (Robertson & Salter, 1995), a non-standardized criterion-referenced battery in common use by educators and language clinicians. The 14 one-syllable words represented seven different English spelling patterns, such as words with diphthongs and words with consonant blends. Words were not arranged in order of difficulty; children read aloud the entire list. Children were given one point per correct word; scores were calculated as percent correct.

Because bilinguals and monolinguals should have comparable literacy skills by the end of Grade 2 (Lesaux & Siegel, 2003), mean group scores on the reading subtests should not be significantly different. If both the bilingual and monolingual groups show standard scores in the

\textsuperscript{4} If the children could read both real words and non-words in these reading tests, it was also inferred that they had the capacity to recognize the letters in the unpronounceable non-words of the \textit{visual} condition.
average range on the WRAT-3 subtest and can decode the majority of the nonsense words, the tests will have confirmed participants' ability to process the written stimuli in the Picture-Word Stroop test.

Simon task
The Simon task was used to measure inhibition of perceptual information. The task used in the current study was the same as the one used by Bialystok, Martin, and Viswanathan (2005) and Marcoux (2004). This version of the task was presented using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b) on a HP Notebook with an 8.5" by 11" monitor. Children were instructed to press a designated key on the left side of the keyboard when a red square appeared on the screen, and to press a designated key on the right side of the keyboard when a blue square appeared. The red and blue squares appeared one at a time, and were randomly presented on the right or the left of the computer screen. Children completed four practice trials, one for each possible condition (congruent red, congruent blue, incongruent red, incongruent blue). Then 36 test trials were completed in a random order, with each response automatically triggering the presentation of the next trial. Children pressed a key for each trial; response times were measured via the computer software.

Picture-Word Stroop task
The picture-word Stroop task in the current study was designed to measure inhibition for written stimuli that *did* or *did not* involve conceptual processing. All picture naming responses were in English, the first language of the monolinguals and the second language of the bilinguals. The words were chosen from the MacArthur Communicative Development Inventory: Words and Gestures (MacArthur CDI; Fenson et al., 1993), an evidence-based checklist of vocabulary comprehension and production items designed for assessing 8- to 18-month olds. By using words
that are expected to be part of a child's vocabulary very early in development, it is likely that children will be highly familiar with these words by ages 7-8.

Twenty words were chosen from the MacArthur CDI to serve as stimuli in the picture-word Stroop task. These words were concrete (easily-pictured) one-syllable nouns, 10 of which were designated as picture targets and the other 10 of which were the distracter words. The mean frequency of this group of 20 items was 92.9 (Kucera & Francis, 1967). The distracter words were all composed of four or five letters. Three additional words were chosen from the CDI list to serve as picture stimuli in the practice trials.

The pictures chosen to represent the 10 target words were Picture Communication Symbols from Boardmaker software (Mayer-Johnson). These pictures are simple black-and-white line drawings that are iconic and highly transparent. Each of the 10 pictures was paired randomly with one of the 10 distracter words (without replacement), yielding 10 unique picture-word combinations in each condition. The nature of the distracter changed from condition to condition as outlined below.

In all conditions of the picture-word Stroop task, the child had to name the picture and ignore any word that appeared inside. The distracter words were constructed differently in each of the five experimental conditions. In the baseline condition, the target pictures appeared without a distracter. In the direct condition, the 10 pictures appeared with distracters: real words of four or five letters. Distracters in the phonological condition were words that sounded the same as real English words when decoded. To reduce the visual similarity between these words and real words, each distracter in the phonological condition had a different number of letters than the real word that it represented, and (where possible) a different first or last letter. In the visual condition, the distracters were unpronounceable non-words with some visual similarity to
the real words in the direct condition; they preserved the number of letters, the exact first and last letters, and the word shape – ascenders and descenders in the same position relative to the print line – of the real words (after Rayner & Posnansky, 1978); within these constraints, letters were chosen randomly. Finally, in the Chinese condition, distracters were Chinese translations of the English words. Each Chinese word was written with two characters of the kind currently used in Mainland China (simplified). The 10 pictures in each of the five conditions are shown in Appendix B.

Children were required to name all 10 picture targets from a laminated card prior to testing to ensure that unfamiliar or misunderstood pictures would not confound the naming responses. The vast majority of children easily recognized the 10 drawings in this pretest. If a child gave anything other than the desired one-syllable object name, the experimenter supplied the correct response; for example, for the few children that initially said lamb for the picture of the sheep, the experimenter said "Right, but let's call it a sheep in this game" and re-tested the item after a short delay. The only picture that was misinterpreted in a few cases was the moon, which several children initially called banana. Upon re-testing, all these children identified the moon correctly.

The picture-word Stroop task was presented using the same computer equipment as for the Simon task. In this task, however, a head-mounted microphone was placed on the child to measure the RT from the onset of the picture presentation to the onset of the naming response. Children were instructed to name as quickly as possible all pictures that appeared on the computer screen. Children's motivation was increased by creating a game-like format and by using their vocal responses to trigger the disappearance of the picture on each trial. The children completed six practice trials, followed by all trials of the baseline condition, pictures with no
distracters. In this condition, 20 trials (i.e., 2 blocks\(^5\) of 10 pictures) were presented, using a random order within each block. The child was then told that letters and words would appear inside the pictures but that the task remained the same: naming the picture. He/she then completed a large randomized block of 80 experimental trials (i.e., 2 blocks of 10 pictures, in each of the 4 conditions). After each trial, the experimenter pressed a button to record whether the child's naming response was correct, incorrect, or a microphone error. Microphone errors were trials on which the computer software measured a non-target response rather than the onset of a valid naming response. Examples of such errors included a sharp intake of breath without a response, an interjection ("um"), or clicking sound before a correct response.

\(^5\) Each stimulus in each condition was presented twice. To enhance reliability of results, RTs on these two presentations of the same stimulus were averaged for use in each subject's RT calculations.
Results

Reading Tasks

On the WRAT-3 sight word reading subtest, the mean standard score was 107 ($SD = 10$) for the monolingual group and 107 (12) for the bilingual group. These values are shown in Table 2. A $t$-test found no difference between group means, $t(39) = 0.03, p = .98$. All scores were in the average range expected for that age. These scores confirm that participants in both groups have the basic reading ability necessary to process the real-word distracters in the Picture-Word Stroop task.

Children's performance on the decoding task is displayed in Table 2. A $t$-test revealed no significant difference between the groups' mean scores on this task, $t(40) = 0.38, p = .71$. One bilingual child, however, was a statistical outlier from the overall mean on this task, scoring .07 (decoding only 1/14 items correctly). Relatively high scores were expected from all participants on this criterion-referenced decoding subtest. Its purpose was to check whether children had the potential to process the distracter words in the phonological condition of the picture-word Stroop task (i.e., words that, when decoded, sounded like real English words). Because this participant's decoding scores were so low, her accuracy and RT scores in the phonological condition may not be valid. In fact, this child's RT fell below the mean for this condition, although it was not an outlier. To prevent this participant's invalid scores from interfering with results, however, her data was eliminated from statistical analyses involving the picture-word Stroop task phonological condition.
Table 2
Mean Reading Task Scores (and Standard Deviations) of Each Group

<table>
<thead>
<tr>
<th>Group</th>
<th>WRAT-3 Standard Score</th>
<th>Decoding Proportion correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolingual</td>
<td>107 (10)</td>
<td>.77 (.21)</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>107 (12)</td>
<td>.74 (.26)</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Simon Task
Children's accuracy (the number of trials on which the correct button was pressed as a proportion of total trials) and speed (RT in milliseconds) were recorded on each trial of the Simon task. RT scores were trimmed prior to analysis to remove the influence of extreme outliers. First, the mean and SD of all RT scores were calculated for each group (monolingual and bilingual) in each of the two conditions (congruent and incongruent). Any RT falling above or below three SDs from the mean of its group and condition was trimmed off the data set. This method is often used in RT research to enhance reliability of scores (see Miyake, Friedman, Emerson, Witzki, and Howarter, 2000). In the current study, no RTs fell three SDs below the mean. Table 3 shows the number of trials on which the RT was three or more SDs above the mean. These extremely long RTs were likely attributable to children's momentary inattentiveness during the task, and were thus excluded from the data set. Groups did not differ on the number of trials trimmed overall on congruent or incongruent trials.
Table 3

No. of Trimmed Simon Task Trials (% of Data Excluded by Trimming) by Group and Condition

<table>
<thead>
<tr>
<th>Group</th>
<th>Trimmed trials (% of data)</th>
<th>Congruent</th>
<th>Incongruent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monolingual</td>
<td></td>
<td>3 (0.8%)</td>
<td>7 (1.9%)</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td></td>
<td>6 (1.6%)</td>
<td>4 (1.1%)</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Following another common practice, only the RTs of correct responses were included in the analysis of the Simon task. Accuracy scores for each group, overall and in both congruency conditions, are summarized in Table 4 along with RTs of the accurate trials.

Table 4

Simon Task Mean Accuracy and RT (and SD) by Group and Condition

<table>
<thead>
<tr>
<th>Group</th>
<th>Accuracy</th>
<th>RT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congruent</td>
<td>Incongruent</td>
</tr>
<tr>
<td></td>
<td>Congruent</td>
<td>Incongruent</td>
</tr>
<tr>
<td>Monolingual</td>
<td>.96 (.05)</td>
<td>.93 (.07)</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>.94 (.06)</td>
<td>.93 (.07)</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Accuracy values represent the proportions correct; RT values are in milliseconds.

The data show no group differences in overall accuracy on the Simon task. A two-way mixed Analysis of Variance (ANOVA) on accuracy scores with one between-subjects factor
(group) and one within-subjects factor (condition: congruent or incongruent) found no main
effect of either condition or group, and no interaction between them. This test gives evidence that
neither monolinguals nor bilinguals were significantly more accurate, and the congruency or
incongruency of trials appeared to have no effect on accuracy.

For RT data, a two-way mixed ANOVA for language group and condition found no
significant effect of group, and no interaction between group and condition. There was a main
effect of condition, $F(1,40) = 6.40, p < .05$; the incongruent condition produced significantly
longer RTs. This replicates a common finding in research on the Simon task and confirms
(overall and within each group) the need for inhibition when the stimulus and response are in
opposite spatial locations.

The Simon effect, or RT interference, was calculated by subtracting each participant's RT
on congruent trials from that on incongruent trials. The monolingual group in this study had a
mean Simon effect of 17 ($SD = 73$), while the bilingual group's mean Simon effect was 35 (59).
Scores were widely variable, and a t-test comparison of the mean interference scores of the two
language groups showed no significant difference. The magnitude of these interference scores is
within the range reported in previous studies, but many studies also found great variability. Study
2 in Bialystok, Craik, Klein, and Viswanathan's (2004) investigation of the Simon task in
younger and older adults, for example, found mean group Simon effects ranging from 8 (27.3) to
583 (174.9). In Marcoux's (2004) study of the Simon task in 8- to 10-year-olds (two years older
than the children in this study), the monolinguals' Simon effect was approximately 43
milliseconds ($SDs$ were not reported) and the bilinguals' was 36.

Upon closer inspection, some individual participants' interference scores were found to
be negative. Contrary to what is expected in the Simon task, six monolinguals (29% of the
sample) and six bilinguals (29%) had negative interference scores, indicating that they reacted faster on incongruent than congruent trials. This pattern increased the variation in scores and produced large SDs. Because an equal number of participants in each group exhibited this pattern, it might be attributable to normal variability in this age group.

**Picture-Word Stroop Task**

Accuracy and speed of naming responses, rather than motor responses, were measured in the picture-word Stroop task. Using the same method as in the Simon task, RTs were trimmed to remove the influence of extreme outliers. Again, no RTs fell three SDs below the mean. Table 5 shows the number of trials that were excluded from the analyses because they fell three or more SDs above the mean. A total of 92 trials (2.2% of the data) were trimmed. Because of the similar number of trials trimmed in each of the conditions, experimental condition did not appear to influence the occurrence of outlying RTs. Again, this pattern is consistent with the explanation that these slow RTs were the result of momentary inattention or distraction, randomly observed throughout the trials.

**Table 5**

Number of Trimmed Picture-Word Stroop Task Trials (% of Data Excluded by Trimming) by Group and Condition

<table>
<thead>
<tr>
<th>Group</th>
<th>Baseline</th>
<th>Direct</th>
<th>Phonological</th>
<th>Visual</th>
<th>Chinese</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolingual</td>
<td>13 (3.1%)</td>
<td>9 (2.1%)</td>
<td>7 (1.7%)</td>
<td>10 (2.4%)</td>
<td>9 (2.1%)</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilingual</td>
<td>7 (1.7%)</td>
<td>10 (2.4%)</td>
<td>10 (2.4%)</td>
<td>7 (1.7%)</td>
<td>10 (2.4%)</td>
</tr>
<tr>
<td>(n = 21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20 (2.4%)</td>
<td>19 (2.3%)</td>
<td>17 (2.0%)</td>
<td>17 (2.0%)</td>
<td>19 (2.3%)</td>
</tr>
</tbody>
</table>
On this task, microphone errors accounted for 13.6% of the responses. These voice-trigger errors were evenly distributed throughout all groups and conditions. Previous naming studies with children have found similar rates of microphone errors. Wright, Waterman, Prescott, and Murdoch-Eaton (2003), for example, found that these errors comprised 8% of trials on their Stroop-like inhibition task.

Accuracy scores on the picture-word Stroop task were based on all trials except those that were coded online as microphone errors. Accuracy was calculated as a proportion of correct naming responses to all valid (non-microphone-error) responses. Furthermore, only the trials on which a child responded correctly were included in RT analyses. Table 6 shows accuracy scores and RTs for each group in each condition.

Table 6

<table>
<thead>
<tr>
<th>Group</th>
<th>ACCURACY</th>
<th>RT</th>
</tr>
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<tr>
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<td>Baseline</td>
<td>Direct</td>
</tr>
<tr>
<td>Monolingual</td>
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<td>.89</td>
</tr>
<tr>
<td></td>
<td>(.03)</td>
<td>(.10)</td>
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<tr>
<td>Bilingual</td>
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<td>.90</td>
</tr>
<tr>
<td></td>
<td>(.03)</td>
<td>(.10)</td>
</tr>
<tr>
<td>Total</td>
<td>.98</td>
<td>.90</td>
</tr>
<tr>
<td></td>
<td>(.03)</td>
<td>(.10)</td>
</tr>
</tbody>
</table>

Note. Accuracy values represent the proportions correct; RT values are in milliseconds.

A t-test showed no group differences in overall accuracy on the picture-word Stroop task. A two-way ANOVA on accuracy scores for group and specific condition found a main effect of condition, $F(4,156) = 16.39, p < .001$, but no main effect of group and no group-condition interaction.

6 Phon = phonological condition
interaction. *T*-tests were carried out on all conditions suspected to differ from each other in accuracy. Across groups, the *direct* condition was less accurate than all the other conditions: the *phonological* condition, *t*(40) = 3.74, *p* = .001, the *visual* condition, *t*(40) = 5.83, *p* < .001, the *Chinese* condition, *t*(40) = 5.11, *p* < .001, and the *baseline* condition, *t*(40) = 5.50, *p* < .001.

Average RTs for each participant in each condition were also calculated. Recall that, in each condition of the picture-word Stroop task, each of the 10 identical stimuli was presented twice. RTs for the two randomized presentations of the same stimulus were averaged for use in the RT calculations, as this procedure was expected to yield more reliable RT data. A two-way ANOVA on RT data for group and condition found a main effect of condition, *F*(4,160) = 66.15, *p* < .001, no main effect of language group, and no group-condition interaction. The monolingual-bilingual group difference in the absolute RT values on the Chinese condition did not reach significance. Results from *t*-test comparisons revealed that the RTs in each condition differed significantly from those of each other condition.

Normally in inhibition tasks, each participant's baseline RT score is subtracted from his or her RT in each condition to get an estimate of RT interference by condition. When this procedure was carried out, a two-way ANOVA on interference scores for condition and language group found a main effect of condition, *F*(3, 117) = 38.09, *p* < .001, but no effect of group and no interaction between the two. These results (i.e., effect of condition but not group) parallel the findings from overall RT scores in each condition (above). Because participants' baseline scores were similar, subtracting these baselines from the raw RT values in each condition did not add any significant information to the task results.

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7 Monolinguals' average RT on the *Chinese* condition was 867 and bilinguals' was 921, results which suggested that the bilinguals experienced more interference. This difference, however, did not reach statistical significance.
In sum, Simon task RT and RT interference appeared to depend on the trial's congruency, but not on whether the participant was monolingual or bilingual. Accuracy depended on neither congruency nor language group. On the picture-word Stroop task, real-word distracters were associated with more mistakes than all other conditions. RT and RT interference varied by condition: in both groups, the baseline condition produced the fastest RTs, followed by the Chinese condition, the visual condition, the phonological condition, and finally, the direct condition. All RT differences were significant \( (p < .05) \). No monolingual-bilingual group differences were observed on any of the picture-word Stroop conditions. Initially there appeared to be a group difference on the Chinese condition, but it failed to reach statistical significance.

Correlations between scores on the Simon task and those on the picture-word Stroop task were not found to be significant. Simon task interference and picture-word Stroop task direct condition interference appeared to be unrelated \( (r = .13, p = .40) \).

Background Measures

Bialystok (2006b) found that 21- to 22-year-old bilingual and monolingual participants who had extensive experience playing video games produced faster RTs on the Simon task than those who had less experience. This effect was observed even in conditions that did not involve a conflict. She hypothesized that experience with activities such as video games, which involve some of the same processes of attentional control as the Simon task, can modify performance on that task. In the current study, parents were asked to report how many hours per day their children spent playing video games. Bilingual children played significantly more hours of video games each day \( (M = 1.5; SD = 1) \) than monolingual children \( (M = 0.5; SD = 1) \), \( t(38) = 3.98, p < .001 \). Despite this group's hypothesized advantages of both bilingualism and video game
practice, the findings of the current study showed that bilinguals were not significantly faster than monolinguals on either the congruent or the incongruent trials of the Simon task.
Discussion

This study compared monolingual and bilingual Grade 2 children on two tasks of inhibition. In the following section, the results of each task will be discussed in turn. Implications of these results, as well as directions for future study, will be addressed.

On the Simon task, spatially-congruent trials were expected to be associated with greater accuracy than incongruent trials. Results showed, however, that congruency was not related to accuracy. Participants were highly accurate in both conditions; possibly, in a speed-accuracy tradeoff, these participants prioritized accuracy over speed. Alternatively, the Simon task used in this study may have presented a rather low level of difficulty for these Grade 2 children, so they could achieve relatively high levels of speed and accuracy. Regarding Simon task RTs, responses were slower for the incongruent than the congruent trials (as hypothesized). Incongruent trials were likely more difficult (and therefore slower) than congruent ones because of the requirement to inhibit perceptual features of the stimuli.

The bilingual group was expected to produce faster RTs than monolinguals on both congruent and incongruent trials of the Simon task. According to previous studies, bilinguals have a better ability to manage attention in the context of a task with rapidly-changing inhibitory demands (Bialystok, Martin, & Viswanathan, 2005), so they should show a RT advantage on both the congruent and incongruent trials. The bilinguals in this study had significantly more practice playing video games than the monolingual group, which should have conferred a further speed advantage (Bialystok, 2006b). Despite these factors, the Grade 2 bilinguals showed no advantage on either the congruent or incongruent trials of the Simon task. Bilingual children in both younger (Bialystok, Martin, & Viswanathan, 2005) and older (Marcoux, 2004) age groups have shown an RT advantage on the Simon task in previous studies, so it is unlikely that the
bilingual inhibitory advantage selectively disappeared in second graders. Most likely, no bilingual advantage was observed on this task because one or both of the participant groups differed from those of previous studies. Many past studies included only simultaneous bilinguals: those who were exposed to both languages before the age of 3 (e.g., Marcoux, 2004). The bilinguals in this study were successive bilinguals with (on average) only a few years' experience in their second language (English). Perhaps their relative lack of experience with two languages precluded their ability to show the positive cognitive effects of bilingualism (Cummins, 1976, 2000). This group-mismatch probably accounts for this study's failure to converge with past research; it underscores the need for detailed participant descriptions in future studies, since background characteristics of the bilinguals may be an important factor in determining which studies' results can be validly compared.

An interesting finding on the Simon task of this study was that a proportion of individuals within each group reacted faster on incongruent trials (on average) than congruent trials. Nothing about the background of these children appeared to influence whether they exhibited this pattern. There were equal numbers of monolingual and bilingual participants who showed this reverse interference. Possibly these effects were due to the use of a response strategy (e.g., sub-vocalizing the colour of the stimulus in order to facilitate a response). The simplest explanation of these scores, however, is that they resulted from normal variation. Future studies of the Simon task in monolinguals and bilinguals should report the proportion of participants who show reverse interference scores, in case the pattern is systematic.

The picture-word Stroop task of the current study included a hypothesis that accuracy would not vary by condition. Results showed, however, that the direct condition was less
accurate than all the others. Of the two conditions that involved conceptual processing (by the connectionist model), only one of them was associated with lower accuracy, indicating that conceptual processing was not the only thing that affected accuracy. What made the direct condition unique was that its distracters were processed by the most direct or efficient route to semantics, according to the connectionist model. Thus, only distracters that reached the semantic level, and did so by a direct route, had the potential to influence accuracy.

Across groups, RT and RT interference varied by condition. The distracters in the different conditions of this task were therefore appropriate for producing useful behavioural information at this age. Groups performed equivalently on the baseline condition, meaning that neither group was faster at naming responses overall. Both groups showed the same RT pattern: the direct condition, in which distracters were real English words, was associated with the longest RTs; the phonological condition produced the next highest RTs, followed by the visual condition and the Chinese condition, respectively. Two previously-mentioned maxims were generally substantiated by these RT results: a distracter is more difficult to inhibit if it is (a) conceptually processed, and (b) connected more directly to the conceptual level. For all participants, the two English distracter conditions that involved conceptual processing were associated with the greatest RTs: the direct and phonological conditions. And between these two, the condition that accessed the semantic level most efficiently (the direct condition) was associated with longer RTs. Thus, the monolingual group's RTs by condition were exactly as predicted. Bilinguals, however, exhibited a slightly different pattern than was hypothesized. The bilingual group was expected to show longer RTs on the Chinese condition (which should have involved some amount of conceptual processing for them) than on the visual condition (which

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As explained above, the direct condition and the phonological condition both involved conceptual processing.
involved no access to concepts). In actuality, these two conditions were reversed in the bilingual group; even though the Chinese distracters probably involved access to the semantic level for bilinguals, these children found the visual condition stimuli easier to inhibit. Perhaps because the bilinguals were in an English response mode, conceptual interference from their other language was reduced (MacLeod, 1991). Alternatively, the Chinese-word distracters may have been effectively inhibited simply because the Chinese children had not developed automaticity in their recognition of Chinese characters. Recall that a written distracter's ability to interfere depends on the child's basic ability to read the distracter words (Cox et al., 1997). While background information suggested that most had some exposure to Chinese characters at home and/or through extra-curricular language classes, bilingual children's Chinese literacy was not explicitly tested in this study. The possibility remains that their Chinese literacy was not well developed.

Results of previous studies conflicted on the issue of whether the bilingual inhibitory advantage was affected by conceptual (semantic) inhibition (Bialystok & Martin, 2004; Bialystok & Shapero, 2005). In the current study, some conditions involved conceptual processing and others did not. Group differences were not observed on the picture-word Stroop task of this study, regardless of condition. This result can be interpreted in two different ways. First, the failure to observe a bilingual advantage in conditions with and without conceptual processing could be a result of the bilingual advantage having little to do with the requirement to inhibit conceptual information. Or secondly, perhaps the bilingual advantage does disappear when conceptual inhibition is involved, but this applies only to simultaneous bilinguals (e.g. Bialystok & Martin, 2004) rather than the successive bilinguals of the current study. In light of the Simon task results (where these bilinguals and monolinguals performed equivalently on a task of perceptual inhibition), the latter explanation cannot be ruled out. At least, this study offers
no evidence that access to semantics in tasks of inhibition has any affect on whether bilinguals outperform monolinguals at this age. More research is necessary to clarify how inhibitory abilities develop in children who are successive, rather than simultaneous, bilinguals.

This study successfully demonstrated the application of current connectionist processing models to language tasks of inhibition. Such models of analysis can help define the specific skills involved in different task conditions; in this case, a model helped indicate which distracters of the picture-word Stroop task involved processing at the semantic level. Connectionist models help avoid vague definitions and allow tasks in one study to be compared with those of other studies.

The current research also highlights the issue of treating successive and simultaneous bilingual groups differently in research on the bilingual cognitive advantage. Apparently, most of the existing literature on inhibition does not apply to successive bilingual groups. The development of inhibition in bilinguals who have not learned both languages from age 3 probably diverges from that of children who become bilingual at a later age. Future studies should explicitly separate these two groups.

A secondary issue addressed in the current study is whether results support the idea that a single inhibitory ability accounts for performance in all tasks of inhibition. The fact that monolingual and bilingual groups showed equivalent performance on the Simon and picture-word Stroop tasks could support the existence of a single inhibitory capacity. Within groups, however, performance on the two tasks was not highly correlated. This apparent dissociation could be considered evidence for different inhibitory capacities used on the two tasks, provided that the two tasks were of approximately equal difficulty. Taken together, results of this study do not strongly support either a single, or a multi-faceted, inhibitory ability.
Strengths and Limitations

An important strength of this study is its potential generalizability. The participants were bilinguals who spoke a minority language (Chinese) at home and, according to parent report, generally had low English proficiency when they entered English school. Such minority language students comprise a very significant population in many areas. In the Vancouver School Board, for example, 61% of children speak a non-English language at home, of which approximately 30% receive funding for extra ESL support ("About ESL," 2007). More studies of bilinguals should include this population, since results could potentially benefit a large number of children.

As mentioned above, interpretation of the results of this study was limited by the lack of detailed background information on participants in both the current study and previous studies. Specifically, the brief background questionnaires filled out by these participants' parents elicited little information on the extent of bilingual children's Chinese literacy and the contexts in which this exposure occurred.

The current study could have been methodologically strengthened by measuring bilinguals' proficiency in both languages and comparing it with monolinguals' English proficiency. Standardized tests are commonly used for this purpose, but they have proven inadequate when assessing bilingual populations since most bilingual children come from language backgrounds that are different from the tests' norm groups. In future studies, a valid method of comparing language proficiency of the two groups should be investigated.

Future Directions

The practical implications of inhibition research deserve careful consideration in future studies because the tasks of inhibition devised by researchers are usually very different from real-life scenarios. Subsequent research may help determine whether performance on Stroop-like
tasks of inhibition is related to practical information-filtering activities, such as skimming a written text. Eventually, guidelines for normal performance on tasks of inhibition could be useful in identifying children with certain academic/cognitive problems such as hyperactivity or attention deficit (Wright, Waterman, Prescott, & Murdoch-Eaton, 2003).

Longitudinal research with successive bilinguals on tasks of inhibition throughout the school years could explore how their performance diverges from that of bilinguals who acquired their two languages from an early age. Furthermore, cross-sectional studies tracking the performance of developing monolinguals and bilinguals on a single task, especially through the older school years (where prior research leaves a gap), may give valuable insight into how the bilingual advantage changes over the life span.

Researchers should continue the practice of testing children on more than one inhibition task. By devising ways of correlating or dissociating scores of the same population on different measures of inhibition, researchers will learn whether specialized cognitive skills are used for inhibiting different kinds of information. Such research will address the fundamental question of whether children use different inhibitory processes for the different tasks that involve control of representations. With further research, teachers and language clinicians will come to a better understanding of bilingual children's unique set of cognitive abilities and how to adapt their practices accordingly.
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Appendix A: Word Reading Tests

Sight word reading task
The first 30 items of this test (WRAT-3, Jastak & Wilkinson, 1993) are shown.

1. see
2. red
3. milk
4. was
5. then
6. jar
7. letter
8. city
9. between
10. cliff
11. stalk
12. grunt
13. huge
14. plot
15. sour
16. humidity
17. clarify
18. residence
19. urge
20. rancid
21. conspiracy
22. deny
23. quarantine
24. deteriorate
25. rudimentary
26. mosaic
27. rescinded
28. audacious
29. mitosis
30. protuberance
Word decoding task

All 14 selected items of this task (The Phonological Awareness Profile, Robertson & Salter, 1995) are shown.

1. keb
2. rop
3. flig
4. bund
5. mave
6. pote
7. loe
8. faim
9. moy
10. poil
11. sarp
12. curf
13. nish
14. whuff
Appendix B: Picture-Word Stroop Task Stimuli

Figure B1. Stimuli in the baseline condition.
Figure B2. Stimuli in the *direct* (real-word) condition.
Figure B3. Stimuli in the *phonological* condition.
Figure B4. Stimuli in the visual condition.
Figure B5. Stimuli in the *Chinese* condition.
Appendix C: UBC Research Ethics Board Certificates of Approval
CERTIFICATE OF APPROVAL - MINIMAL RISK AMENDMENT

PRINCIPAL INVESTIGATOR: Stefka Marinova-Todd
DEPARTMENT: UBC/Medicine, Faculty of/Audiology & Speech Sciences
UBC BREB NUMBER: H07-00870

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

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</table>

Other locations where the research will be conducted:

Subject testing will be conducted at the following two locations: 1) Elementary schools in greater Vancouver 2) Subjects' homes In the interest of efficient data collection, subjects recruited through the schools will not be given the option of doing the testing at home. Data entry and analysis will be carried out at the following location: 3) Bilingualism Research Laboratory IRC B4E, UBC

CO-INVESTIGATOR(S):
Kristina Campbell

SPONSORING AGENCIES:
Natural Sciences and Engineering Research Council of Canada (NSERC) - "Restructuring phonetic perceptual boundaries: Chinese adoptees’ acquisition of english phonemes"

PROJECT TITLE:
Bilingualism and the development of attentional control

Expiry Date - Approval of an amendment does not change the expiry date on the current UBC BREB approval of this study. An application for renewal is required on or before: May 10, 2008

AMENDMENT(S):

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The amendment(s) and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board and signed electronically by one of the following: 65