Bilingualism across the lifespan: The rise and fall of inhibitory control

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Abstract

Previous research has shown that bilingual children perform better than comparable monolinguals on tasks requiring control of attention to inhibit misleading information. The present paper reports a series of studies that traces this processing difference into adulthood and eventually aging. The task used in all groups, from children to older adults, is the Simon task, a measure of stimulus-response incompatibility. The results showed that bilinguals performed better than monolinguals in early childhood, adulthood, and later adulthood. There was no difference in performance between monolinguals and bilinguals who were young adults, specifically university undergraduates. Our interpretation is that performance is at its peak efficiency for that group and bilingualism offers no further boost. The results are discussed in terms of the effect of bilingualism on control of attention and inhibition through the lifespan.

Key words

inhibition

executive processes

Simon task

1 Introduction

For those fortunate individuals who have mastered multiple languages, either by the force of circumstance or the fruit of free choice, there is little doubt that life is enriched and experience enhanced. In spite of the ongoing debate over the educational aspects of foreign and second language learning (e.g., the continuing unresolved struggle for bilingual education in the United States, the relative merits and disadvantages of immersion education in Canada), few would deny that the outcome of this experience, namely, mastery of at least one other language, is inherently positive. This salubrious judgment typically reflects the value of knowing other languages, such as a broadened perspective and access to other cultures and ideas, but sometimes includes claims of *metalinguistic* advantages as well, namely, an enhanced understanding of language itself. But what if it could be shown that bilingualism also enhances cognition, making some

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central processes more efficient in the bilingual mind than they are for monolinguals? Evidence for such an effect would have a broad impact on both theoretical beliefs and practical policy.

The expectation for such effects depends on at least two assumptions about language, cognition, and their development. The first assumption is that cognition is largely organized around central processing skills rather than modularized units of thought. If the mind consisted of functionally independent domains, then it would be implausible for experience in one domain, language, to affect processing in another. The second assumption is that cognitive (and possibly neural) organization is plastic and is influenced by experience. If development were primarily defined by maturational factors, then variations in experience should not have systematic consequence on that development. Evidence that bilingualism influences the development of nonlinguistic cognitive processes would lend support to these two assumptions about mind.

There has been a small but consistent research enterprise aimed at determining whether bilingualism affects children's cognitive development, but little investigation of whether such effects might be found for adults. The history of the research with children is well known—early warnings of disastrous consequences of bilingualism on children's cognition were replaced by enthusiastic claims of widespread advantages (review in Hakuta, 1986). However, neither extreme seems to capture the subtlety with which bilingualism influences children's ability to perform across a range of tasks. Benefits are not always found for bilinguals, and many factors appear to be at least as important as bilingualism in predicting outcomes on particular tasks. Moreover, there seems to be little consistency in the types of tasks that reveal bilingual advantages as they cross the boundaries of usual domains of thought. For example, in the domains of language, number, and reasoning, studies have found both advantages for bilinguals as well as no group differences (review in Bialystok, 2001).

A different way of interpreting the research findings is to organize the tasks by the processes required for their solution rather than the problem domain to which the tasks belong. In a review of the contradictory findings regarding the possibility of a cognitive advantage for bilinguals, Reynolds (1991) asserted that consistency would not be found with the current methodologies that focused on the products or outcomes of cognition and not the processes. An acceptable model would need to approach the question by examining processes and include in the question an explanation of why bilinguals might solve these problems differently from monolinguals. Reynolds states: "What we need is a theoretical, preferably process-oriented, framework of intellectual functioning within which to conduct our studies and to answer questions like those just posed" (Reynolds, 1991, p. 164).

This type of process-oriented approach has been pursued by Bialystok (1993, 2001) by positing that two central cognitive processes are differentially affected by bilingualism. These processes are called analysis of representations and control of attention. Analysis is the ability to mentally represent increasingly explicit and abstract structures. Children's intellectual development not only includes adding *more* knowledge to their conceptual structures but also changing the way in which that knowledge is represented. In the early stages of development, knowledge is represented as implicit routines, embedded in concrete contexts, and unrelated to other representations that share some abstract similarity. For example, children's early knowledge of the alphabet is a memorized routine. As the routine becomes analyzed, the child comes to understand that the routine is comprised of constituents (letters), that the constituents have individual functions (they signify sounds), that the functions have a computational significance (they can spell words), and that there are other systems that work that way (numbers). The way in which children's knowledge of the letters is represented at each of these levels of understanding is different, and that difference indicates the explication and analysis that is applied to the initially implicit, unanalyzed representation of the alphabet. As mental representations become analyzed, knowledge can be organized around abstract categories and details retrieved independently of their contexts. These are essential characteristics for the development of thought. Developments in analysis proceed through the mechanisms identified by Karmiloff-Smith (1992) as the process of representational redescription. Other developmental models point to similar processes but use different terminology. The cognitive complexity and control theory posited by Zelazo and Frye (1997) places the burden of development on the ability to construct complex embedded representations.

Control is the ability to selectively attend to specific aspects of a representation, particularly in misleading situations. Problem-solving inevitably requires an intentional focus on some parts of a problem display, some aspects of an associated mental representation, or some portion of a knowledge base. Identifying the relevant details entails excluding irrelevant ones that may appear to be connected to the problem. This selective attention is more difficult if some habitual or salient response to the problem contradicts the optimal one and must be overruled (Jacoby, 1991). Therefore, the process of control is a function of attention and depends largely on *inhibition*. The processes underlying selective attention have been studied by Tipper and his colleagues (Tipper, 1992; Tipper & McLaren, 1990) who have demonstrated the developmental nature of this inhibition. Other researchers, too, have documented the development of inhibition in young children and connected it to important changes in problem solving (Dagenbach & Carr, 1994; Dempster, 1992; Harnishfeger & Bjorklund, 1993). Diamond (2002), argues that most cognitive tasks, such as those used in Piagetian research, require both working memory and inhibition, and her description of these processes is compatible with the function of control described in our framework.

The distinction between analysis and control has been a productive mechanism for classifying problems and examining group differences in mastery by monolingual and bilingual children. Across tasks in various domains, specific problems whose solution depends most heavily on analyzed representations of knowledge are solved equally well by monolingual and bilingual children; problems whose solution depends most heavily on control of attention because they include misleading information are solved better by bilinguals. This dissociation has been found for problems in metalinguistic judgments (Bialystok, 1986, 1988; Cromdal, 1999), number concepts (Bialystok & Codd, 1997), and analytic problem solving (Bialystok & Majumder, 1998). In all these cases, the presence of misleading information, usually perceptual cues, that needed to be ignored for the correct response to be made, created a disadvantage for monolinguals but did not interfere with the ability of comparable bilingual children to solve the problems.

The research showing a consistent advantage for bilingual children in solving problems that are based on the need to ignore misleading information leads to two further questions that potentially have far greater consequence. The first is whether the processes that are boosted in development for bilingual children remain more efficient for bilingual adults. In the research with children, bilinguals solve the tasks earlier than their monolingual peers, but within about a year, monolingual children solve them equally well. Therefore, the advantage found for bilingual children may be a temporary effect in which some kinds of problems are solved somewhat earlier but no lasting change is recorded in cognition. However, the processes responsible for this advantage with children may be more permanently enhanced, making problem solving that requires control over attention easier for bilinguals at all stages of development. The first question, therefore, is whether the same group differences in control are found for monolingual and bilingual adults.

The second question follows from the identification of control of attention, including inhibition and selectivity, as the prime locus of influence for bilingualism on children's cognition. Processes such as these have been shown to decline in normal cognitive aging, leaving older adults with less control over attention and less ability to inhibit prepotent and misleading responses (McDowd & Shaw, 2000, for review). Furthermore, among the components of selective attention, inhibition is a persistent victim of aging. Hasher and Zacks (1988) propose a model of attention that includes both the excitatory mechanisms that are triggered by environmental stimuli and the inhibitory mechanisms that are required to suppress the activation of extraneous information. They argue that as inhibitory control declines, working memory becomes cluttered with irrelevant information and decreases the efficiency of cognitive processing (Hasher, Zacks, & May, 1999). Dempster (1992) proposes a similar description of the function and decline of these inhibitory processes. Other researchers consider that the relevant feature is a capacity-limited resource that declines with age (McDowd, 1997). In all these descriptions, older adults have less control over the contents of working memory and therefore less executive control in general than do younger adults. If it turns out that bilingualism facilitates the function of control of attention in adulthood, the second question is whether it can also delay its decline with aging. In this sense, bilingualism may provide a defense against a normal erosion of cognitive control over attention that comes with aging.

Among the many obstacles to designing empirical investigations of such wide-ranging questions as these, one impediment is finding a task that is suitable for participants of all ages. If age-appropriate tasks are selected for each age group so that estimates of processing for participants of different ages are measured by different tasks, then the longer trajectories of these processes across the lifespan cannot be reliably extracted. If the same task is given for all ages, then the content of the tasks may influence solutions at different ages, and tasks that are too easy or too difficult for a group would mask processing differences that emanate from this specific language experience. Nonetheless, a few studies have managed to investigate these processes across the lifespan. Williams et al., (1999), for example, used a stop-signal paradigm and found that inhibitory control increased in childhood and declined in late adulthood.

Another task that seems to offer a methodology that can be applied broadly is the Simon task (Lu & Proctor, 1995, for review). The task is a problem in stimulus-response incompatibility in which participants are required to ignore the position of a target stimulus in order to respond to its color. In half of the trials, the position of the stimulus conflicts with the position of the response key that is required for the correct solution and the need to ignore this irrelevant position information takes time. This time, expressed as a reaction time cost for misleading trials, is the Simon effect and is a measure of inhibitory control. The task, therefore, is simple enough for participants of all ages to solve, and adjusting some of the experimental parameters, for example making the trial sequences run faster or slower, allows the task to be adapted to different age groups. In this paper, we report a series of studies using the Simon task to trace the development of inhibitory control in childhood, its stabilization in young adulthood, and its decline with aging to determine if bilingualism influences that lifetime pattern.

2 The origins of inhibitory control

Just as difficult as finding a reliable research instrument that is applicable to the whole lifespan is the problem of identifying an appropriate population of bilinguals that provides valid comparison to a group of monolinguals. Five-year-old children with enough linguistic experience to be considered bilingual by the rigid criteria necessary to conduct controlled research are rare. The ideal participants are children who have been exposed to at least two languages from birth on a daily basis. In the present studies, all of the children speak French at home but speak English in the community and are fluent in both these languages.

For the first experiment, Study 1, the bilingual children were recruited from French after-school childcare programs in an English-speaking community. According to questionnaires completed by the parents, the children had English-speaking friends, participated in social activities in English, and watched television in English. The experimental sessions were conducted mainly in English by a French-English bilingual experimenter, providing a further informal assessment of their English fluency. The monolingual children were selected from daycare centers in similar neighborhoods in the same city. According to the parents, these children had no experience with a second language, either spoken or written. Children who attended immersion programs or received any kind of second language instruction, however limited, were excluded. The sample included 17 monolinguals and 17 bilinguals.

The Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 1981) and the Forward Digit Span from the WISC (Wechsler, 1974) were given to the two groups of children to equate them on receptive vocabulary and a simple memory measure. The French children also received the Échelle Vocabulaire en Images Peabody (EVIP) to evaluate the children's relative proficiency in their two languages. Children in the two language groups performed the same on the digit span, but the monolingual children outscored the bilingual children on English receptive vocabulary. This is not uncommon in bilingual research (Ben-Zeev, 1977; Bialystok, 1988; Merriman & Kutlesic, 1993; Rosenblum & Pinker, 1983; Umbel, Pearson, Fernández, & Oller, 1992), and should not be over-interpreted because the scores obtained by the bilinguals on the English test were still in the normal range. Furthermore, the French-English bilingual children demonstrated equivalent receptive vocabularies in French and English, indicating a balanced knowledge of their respective languages. Young bilingual children seem to share their lexical knowledge to some extent across their two languages.

The experimental task was a version of the Simon task suitable for young children. Participants are required to respond to the color of a stimulus but a salient and misleading location cue conflicts with that response on half the trials. The adaptation of the task to make it appropriate for young children was to use a slower presentation rate and reduce the trials to a very few so that children would not become bored. In this first study, there were only 36 trials, divided among three conditions.

Children sat in front of an IBM laptop computer and listened to pre-recorded instructions explaining that they should press the red button (a shift key covered with a red sticker) when they see a red square and the blue button (the opposite shift covered with a blue sticker) when they see a blue square. The squares appeared either on the extreme left or right side of the computer screen, above the shift keys. In congruent trials, the red square appeared above the red button and the blue square appeared above the blue button, and in incongruent trials, the red square appeared above the blue button, and the blue square appeared above the red button. If children did not respond in 5500 ms, the trial ended and the next one began.

Figure 1 shows the mean reaction times for the congruent and incongruent items by group. The bilingual children responded significantly faster than the monolinguals in both the congruent and the incongruent trials, $F(1, 32) = 7.4$, $p < .01$.

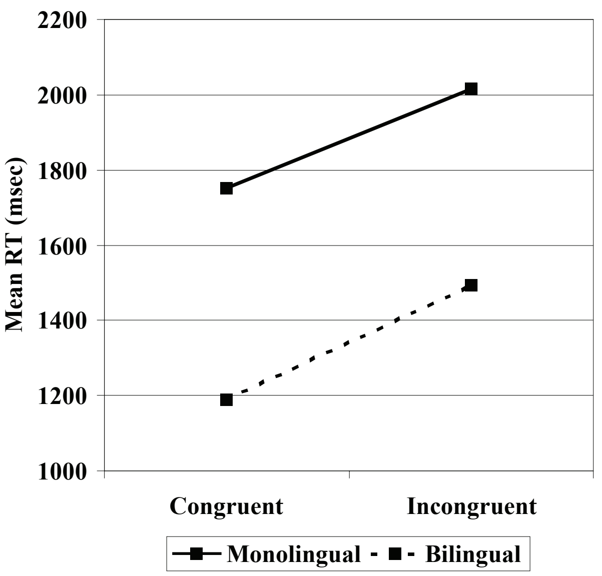

Figure 1
Mean RT by language group on Simon task in Study 1

The results are promising, but the bilingual advantage on both congruent and incongruent items was surprising. Because the results were based on a very small number of experimental trials, Study 2 was designed to replicate and extend these findings. A new group of 18 French-English bilinguals, similar to the group in the first study, and a new group of 22 English monolinguals were recruited. The groups were again equated on digit span, and the monolingual advantage on the PPVT-R was replicated.

The Simon task was presented on a laptop computer using the same rules as those in Study 1 except that the set included 40 trials. Children were offered a short break after 20 trials. A fixation was again presented for 500 ms followed by the appearance of the square. Children were told to respond as quickly and as accurately as they could without making any mistakes. If they had not responded after 5500 ms, the trial ended, and a new trial began.

The results are plotted in Figure 2 and show the replication of the pattern obtained in Study 1. Although the difference between the groups is smaller, the bilinguals continued to respond more rapidly than the monolinguals on both the congruent and incongruent trials.

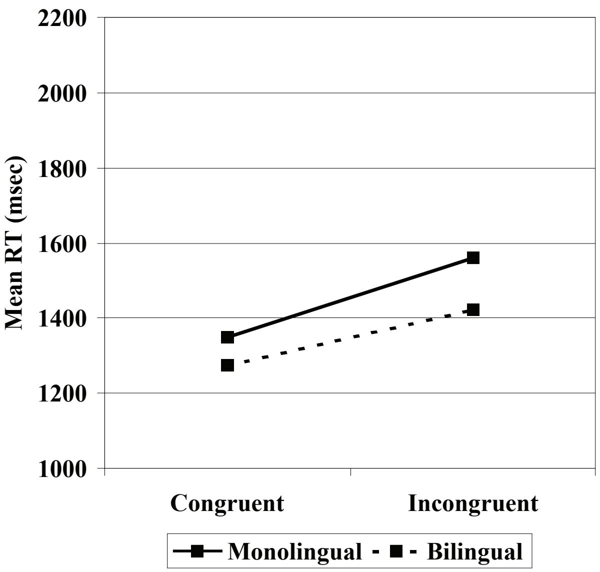

Figure 2
Mean RT by language group on Simon task in Study 2

The results of both studies confirmed the prediction that bilinguals solve the Simon task more readily than monolinguals but the advantage was more extensive than predicted. If the task relies simply on inhibition of attention, then it is puzzling that bilinguals were faster than monolinguals in the congruent trials where no inhibition appears to be required. It is possible that the bilinguals were simply faster than the monolinguals and that they have no privileged access to control of attention. Our subsequent studies include control conditions that do not contain the conflict created by the Simon task to test this possibility. To anticipate those results, no differences in these control conditions by language group have been found. Alternatively, it may be that the structure of the task in which congruent and incongruent items alternate randomly and require constant monitoring and evaluating of the rules places high demands on executive function irrespective of the demands of individual trials. In this way, the bilingual advantage is for greater control and benefits their performance for both types of items. We shall return to this point in the discussion.

3 The stability of young adulthood

Like the vast majority of psychological research, the primary population for investigations of the Simon task has been university undergraduates, usually psychology majors, often rewarded with bonus points on their Introductory Psychology course grade. This is not a bad thing; we assume that university undergraduates are in most respects typical of the species. In this way, myriad studies have been conducted using the Simon task as a means of investigating the effect of stimulus-responsible compatibility on detailed aspects of cognitive processing and creating small variations in the paradigm to isolate small but crucial aspects of cognition (review in Lu & Proctor, 1995).

Yet, in spite of our assumption about their typicality, university undergraduates are not a random sampling of the population. They are young, bright, successful, and often privileged. Perhaps most importantly, they have grown up with computers. This is the population that has set the standards for defining typical responses to the Simon task. In this group, the usual finding is that the RT cost of the incongruent trials, that is, the Simon effect, is in the order of about 20ms. By any standards, this is a breathtakingly small difference.

For most research purposes, this selected, efficient group of skilled performers is the ideal population for cognitive psychologists. As a group they are relatively homogenous, and as individuals they are high functioning and bright. Therefore, small differences, such as the minuscule reaction times that differentiate performance on congruent and incongruent trials of the Simon task, emerge from the background of the usual noise as clear and significant research findings. The population is, in other words, at their peak of cognitive efficiency performing in a task that is perfectly suited to their skills and interests—hit computer keys as quickly as possible to a series of random colored stimuli that flashes across the screen.

Our purpose in using the Simon task is different. In our attempt to trace processing differences between monolinguals and bilinguals across the lifespan, the journey inevitably rests at some point on young adults, 20 to 30 years old, and the obvious source of this segment is university undergraduates. It is here, then, that we seek processing differences that dissect even further the small cost of ignoring the misleading position information from incongruent trials.

Study 3 included 96 undergraduates, 56 of whom were bilingual. Bilingualism was determined by a strict set of questions regarding the participants' language experiences in order to confirm that they had used two languages, essentially daily, since they began to speak. The participants were drawn from the undergraduate population of a large multicultural university, so there were plenty of potential participants for the research. Nonetheless, many individuals who offered themselves as bilinguals were told, to their surprise, that they were not sufficiently bilingual for our criteria. Typically, the bilingual participants who met our rigorous standards were children or grandchildren of immigrants who were born into an English-speaking community but had always spoken, and continued to speak, their heritage language at home. These languages included Portuguese, Cantonese, Italian, and Tamil.

There were two conditions that varied the extent to which the position cue created conflict with the color-mapping rule. In the experimental condition, squares that were red or blue were presented on the left or right side of the screen, accompanied by the rules to press the left key for red and the right key for blue. The experiment began with 24 practice trials that exposed participants to all the conditions, and was followed by 40 trials for each condition presented in counterbalanced order, producing a set of 80 trials.

The control condition was presented in separate blocks, interspersed with the experimental condition, in a counterbalanced order. The purpose of the control condition was to establish that the rate of responding was comparable for the two groups when there were no position cues to ignore. Therefore, the squares were presented in two positions, as in the experimental condition, but they were the top center and bottom center of the screen. The idea was to keep the design as similar as possible to the experimental condition but change only the interference from position.

The mean reaction times for the control condition plus the congruent and incongruent items in the Simon condition are shown in Figure 3. There was a significant difference between scores in these three positions, $F(2, 188) = 8.96$, $p < .0003$, shown by contrasts to indicate that the incongruent items took reliably longer than either the control or congruent which did not differ from each other. The monolinguals and bilinguals, however, performed exactly the same, revealing both the same pattern of conditions and the same absolute speed of response.

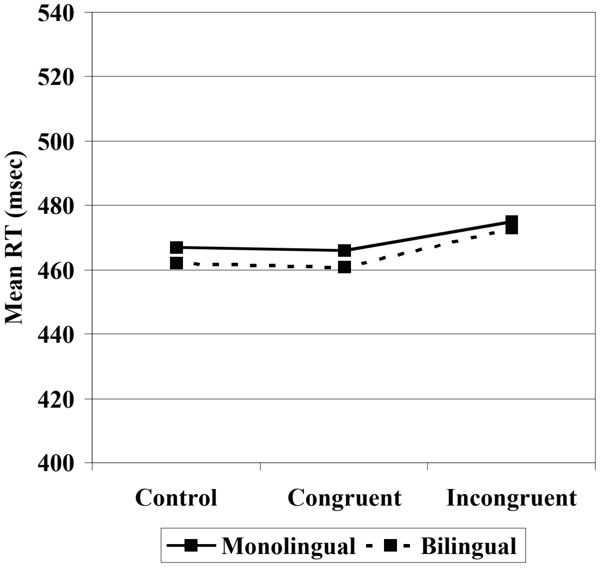

Figure 3

Mean RT for control and Simon conditions by language group in Study 3

All the participants in this study were very fast and accurate. In many ways, the task appeals to the kinds of skills that young educated students have most cultivated—the use of a computer for rapid controlled responding. In fact, some students spend a good portion of their time practicing just this skill; the legions of computer games, particularly the video-style action games, require precisely the skills that are recruited in the Simon task. Therefore, we investigated the extent to which that experience could influence performance on this task.

The participants completed a questionnaire investigating the extent to which they play speeded video games and on the basis of their answers were classified as either high or low computer users. The division between high and low computer users was roughly equal for each of the monolingual and bilingual group, producing subsamples of equivalent size for each. Specifically, the monolingual group consisted of 22 low computer participants and 18 high computer participants and the bilingual group consisted of 34 low computer participants and 22 high computer participants. Using computer experience as a grouping factor, there was a reliable advantage for those individuals who were considered to be experienced computer users, $F(1, 94) = 4.06$, $p < .04$, as shown in Figure 4, and an interaction between computer experience and the three positions, $F(2, 188) = 3.56$, $p < .03$. Simple effects analysis showed that the difference between groups based on computer experience was significant for the congruent, $F(1, 94) = 5.35$, $p < .02$, and incongruent items, $F(1, 94) = 4.86$, $p < .03$, but not the control items, $F(1, 94) = 1.58$, $p = .2$. Therefore, the ability to respond more quickly improved performance on the conditions of the problem where executive processing was more in demand. The improvement had the same impact on both the congruent and incongruent trials, just as the bilingual children were more skilled than monolinguals in both congruent and incongruent trials.

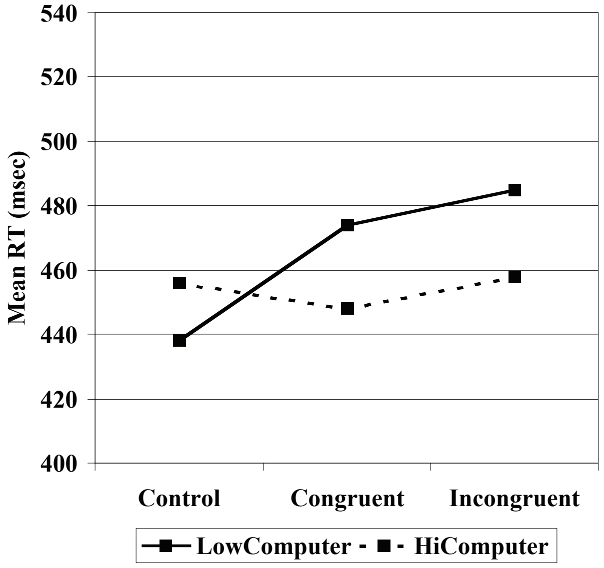

Figure 4
Mean RT for control and Simon conditions by computer group in Study 3

There was no change in performance on this task that could be traced to differences in language experience, but a reliable difference between two subgroups in the sample nonetheless emerged. The speed with which individuals could solve the task was affected by the extent to which they engaged in recreational play with computers, honing their reaction times and practicing attentional strategies to visual stimuli that rapidly appear across a screen. Still, the most pervasive finding is the homogeneity of this group of participants, the irrelevance of language experience, and the durability of the Simon effect in its cost on processing.

4 Cognitive control in adulthood and aging

The studies discussed above reveal a bilingual advantage on the Simon task for children but no difference between the RTs of the monolinguals and the bilinguals for young adults. Could the bilingual advantage reappear in the course of a lifetime?

A number of researchers have shown that inhibitory control declines with aging (e.g., Hasher, Stoltzfus, Zacks, & Rypma, 1991; Salthouse, 1994; Zacks & Hasher, 1994). Spieler, Balota, and Faust (1996) demonstrated that older adults' performance was impaired compared to young adults on Stroop-like tasks, and Simon and Wolf (1963) reported a disadvantage for older adults on a discrimination task. In this task, participants were asked to respond to stimuli on the screen by pressing the key that corresponded to the side where the stimuli appeared. The stimuli were rotated to alter the stimulus-response relationship, and it was found that the fastest RTs occurred when the stimulus was most compatible with the prepotent tendency at 0°. The older adults were slower in all the conditions, even when the stimulus was not rotated. Therefore, older adults had difficulty in overcoming a prepotent response, even under simple conditions, suggesting that the Simon task might be especially difficult for this group. If bilingualism exerts any influence on cognitive processing in adulthood and aging, it may be that older bilingual adults show less deterioration in their performance on the Simon task than older monolinguals.

The results of studies examining declines in inhibitory control with aging are usually extracted from comparisons between older adults, normally above the age of 60 years, and young adults in their 20s, normally undergraduates. It is not surprising that such contrasts reveal sharp differences in performance, not least because of the advantages bestowed on the undergraduate population by virtue of their age and experience as described above. In contrast, our interest was in constructing a more complete profile of these cognitive changes in the two population groups by comparing the performance of older adults not with undergraduates but with middle adults, individuals between the ages of 30 and 60 years.

Study 4 included 40 participants comprising two age groups—30 to 59 years and 60 to 80 years. Half the participants in each age group were bilingual. The bilinguals were selected according to rigorous criteria for language experience and education that was determined through an interview. All the bilinguals had used English plus another language in their daily lives at least since the time they started school, and all had completed some post-secondary education. The bilingual participants were tested in India and the monolingual participants were tested in Canada. All the participants completed Ravens Progessive Matrices and PPVT-R vocabulary tests and no differences between the groups on these scores were found.

Because there is no previous literature with older adults performing the Simon task, the simple adaptation used with the children in Study 1 was also used in this study. The intention was to determine whether the group differences found for children would be replicated with adults using exactly the same instrument. Two modifications were made: first, the response keys were marked with and 'X' and an 'O' instead of a colored patch to indicate the red and blue squares respectively, and second, the number of trials was increased to 28 per condition following a set of eight practice trials. Trials began with a fixation cross in the center of the screen for 800 ms, and then a 250 ms interval before onset of the red or blue stimulus square. Half the trials were congruent and half incongruent, presented in a unique random order for each participant.

The mean reaction times for congruent and incongruent trials are shown in Figure 5. Both language group and age led to significant changes in response times to this task. Consistent with the effects of aging, middle adults were faster than older adults, $F(1, 36) = 28.29$, $p < .0001$, and bilinguals were faster than monolinguals, $F(1, 36) = 16.12$, $p < .001$, (with no interaction) for both congruent and incongruent trials. This replicates the results of Study 1 with children where the same paradigm elicited a bilingual advantage on both items as well.

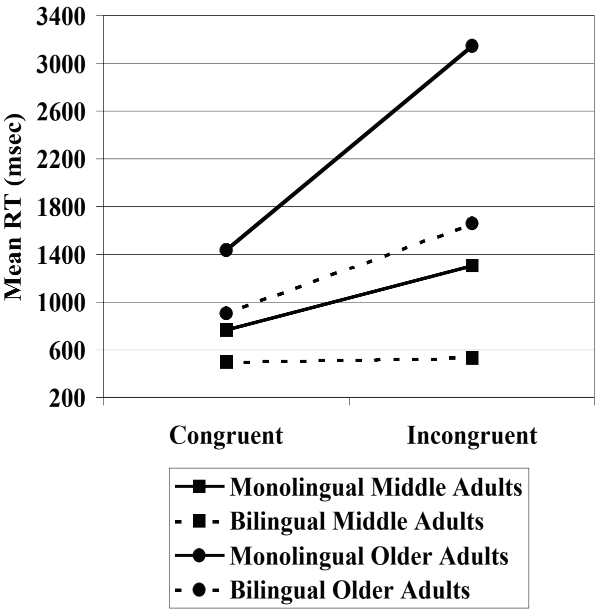

Figure 5
Mean RT for Simon task by language groups for middle and older adults in Study 4

The surprising result is once again that the bilingual advantage is evident for *both* the congruent and incongruent trials. The congruent items present no misleading cues, and no special attentional strategies are necessary to focus on the relevant information. It is possible, therefore, that the bilingual participants are simply faster than the monolingual participants, a situation that would undermine any conclusion about privileged executive processing. Therefore, the next study was designed to determine whether groups would be comparable on a task that presented no conflicting information.

Study 5 was designed to rule out base differences in reaction time by including a control condition. For this control condition, the red and blue stimuli always appeared in the center of the screen and participants merely had to respond to the color of the stimulus with no other position information.

Two new groups of middle adults and older adults completed both the control (central presentation) and experimental (side presentation) conditions of this problem. There were 94 participants consisting of a group of middle adults (30 to 59 years old) and older adults (60 to 80 years old). Half the participants in each age group were bilingual, chosen by the same criteria used in the previous study. The bilinguals in the present study were tested in Hong Kong, India and Canada. All the bilinguals learned both languages before the age of six, used both their languages daily, had been educated in both languages, and had completed at least some postsecondary education. As in the previous study, the participants in the two groups scored the same on a set of cognitive and language tasks.

Participants completed both the control and experimental conditions in counterbalanced order on a laptop computer. In the control condition, a fixation point appeared in the center of the screen for 300 ms and was accompanied by an auditory cue. Following this, a blue or brown square appeared in place of the fixation. Participants were instructed to press the left shift key (marked 'X') when a blue square appeared and the right shift key (marked 'O') when a brown square appeared. There were an equal number of squares in each color and the order in which they appeared was random. The experimental condition consisted of blue or brown squares appearing on the left or right side of the screen as in the previous studies. Practice trials preceded each condition to be sure that participants understood the instructions and could perform appropriately. There were 48 trials in each of the control and experimental conditions.

The mean reaction times for control, congruent, and incongruent trials are shown in Figure 6. Middle-aged adults were consistently faster than older adults for all three trial types, $F(1, 90) = 369.82$, $p < .0001$, but there was also an interaction between the condition and language group. In the control condition, the younger adults were faster than the older ones, $F(1, 90) = 687.58$, $p < .0001$, but there was no difference between the language groups, $F < 1$. In contrast, the bilinguals were faster than the monolinguals in the experimental conditions, $F(1, 90) = 235.37$, $p < .0001$. This bilingual advantage occurred for both middle and older adults and for both congruent and incongruent trials in the experimental condition. Therefore, the bilingual advantage cannot be attributed to baseline differences in speed of response but reflects instead differences in the efficiency with which these two groups can make the response decisions in the experimental condition. It is noteworthy that there was no difference in reaction time between the congruent and incongruent trials for the middle-aged bilinguals. In other words, there was no additional cost for this group in responding when it was necessary to ignore irrelevant information. At the same time, the older bilingual adults were the only group to show facilitation in response time from the congruent trials. Not only was there less cost when the stimulus was conflicting, but there was also facilitation when the stimulus was supporting.

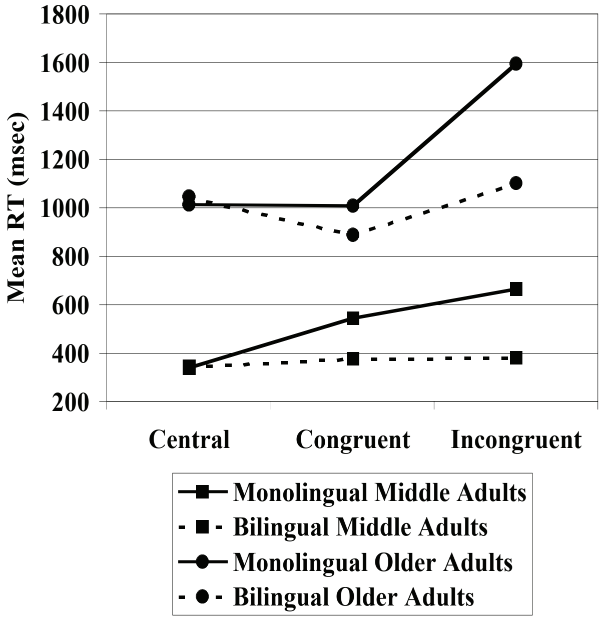

Figure 6
Mean RT for age and language groups in Study 5

In the two studies with middle adults and older adults, we found reliable language differences and age differences. Older adults were slower in all the conditions, but bilinguals at both age levels maintained an advantage over monolinguals in their responses to the experimental trials. Importantly, no differences between the groups were found for the control condition, locating the source of group difference only in the more demanding Simon task trials.

5 Discussion

The Simon task is a simple means of assessing the degree to which individuals can override a habitual response and replace it with a more intentional choice. The position cue that accompanies the incongruent items is a powerful and misleading signal that cues the incorrect response. Some type of executive control, including both the working memory to keep focused on the rule and the inhibition to avoid executing the automatic response, is necessary to produce the correct key press. This extra effort takes time, and that time is indicated by the longer reaction times needed to answer the incongruent items compared to the congruent items.

For children, middle aged adults and older adults, this task was performed more quickly and efficiently by bilinguals than by comparable monolinguals. However, the bilingual advantage was not only for the incongruent items where executive processing is most apparent, but for both types of items—congruent and incongruent. A control condition in the study with adults confirmed that the two groups are equivalent on items that make no executive demands, ruling out the possibility of a simple reaction time difference between the groups. Our interpretation is that the executive demands of the Simon task extend to the need to carry out local switches between randomly presented items, and this aspect of processing is also more efficient in bilinguals, showing up as an advantage in both types of trials.

As clear as the bilingual advantage was for children and older adults, there was no trace of a processing difference for young adults who were university undergraduates. Our explanation is that the subtle advantage in inhibitory control that comes from bilingualism is irrelevant for individuals who are already in control of efficient processing. The only benefit for university students came from a reaction time advantage that was the result of massive practice with speeded computer games, a boost that affected both language groups equally. Instead, the effect of bilingualism can be seen only when these processes are developing in childhood, giving bilinguals a developmental boost, or when they are beginning to wane in adulthood, protecting bilinguals from a steep decline. This pattern is similar to that noted by Stuss (1992) for the rise and fall of executive processing across the lifespan and adds to that argument the role of a particular experience, bilingualism, in mitigating that trajectory.

Where bilingualism affected solutions to the Simon task, it did so for both congruent and incongruent trials, indicating that the attentional processes required to manage a mixed set of items is under the same executive control as that needed to inhibit the misleading cue in the incongruent trials. The study with undergraduates demonstrated the cost of increasing the need for this trial-to-trial monitoring, but showed no difference in the ability to manage that increase as a function of language group. Presumably, increasing the demands for those switches in the groups that did benefit from bilingualism would reveal a greater group disparity where those executive demands were higher. This prediction is consistent as well with the results produced by Hernandez and Kohnert (1999) showing greater processing costs in conditions that contained a larger number of switches in each block.

The results of these studies indicate a role for bilingualism in executive processing throughout the lifespan. In both development and aging, bilinguals were better able than monolinguals to control attention when misleading information provided a compelling but incorrect alternative. These results substantiate the assumptions that motivated the studies. In terms of the distinction between the processes of analysis and control, the results provide further evidence that bilingualism enhances the function of control in a nonverbal cognitive task. Further research will need to establish that similar populations performing in similar tasks do not differ in their solutions to problems based primarily on analysis of representations. The present study did not test that hypothesis.

Finally, for the lifelong use of two languages to significantly alter a subtle cognitive function, it must be that the use of language is not isolated from general cognitive processes but is inextricably tied to it. Our explanation is that the need to manage two active language systems and to manipulate attention to both during language use is carried out by the same general executive functions that are responsible for managing attention to any set of systems or stimuli. The experience of exercising these attentional systems enhances their function, and the benefit can be seen whenever control of attentional processing is required. It is incontrovertible that bilingualism enriches life by opening the individual to other forms of knowledge, other cultures, and other types of thought. It is a serendipitous bonus that it may also bestow the individual with an enhanced skill in executing a fundamental cognitive process.

References

BEN-ZEEV, S. (1977). The influence of bilingualism on cognitive strategy and cognitive development. *Child Development*, **48**, 1009–1018.

BIALYSTOK, E. (1986). Factors in the growth of linguistic awareness. *Child Development*, **57**, 498–510.

BIALYSTOK, E. (1988). Levels of bilingualism and levels of linguistic awareness. *Developmental Psychology*, **24**, 560–567.

BIALYSTOK, E. (1993). Metalinguistic awareness: The development of children's representations of language. In C. Pratt & A. Garton (Eds.), *Systems of representation in children: Development and use* (pp. 211–233). London: Wiley and Sons.

BIALYSTOK, E. (2001). *Bilingualism in development: Language, literacy, and cognition*. New York: Cambridge University Press.

BIALYSTOK, E., & CODD, J. (1997). Cardinal limits evidence from language awareness and bilingualism for developing concepts of number. *Cognitive Development*, **12**, 85–106.

BIALYSTOK, E., & MAJUMDER, S. (1998). The relationship between bilingualism and the development of cognitive processes in problem-solving. *Applied Psycholinguistics*, **19**, 69–85.

CROMDAL, J. (1999). Childhood bilingualism and metalinguistic skills: Analysis and control in young Swedish-English bilinguals. *Applied Psycholinguistics*, **20**, 1–20.

DAGENBACH, D., & CARR, T. (1994). *Inhibitory processes in attention, memory, and language*. New York: Academic Press.

DEMPSTER, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, **12**, 45–75.

DIAMOND, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: cognitive functions, anatomy, and biochemistry. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 466–503). New York: Oxford University Press.

DUNN, L. M., & DUNN, L. M. (1981). *Peabody Picture Vocabulary Test-Revised*. Circle Pines, MN: American Guidance Service.

HAKUTA, K. (1986). *Mirror of language: The debate on bilingualism*. New York: Basic Books.

HARNISHFEGER, K. K., & BJORKLUND, D. F. (1993). The ontogeny of inhibition mechanisms: A renewed approach to cognitive development. In R. Pasnak & M. Howe (Eds.), *Emerging themes in cognitive development*, *Volume 1* (pp. 28–49). New York: Springer Verlag.

HASHER, L., & ZACKS, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Vol. 22* (pp. 193–225). San Diego: Academic Press.

HASHER, L., ZACKS, R. T., & MAY, C. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance: XVII. Cognitive regulation of performance: Interaction of theory and application* (pp. 653–675). Cambridge, MA: MIT Press.

HASHER, L., STOLTZFUS, E. R., ZACKS, R. T., & RYPMA, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **17**, 163–169.

HERNANDEZ, A. E., & KOHNERT, K. J. (1999). Aging and language switching in bilinguals. *Aging, Neuropsychology, and Cognition*, **6**, 69–83.

JACOBY, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, **30**, 513–541.

KARMILOFF-SMITH, A. (1992). *Beyond modularity: A developmental perspective on cognitive science*. Cambridge, MA: MIT Press.

LU, C-H., & PROCTOR, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin and Review*, **2**, 174–207.

McDOWD, J. M. (1997). Inhibition in attention and aging. *Journal of Gerontology: Psychological Sciences*, **52B**, 265–273.

McDOWD, J. M., & SHAW, R.J. (2000). Attention and aging: A functional perspective. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition, Second Edition* (pp. 221–292). Mahwah, NJ; Erlbaum.

MERRIMAN, W. E., & KUTLESIC, V. (1993). Bilingual and monolingual children's use of two lexical acquisition heuristics. *Applied Psycholinguistics*, **14**, 229–249.

REYNOLDS, A. G. (1991). The cognitive consequences of bilingualism. In A. G. Reynolds (Ed.), *Bilingualism, multiculturalism, and second language learning: The McGill Conference in honor of Wallace E. Lambert* (pp. 145–182). Hillsdale, NJ: Erlbaum.

ROSENBLUM, T., & PINKER, S. A. (1983). Word magic revisited: Monolingual and bilingual children's understanding of the word-object relationship. *Child Development*, **54**, 773-780.

SALTHOUSE, T. A. (1994). The aging of working memory. *Neuropsychology*, **8**, 535–543.

SIMON, J. R., & WOLF, J. D. (1963). Choice reaction time as a function of angular stimulus-response correspondence and age. *Ergonomics*, **6**, 99–105.

SPIELER, D. H., BALOTA, D. A., & FAUST, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception and Performance*, **22**, 461–479.

STUSS, D. T. (1992). Biological and psychological development of executive functions. *Brain and Cognition*, **20**, 8–23.

TIPPER, S. P. (1992). Selection for actions: The role of inhibitory mechanisms. *Current Directions in Psychological Science*, **1**, 105–112.

TIPPER, S. P., & MCLAREN, J. (1990). Evidence for efficient visual selectivity in children. In J. T. Enns (Ed.), *The development of attention: Research and theory* (pp. 197–210). Elsevier Science Publishers.

UMBEL, V. M., PEARSON, B. Z., FERNANDEZ, M. C., & OLLER, D. K. (1992). Measuring bilingual children's receptive vocabularies. *Child Development*, **92**, 1012–1020.

WESCHLER, D. A. (1974). *Wechsler Intelligence Scale for Children—Revised*. San Antonio, TX: Psychological Corporation.

WILLIAMS, B. R., PONESSE, J. S., SCHACHAR, R. J., LOGAN, G. D., & TANNOCK, R. (1999). Development of inhibitory control across the lifespan. *Developmental Psychology*, **35**, 205–213.

ZACKS, R. T., & HASHER, L. (1994). Directed ignoring: Inhibitory regulation of working memory. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory and language* (pp. 241–264). San Diego, CA: Academic Press.

ZELAZO, P. D., & FRYE, D. (1997). Cognitive complexity and control: A theory of the development of deliberate reasoning and intentional action. In M. Stamenov (Ed.), *Language structure, discourse, and the access to consciousness* (pp. 113–153). Amsterdam and Philadelphia: John Benjamins.