Consequences of Bilingualism for Cognitive Development

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Abstract

Research addressing the possible cognitive consequences of bilingualism for children's development has found mixed results when seeking effects in domains such as language ability and intelligence. The approach in the research reported in this chapter is to investigate the effect that bilingualism might have on specific cognitive processes rather than domains of skill development. Three cognitive domains are examined: concepts of quantity, task-switching and concept formation, and theory of mind. The common finding in these disparate domains is that bilingual children are more advanced than monolinguals in solving problems requiring the inhibition of misleading information. The conclusion is that bilingualism accelerates the development of a general cognitive function concerned with attention and inhibition, and that facilitating effects of bilingualism are found on tasks and processes in which this function is most required.

Consequences of Bilingualism for Cognitive Development

A significant portion of children in the world enter the realm of language learning being exposed to multiple languages, required to communicate using different systems and proceed to school where the instructional discourse bears no resemblance to the language at home. Normally, few questions are asked and few concerns are expressed by parents, teachers, or politicians. In many cultures, this quiet acceptance indicates that the experience is either so common that it is not detected as anomalous or so crucial for survival that it is futile to challenge it. Yet, an experience as broad in its impact as the way in which language is learned and used in the first years may well impact on the child's cognitive development. This chapter explores research that has addressed itself to identifying whether childhood bilingualism alters the typical course of cognitive development, either favorably or deleteriously, for children whose language acquisition has proceeded by building two linguistic systems.

The cognitive effect of the linguistic environment in which children are raised appears on the surface to be an issue of psychological and educational relevance but it conceals an underlying dimension that is explosively political. Children who are recipients of this experience, for better or worse, are not randomly chosen, nor are they randomly distributed through the population. They tend to belong to specific ethnic groups, occupy particular social positions, and be members of communities who have recently immigrated. It is not surprising, then, that historically some attempts to investigate the psychological and educational questions that follow from this situation have failed to meet standards of scientific objectivity. Instead, the judgment about the effect of bilingualism on children's development in early studies was sometimes used to reflect societal attitudes towards such issues as immigration and to reinforce preconceived views of language and its role in education.

In some nontrivial way, bilingual minds cannot resemble the more homogenous mental landscape of a monolingual. Although there is debate about the precise manner in which languages and concepts are interconnected in bilingual minds (discussed below), it is uncontroversial that the configuration is more complex than that of a monolingual for whom concepts and languages ultimately converge in unambiguous and predictable manners. Monolinguals may have multiple names for individual concepts, but the relation among those alternatives, as synonyms for example, does not invoke the activation of entire systems of meaning, as the alternative names from different languages is likely to do. From the beginning, therefore, bilingualism has consequence. What is *not* inevitable, however, is that one of these consequences is to influence the quality or manner of cognitive development.

Early research on the cognitive consequences of bilingualism paid virtually no attention to such issues as the nature of bilingual populations tested, their facility in the language of testing, or the interpretation of the tests used. As an apparent default, cognitive ability was taken to be determined by performance on IQ tests, at best a questionable measure of intelligence (see Gould, 1981). For example, Saer (1923) used the Stanford Binet Test and compared Welsh children who were bilingual with monolingual English children and reported the inferiority and "mental confusion" of the bilinguals. Darcy (1963) reviewed many subsequent studies of this type and pointed to their common finding that bilinguals consistently scored lower on verbal tests and were often disadvantaged on performance tests as well. Although Darcy cautioned that multiple factors should be considered, a more salubrious account of this research is offered by Hakuta (1986) who attributes the inferior results of the bilinguals in comparison to their new native-speaking peers to the tests being conducted in a language they were only beginning to learn.

The antidote to the pessimistic research was almost as extreme in its claims. In a watershed study, Peal and Lambert (1962) tested a carefully selected group of French-English bilingual children and hypothesized that the linguistic abilities of the bilinguals would be superior to those of the monolinguals but that the nonverbal skills would be the same. Even the expectation of an absence of a bilingual deficit was radical departure from the existing studies. Not only was the linguistic advantage confirmed in their results, but they also found an unexpected advantage in some of the nonverbal cognitive measures involving symbolic reorganization. Their conclusion was that bilingualism endowed children with enhanced mental flexibility and that this flexibility was evident across all domains of thought. Subsequent research has supported this notion. Ricciardelli (1992), for example, found that few tests in a large battery of cognitive and metalinguistic measures were solved better by bilinguals, but those that were included tests of creativity and flexible thought. In addition, balanced bilinguals have been found to perform better on concept formation tasks (Bain, 1974), divergent thinking and creativity (Torrance, Wu, Gowan, & Alliotti, 1970), and field independence and Piagetian conservation (Duncan & De Avila, 1979). In a particularly well-designed study, Ben-Zeev (1977) reported bilingual advantages on both verbal and nonverbal measures, in spite of a significant bilingual disadvantage in vocabulary. Her explanation was that the mutual interference between languages forces bilinguals to adopt strategies that accelerate cognitive development. Although she did not develop the idea further, it is broadly consistent with the explanation proposed elsewhere (Bialystok, 2001) and below.

Researchers such as Hakuta, Ferdman, and Diaz (1987), MacNab (1979), and Reynolds (1991) challenged the reliability of many of those studies reporting felicitous cognitive consequences for bilingualism and argued that the data were not yet conclusive. MacNab (1979) was the most critical, but conceded that bilinguals consistently outperformed monolinguals in generating original uses for objects, an ability compatible with the claim of Peal and Lambert for an increase in flexibility of thought. Reynolds' (1991) reservation depended in part on his requirement that evidence for bilingual superiority should be presented in the context of an explanation for why such effects occur. The purpose of the present review is to describe some selected cognitive processes and evaluate the evidence for bilingual influences on their development and to interpret those effects within an explanatory framework. Peal and Lambert's idea that bilingualism would foster flexibility of thought has persisted, often accompanied by supporting evidence. Their explanation was that the experience of having two ways to describe the world gave bilinguals the basis for understanding that many things could be seen in two ways, leading to a more flexible approach to perception and interpretation. We shall return to this idea in the conclusions.

The majority of the more recent literature has focused on the consequences of bilingualism for the development of children's linguistic and metalinguistic concepts. It is entirely plausible that learning two languages in childhood could alter the course of these developments, but documenting those abilities has revealed unexpected complexity. Bilingualism is often (but not consistently) found to promote more rapid development of metalinguistic concepts. In contrast, oral language proficiency, particularly in terms of early vocabulary development, is usually delayed for bilingual children. Reading and the acquisition of literacy is less well studied, but the existing evidence gives little reason to believe that bilingualism itself significantly impacts on the manner or ease with which children learn to read. The effect of bilingualism on all these language-related developments are discussed elsewhere and will not be reviewed here (e.g., Bialystok, 2001, 2002). This chapter will examine only the nonverbal cognitive consequences of becoming bilingual in childhood.

The possibility that bilingualism can affect nonverbal cognitive development is steeped in an assumption – namely, that linguistic and nonlinguistic knowledge share resources in a domain-general representational system and can influence each other. In some theoretical conceptions of language, language representations and processes are isolated from other cognitive systems (e.g., Pinker, 1994). Although it may be possible in these views to understand that bilingualism would influence linguistic and metalinguistic development, it is difficult to imagine that the effect of constructing two languages would extend beyond that domain. Therefore, to even pose the possibility that bilingualism influences nonverbal cognitive growth requires accepting that linguistic and nonlinguistic functioning converge on some essential cognitive mechanism. Such cognitive models typically incorporate an executive function, one that includes the limitations of working memory and representational processes and is limited by a central resource responsible for selective attention, inhibition, and planning (e.g., Norman & Shallice, 1986). If bilingualism alters something essential about nonverbal cognitive development, then it might well be through its impact on such a generalized executive function.

In the following discussion, three areas of cognitive development are examined to determine if they are acquired differently, or on a different time scale, by bilingual children. The three areas are concepts of quantity and arithmetic ability, hierarchical classification in a task switch paradigm, and theory of mind. Following this, the common pattern from the three developmental areas is discussed and a possible explanation for developmental differences between monolingual and bilingual children is proposed.

Quantitative Concepts and Abilities

Quantitative concepts and mathematical abilities were one of the early areas investigated by researchers interested in determining whether or not bilingualism impacted on development. Macnamara (1966, 1967) raised the possibility that bilingualism might interfere with children's competence in these areas. Based on the research available at the time, he concluded that there was no evidence that bilingualism handicapped children's computational ability for mechanical arithmetic but that it did impair children's ability to solve mathematical word problems. His own large-scale study of English-speaking children in Irish language schools confirmed this pattern. He attributed the deficit to what he considered the inevitable language handicap that followed from bilingualism but did not discount the logical possibility that bilingualism itself was to blame. A simpler explanation, however, is compelling: children's competence in Irish was inadequate to the task. The culprit was not bilingualism but rather the use of a language for a complex educational purpose that exceeded the children's proficiency in that language. Although bilingualism frequently compromises children's proficiency in one of the languages, the deficit is neither inevitable nor pervasive. Therefore, bilingualism itself may not have been a factor in the performance of the children in that study.

Macnamara concluded that the mechanical abilities to carry out arithmetic operations were equivalent in monolinguals and bilinguals, but others have presented a different view. Some researchers have reported weak but consistent evidence that adult bilinguals take longer to solve mental arithmetic problems than monolinguals, particularly in their weaker language (Magiste, 1980; Marsh & Maki, 1976; McClain & Huang, 1982). Geary, Cormier, Goggin, and Lunn (1993) speculated that this difference arose because these mechanical problems were solved verbally, by mediating the operations in one of the language, so they developed a task that bypassed the possibility of verbal mediation. They presented arithmetic problems with a solution and participants only needed to judge whether the solution was correct. If verbal mediation were required, participants would conduct these computations in their stronger language, eliminating the burden of the weak language effect. With the language component of the task removed, they found no overall differences in reaction times to solve these problems. In a more detailed follow-up study, they divided the reaction time between time spent encoding and retrieving and time spent computing the operations. Here they found no group difference in encoding but a significant monolingual advantage in the computing. Their interpretation was that both groups had the same automated access to the stored arithmetic facts but that monolinguals could perform computations on these facts more rapidly than bilinguals. They interpreted this as indicating working memory differences between the groups that favored monolinguals.

Frenck-Mestre and Vaid (1993) reported that bilinguals verified simple arithmetic problems most quickly and accurately when the problems were presented as digits, slower when presented in word format in their first language, and slower again in their second language. They point to other studies that indicate that number processing itself is not slower in a second language and so conclude that the explanation for their data is that it is arithmetic ability that is compromised for the bilinguals in their second language. This result may reflect the same difference reported by Geary et al. (1993) regarding the computation aspect of solving these problems in a weak language. Frenck-Mestre and Vaid (1993) conclude that arithmetic is sensitive to the language in which it is learned and that the ability to carry out arithmetic operations is impaired in a second language. However, their bilingual participants were late language learners who had weaker proficiency in their second than in their first language, so it is still possible that the effect was signaling a weakness in language competence.

In an interesting study, Spelke and Tsivkin (2001) trained bilinguals to perform new arithmetic operations in each of their languages and then tested them in both languages. For computations involving accurate access to large numbers, performance was better in the language in which that problem was trained, suggesting that the coding of that information was specific to the language. This effect even generalized to numerical information about time and space, indicating a general encoding process for quantities in which language is part of the representation. These results extend the work of Frenck-Mestre and Vaid (1983) regarding the language specificity of these operations. Additionally, there was a main effect of language in which participants always performed better in their first language, replicating earlier work on this problem.

The differences reported in these studies can also be found in the simplest numerical procedures, namely, counting. In a small-scale study in our laboratory, we compared the speed with which bilingual adults could count forwards and backwards in their two languages. The participants were highly fluent speakers of English and Portuguese. They were first asked to recall a list of words in each language to assure some rough equivalence on a verbal task. Then they were timed as they counted in both directions in both languages. The relevant measure was the ratio of the time required to count backwards over the time required to count forwards in the same language. Backward counting would inevitably be slower, and the more effort required would increase its difference from forward counting. Furthermore, by computing this time as a ratio of the time needed to count forwards in each language, possible differences in the time required simply to recite the number sequence in the two languages were eliminated. The results showed no difference between languages on the verbal task but a significant increase in time required to count backwards in their weaker language.

These studies indicate that bilingual adults generally take longer to solve mathematical problems than monolingual adults do, particularly when the problems are posed in their weak language. The studies also confirm, however, that language itself has a role to play in these mathematical operations. Therefore, it is still conceivable that bilingual children who are initially learning these skills may be compromised in their acquisition, and that the deficit may be greater if instruction takes place in the weaker language. This, in fact, was the point that Macnamara was arguing in his early studies on this issue. Therefore, research with children is required to establish whether bilingualism impacts on the development of mathematical abilities

Secada (1991) studied Hispanic children solving word problems in both English and Spanish. There were two main findings. First, children could solve the problems equally well in both languages. Second, children who were more balanced in their language abilities for the two languages demonstrated higher overall achievement in the problem solving tasks. He concluded that the problem solving ability of the bilingual children was equivalent to that of their monolingual peers. Although his study did not include an explicit comparison with monolingual children solving the same problems, it showed that lower levels of language proficiency did not interfere with the ability of these children to solve the problems in their weaker language. Similarly, Morales, Shute, and Pellegrino (1985) hypothesized that if language proficiency were not an issue, then bilingual children should perform just as well as monolingual children on problem solving tasks. In their study, there were no differences between monolingual and bilingual groups when math problems were presented to each in the dominant language.

This conclusion is different from the one reached by Mestre (1988). He claimed that bilinguals with mathematical skills comparable to monolinguals tended to solve math word problems incorrectly because of language deficiency. His argument is based on studies with bilingual children who were studying in English but for whom English was their weaker language, a situation similar to that in which Macnamara (1966) predicted grave results for bilinguals. Mestre identified the diverse forms of language proficiency that are required to solve these problems, such as literacy, vocabulary, and syntactic knowledge, and argued that all of them are compromised for bilingual children. These results are different from those reported by Secada, but the children in Mestre's study were not as fully bilingual. In Secada's study, the children were in bilingual education programs with most of their instruction conducted in English, and English was the dominant language for most of the children at the time of the study. In Mestre's study, the children lacked some minimal level of competence in the weaker language to proceed through the process of understanding and solving mathematical word problems.

Comparisons in terms of first and second, or stronger and weaker languages help to interpret the results when comparing monolinguals and bilinguals performing arithmetic tasks, but the language itself also contributes importantly to the explanation. In a series of studies examining both children and adults who were Welsh-English bilinguals or English or Welsh monolinguals, Ellis (1992) showed that the longer word names for numbers in Welsh increased working memory demands and reduced the availability of working memory for calculation. This effect of increased time needed to perform in Welsh was independent of the participants' level of bilingualism.

A general result from all these studies is that solving mathematical problems in a weak language is more difficult for bilinguals than it is either for monolinguals or for bilinguals in their strong language. The effect is expressed as longer reactions times in adults and increased errors in children. Some studies have shown that adult bilinguals produce increased reaction time when solving these problems in *both* their languages so there may also be some costs involved in having two systems to manipulate. But the main finding is that weakness in language proficiency can affect the ability to carry out problem solving in other domains and interfere with children's ability to master these problems. This is entirely reasonable, but it may not speak to bilingualism so much as to the necessity for having sufficient language skills to carry out basic cognitive activities in any domain. Studies examining bilingual children in their stronger language generally show no deficit in acquiring mathematical concepts or solving mathematical problems. These results show that bilingualism does not alter children's ability to construct the necessary mental representations for mathematics relative to monolinguals, but that problems framed in a verbal context that exceeds their linguistic sophistication imposes a barrier accessing those representations and interferes with their performance. In that sense, language limitations weaken children's ability to learn concepts and to solve mathematical problems relative to monolinguals.

Prior to the time when arithmetic operations can be carried out, children must establish the concepts of invariant quantity as a system of relational meanings. These concepts include understanding various aspects of the number system and its operations, including rules for correspondence and rules for counting. This knowledge develops gradually as children piece together the system and learn the symbolic and notational indicators of that system. The primary principle that children must internalize is cardinality, the idea that numbers have quantitative significance (Fuson, 1988; Gelman & Gallistel, 1978; Wynn, 1992). If this concept is learned differently by bilinguals and monolinguals, then that could set the stage on which further disparities in mathematical ability could be built.

We tested children's understanding of cardinality using two problems (Bialystok & Codd, 1997). In the towers task, we showed children piles of Lego blocks and piles of Duplo blocks. The Duplo blocks are identical in every to the Lego blocks except they are twice as large on each dimension. We told children that each block was an apartment that one family could live in, even though some apartments are big and some are small. We were going to build apartment buildings out of the blocks and they had to count the apartments (blocks) and tell us which building had more families living in it. Children were shown pairs of towers and reminded each time to count the blocks. The relevant trials were those that compared a Lego tower and a Duplo tower, but in which the higher Duplo tower had fewer blocks. The height is a compelling, although misleading cue, and children need to ignore that height and report that the tower that resulted in a higher number when counting was the tower with more blocks. Children found this difficult, but the bilingual children performed significantly better than the monolinguals in their ability to resist focusing on the height of the tower and attend only to the counting operation.

The second problem was the sharing task. Children were shown two identical dolls and a set of candies that they were asked to divide equally between them. When the candies had been divided and the child agreed that both dolls had the same number of candies, they were asked to count the candies in the pile of the first doll and then to say, without counting, how many candies were in the second doll's pile. Like the towers task, the problem required counting a small set of items and making a statement about quantity based on the counting procedure. The difference was that the towers task contained misleading information that appeared to give them the answer but the sharing task did not. The sharing task was difficult, but both groups performed to the same level. Although these were the same children solving similar problems, the bilingual advantage was found only for the towers task.

Both the towers task and the sharing task are based on the cardinal principle that the last number counted indicates the quantity of the set. The difference between the problems is that the towers task assesses this principle in the context of misleading information, specifically designed to distract the child by presenting a plausible but incorrect alternative to the cardinal principle.

Bilingual children were better able than monolinguals to focus on the counting operation and not attend to the irrelevant height.

In both these domains, bilingual children (and adults) were equivalent to monolinguals on direct assessments of mathematical ability. For problem solving, bilinguals were sometimes hampered by inadequate linguistic competence and performed less well or less efficiently, especially when tested in their weaker language. For children learning basic arithmetic concepts, however, bilinguals performed better than monolinguals when the problem was presented in a misleading context. In this case, the bilingual children demonstrated superiority in their ability to focus attention and ignore misleading cues. These attentional abilities translated into superior performance on a test of basic quantitative concepts.

Task Switching and Concept Formation

A surprising but consistent deficit in young children's performance has been shown on a task that requires children to follow a simple rule to sort a set of cards and then reverse that rule to sort the same cards in a different way. In a series of studies, Zelazo and his colleagues (Frye, Zelazo, & Palfai, 1995; Jacques, Zelazo, Kirkham, & Semcesen, 1999; Zelazo & Frye, 1997; Zelazo, Frye, & Rapus, 1996) have demonstrated children's failure to reverse a rule that has been established for a particular set. In the task, children are shown a container consisting of two sorting compartments, each indicated by a target stimulus, for example, a red square and a blue circle. They are then given a set of cards containing instances of shape-color combinations that reverse the pairings, in this case, blue squares and red circles. Children are first told to sort by one dimension, for example, color, and place all the blue squares in the compartment indicated by the blue circle and all the red circles in the compartment indicated by the red square. Children can perform this classification essentially without errors. When they have completed that phase, they are asked to re-sort the same cards by the opposite dimension, shape. In this case, the blue squares must be placed in the box indicated by the red square and the red circles must be placed in the box indicated by the blue circle. The finding is that preschool children persist in sorting by the first dimension (color), continuing to place the blue squares with the blue circle, even though they are reminded of the new rule on each trial. Bilingual children, however, adapt to the new rule and solve this problem earlier than monolinguals (Bialystok, 1999; Bialystok & Martin, submitted).

There are different possibilities for why children perseverate on the first set of rules. The explanation proposed by Zelazo and Frye (1997) is called the cognitive complexity and control theory. They argue that children cannot solve the problem until they acquire sufficiently complex rule systems and reflective awareness of those rules. According to this interpretation, the task requires children to construct complex embedded representations of rules in which instructions concerning specific dimensions are embedded under a more general representation that classifies the stimuli. The ability to switch the sorting criterion depends on representing the relation between the dimensions in terms of the higher order rule that unifies the specific lower order rules. Young children are unable to do this, and because they represent only the individual rules, they fail the task. By 5-years old, children have the ability to represent a hierarchical structure and can pass the task, seeing the cards as, for example, simultaneously a red thing and a round thing.

There is no doubt that the representational demands of this task are difficult. Children must appreciate the dual nature of the sorting task and recognize that either dimension can be used as a classification criterion. This explanation places much of the burden on the development of adequate representations of the problem. However, the task also imposes high demands on children's ability to control selective attention: Children must inhibit attention to a perceptual dimension that was previously valid and refocus on a different aspect of the same stimulus display.

Our explanation for the difficulty presented by the problem and for the reason for the bilingual advantage comes from the need to selectively attend to and recode specific display features. Children code the target stimuli according to the first rule system, in this case, the red thing and the blue thing. When the second rule system is explained, those descriptions become obsolete and must be revised, re-coding the targets as the square thing and the round thing. Having already represented the targets in one way, however, it is difficult for children to now think of the items as a square thing and a round thing. This re-interpretation of the targets requires inhibition of their original values, and that is difficult because the colors remain perceptually present even though they are now irrelevant.

Two recent studies provide converging support for this interpretation of the primary source of difficulty in this task. Typically, the experimenter names each card when passing it to the child to be sorted, but children persist in sorting it according to the obsolete dimension. Kirkham, Cruess, and Diamond (in press) revised the procedure by requiring the child to name each card before placing it into the sorting box. The modification produced significantly better performance, presumably by redirecting children's attention to the new relevant feature. Furthermore, instructing children to place the cards in the container face up instead of face down as in the standard version made the task more difficult as it increased children's distraction to the obsolete feature. Similarly, Towse, Redbond, Houston-Price, and Cook (2000) presented a test card to children who had made post-switch errors and asked them to name the card. More than half of these children described the card by naming the pre-switch dimension; they continued to see the card as a blue thing even though they had just been taught the shape game. Both these studies indicate that children persist in mentally encoding the cards according to the description relevant in the pre-switch phase. Correct performance in the post-switch phase requires that they inhibit those descriptions so they can reinterpret the card in terms of the post-switch feature.

The conclusion from these studies is that the primary difficulty children face in the post-switch phase of the card sort task is in ignoring the continued presence of the cue that indicated the rule for the pre-switch sorting and re-interpreting that target stimulus in a new way. If the obsolete feature from that target stimulus is removed, children easily reassign the values and sort correctly on the post-switch phase (Bialystok & Martin, submitted, Study 2). In the standard version, however, the problem is difficult because of its demands on control of attention, and bilingual children consistently solve this problem earlier than comparable monolinguals.

Theory of Mind

The final example of a cognitive achievement that may be differentially developed in monolingual and bilingual children is one that has been intensively investigated in the past several years. Researchers have been interested in the emergence of children's understanding of theory of mind, the knowledge that beliefs, attitudes, and perceptions are constructed by individual minds that have a particular (literal or metaphorical) point of view (e.g., review in Wellman, 1990). The breadth and pervasiveness of this understanding across cognitive domains makes its development central to children's intellectual growth.

Explanations for children's success on theory of mind tasks at the age of about 4 years have varied. One view, called the "theory theory", considers that theory of mind is a holistic construct that exists independently of other cognitive achievements and emerges with maturation (Astington, 1993; Perner, 1991). Other explanations take a more processing view by considering the memory and executive functioning demands built into these tasks and demonstrate a correlation between success on these executive tasks and theory of mind problems (Carlson, Moses, & Hix, 1998; Carlson & Moses, 2001; Hala & Russell, 2001; Hughes, 1998). In a reversal of that position, Perner, Stummer, and Lang (1998) argue that it is competence with theory of mind that brings children to higher levels of executive functioning, thereby reversing the direction of putative causality.

In the standard paradigms for assessing theory of mind, children are given information about a situation or an object, the information is then modified, and the child is required to predict whether another person, not present when the amendments were described, would know the updated information. In situation-based tasks, a toy is hidden in a location and then moved; in false contents task, a container that is assumed to hold one kind of item actually holds another; in appearance-reality tasks, an object that looks to be one thing turns out to be a different kind of thing. The question asked of the child is whether another child who was not shown the truth about the location, contents, or identity would know what the correct values were. Children who fail the theory of mind task respond by saying that the novice child would have full access to the information that the experimental child had and be able to answer the questions properly.

Although the modularized view of these abilities is compelling and consistent with much evidence, the tasks nonetheless incorporate complex processing demands. If bilingual children were precocious in the development of at least one of these component processes, then it is possible that they would solve theory of mind tasks earlier than monolinguals. The kinds of tasks for which bilingual children have shown an advantage are those that include misleading information, a situation characteristic as well of these theory of mind tasks. The tasks are based on conflict between two states – real and altered, appearance and reality – and the child must understand which possible configuration will provide the correct answer. The difficulty is that the original state of the display, namely, the appearance of the object or the initial hiding place, remains visible during the questioning, potentially misleading the child into the original response. Therefore, children must resist basing their answers on these previously correct and now obsolete cues.

We examined this possibility in a study in progress using appearance-reality tasks. Three items that appeared to be one thing but were found on inspection to be something else were shown to monolingual and bilingual children who were 4-years old. The three items were an object that looked like a rock but was actually a sponge, a crayon box that had Lego inside instead of crayons, and a plastic snowman that opened up and was really a book. Following the standard procedure for these tasks, the experimenter showed the child each item and discussed what it looked like. When children agreed on the appearance of each object, the experimenter revealed the actual identity (or contents) of the item.

The testing phase consisted of three questions. The first two questions are called the appearance questions because they are based on the original expectation of the object from first looking at it: What did you think this was when you first saw it? What will Tigger (a stuffed toy participating in the initial interaction but hidden during the revelation) think it is when we bring him back? The third question is called the reality question because it assesses the actual identity of the item that is not revealed by its outward appearance: What is it really? There was no difference between responses to the two appearance questions, so they were combined into a single score for appearance questions that was compared to performance on the reality question.

Monolingual and bilingual children exhibited different patterns for the two questions. Both groups performed the same on the appearance question, but the bilingual children outperformed the monolinguals on the reality question. The answers to the appearance question are supported by the continued presence of the objects during questioning. The reality question, in contrast, requires children to go beyond the appearance of the display and state the actual identity or function of the object. Because the appearance conflicts with the correct answer to the reality question, the solution requires children to actively ignore that appearance and state what it is in spite of that misleading perceptual exterior.

On the theory of mind task used in this study, bilingual children outperformed monolinguals on questions that place high demands on the ability to control attention and inhibit misleading perceptual information. Consistently, this is the kind of process that bilingual children master earlier than their monolingual peers.

Bilingualism: What's the Difference?

In the three examples of cognitive performance described above, there is no overall advantage that comes to children who are bilingual. They do not display mathematical precocity and are compromised on certain mathematical computations and problems presented in their weaker language, they do not demonstrate superior skill in monitoring and updating classification problems, and they are not consistently more advanced than monolinguals in establishing the basic concepts for theory of mind. However, in all three domains, problems in which conflicting information, especially perceptual information, interferes with the correct solution and requires attention and effort to evaluate and ultimately ignore one of the options are solved better by bilinguals.

This ability to inhibit attention to misleading information constitutes a significant processing advantage, but other aspects of cognitive development are impaired for bilingual children. One prime area of consistent bilingual *disadvantage* is in receptive vocabulary.

Bilingual children generally score lower than respective monolinguals in each of their languages. This result has been replicated in almost every study that has compared monolingual and bilingual children in the preschool and sometimes early school years (review in Bialystok, 2001). It is this weak competence in the language of schooling that led Macnamara (1966) to caution that bilingual children were disadvantaged both educationally and cognitively, and it was undoubtedly this compromised verbal proficiency that was responsible for his conclusion that bilingualism impaired children's ability to solve mathematical word problems. However, as subsequent research showed, bilingual and monolingual children who were equated for language ability solved mathematical problems to exactly the *same* level of competence. In many domains, therefore, bilingual children develop cognitive skills in the same manner and on the same schedule as do monolinguals. While this may not seem to be newsworthy, early proclamations of the debilitating effect of bilingualism on children's development are safely eradicated by the declaration that the bilingualism might instead have no effect at all on children's development.

What is significant about the bilingual advantage in resolving conflicting information is its persistence across verbal and nonverbal domains of problem solving. This selectivity of attention is an aspect of executive functioning that develops gradually through childhood. Tipper and his colleagues (Tipper, Bourque, Anderson, & Brehaut, 1989; Tipper & McLaren, 1990) have argued that attention is comprised of independent, and independently-developing components. Three of these components are inhibition, selection, and habituation. Two of them, selection and habituation, are as well-formed in childhood and function for children as essentially the same as they do for adults. In contrast, inhibition develops slowly, changing children's performance as it emerges and imposing a measure of selectivity on their behavior.

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; Diamond, in press; Diamond & Taylor, 1996; Harnishfeger & Bjorklund, 1993). Inhibition is the essential factor in distinguishing the performance of the bilingual children, so it may be that bilingualism exerts its effect primarily on the inhibition component of attention.

Inhibition and control of attention are carried out in the frontal lobes (Stuss, 1992). Patients with damage to the frontal lobes experience difficulty in tasks that require switching attention (e.g., Wisconsin Card Sorting Test) and selecting relevant features in the presence of distracting information (e.g., Tower of London) (Burgess & Shallice, 1996; Kimberg, D'Esposito, & Farah, 1997; Luria, 1966; Perrett, 1974). Even automated tasks, like Stroop tests, are difficult for these patients because they have inadequate control over their attention to the irrelevant features of the Stroop stimuli, normally the color word. This performance profile is the reverse of that obtained with bilingual children: What is difficult for frontal patients develops early for bilingual children.

Cognitive control of attention declines in healthy older adults with normal aging. Hasher and Zacks (1988) elaborate 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. Without adequate inhibition, working memory becomes cluttered with irrelevant information and decreases the efficiency of cognitive processing (Hasher, Zacks, & May, 1999). Dempster (1992) proposes a similar description but describes the rise and fall of these inhibitory processes over the entire lifespan, rather than just their decline with aging. The consequence of aging in these views is that older adults have less control over the contents of working memory than do younger adults, a situation that is functionally similar to the difference between monolingual and bilingual children solving problems based on selective attention.

Duncan (1996) uses selective attention and inhibitory control to integrate research from several areas of cognitive processing. He demonstrates that the effects of frontal lobe lesions, differences in intelligence (defined by *g*, the measure of general intelligence proposed by Spearman, 1927), and divided attention, are evidence of the same processes that distinguish between active or passive control of attention. These processes are situated in the frontal lobes, making the frontal structures the seat of highly generalized forms of intelligence. This analysis supports the association between the processes that are enhanced for bilingual children and the processes that are damaged through frontal lobe injury and decline with normal aging. Moreover, these processes are central to general concepts of intelligence as measured by standardized tests. This line of reasoning that includes intelligence, or *g*, in the equation potentially carries profound implications for claims about the effect of bilingualism on intelligence, but such conclusions are vastly premature, as any relevant or detailed research examining the logical steps in this argument does not exist. But bilingualism clearly alters specific cognitive processes that are part of the underpinnings to this broader view of intelligence. Why would bilingualism have this effect?

Current research on the organization of two languages in the mind of adult bilinguals shows convincingly that both languages remain active during language processing in either language. This view is in contrast to earlier models that posited a “switch” that activated only the relevant language (Macnamara & Kushnir, 1971). Evidence for shared processing comes from both psycholinguistic and neuroimaging studies. Psycholinguistic models differ on whether the word level of representation for the two languages is separate (Brauer, 1998; Durgunoglu &

Roediger, 1987; Van Hell & de Groot, 1998) or common (Chen & Ng, 1989; Francis, 1999a; Grainger, 1993; Guttentag, Haith, Goodman, & Hauch, 1984; Hermans, Bongaerts, de Bot, & Schreuder,1998) but agree that these lexical representations are connected through a common conceptual system (review in Smith, 1997). Some of the contradiction between the positions on how words are represented is resolved when proficiency levels are included in the analysis (Francis, 1999b; Kroll & de Groot, 1997; Kroll & Stewart, 1994). Higher levels of proficiency in the second language produce lexical-semantic (conceptual) configurations that more closely resemble those constructed in the first language, whereas second languages with low proficiency levels require mediation of the first language. In fact, below some threshold of proficiency, it becomes debatable whether the individuals are bilinguals or second-language learners. The research examining cognitive consequences of bilingualism that is described above considers only bilinguals who are reasonably proficient in both languages, thereby assuming some approach to balanced proficiency. This is the situation, then, for bilinguals in studies that have demonstrated shared representations that are mutually active during language processing in either language.

Neuroimaging studies of language processing in bilinguals provide a unique perspective on this issue by attempting to identify the regions of cortical activation. Studies by Chee, Tan, & Thiel (1999) and Illes et al. (1999) using fMRI, Klein and colleagues (Klein, Milner, Zatorre, Zhao, & Nikelski, 1999; Klein, Zatorre, Milner, Meyer, & Evans, 1995) using PET, and Pouratian et al., (2000) using iOIS (intraoperative optical imaging of intrinsic signals) found no disparity in the activated regions when performing tasks in either the first or second language (although Pouratian et al., 2000 did additionally find some areas unique to each language in a naming task). Conversely, studies by Kim, Relkin, Lee, and Hirsch (1997) and Dehaene et al.

(1997) using fMRI found some evidence of separate activation when using each of the languages, at least for some bilinguals on some kinds of tasks. Again, part of the conflict can be attributed to the level of proficiency in the second language (e.g., Perani et al., 1998). As in the behavioral studies, high proficiency in both languages was associated with more complete overlap in the processing regions.

If two languages are mutually active (psycholinguistic evidence) and share common representational regions, (neuroimaging evidence), then a mechanism is required to keep them functionally distinct. Without procedures for separating the languages, any use of one language would evoke unwanted intrusions from the other. Green (1998) addresses this question with a model based on inhibitory control, an executive system for activating or inhibiting linguistic representations (lemmas). The model has three components: a hierarchy of language task schemas, lexical representations, and a selection mechanism based on inhibition. A regulatory system, modeled after Shallice’s (1988) supervisory attentional system (SAS), controls levels of activation by regulating the language task schemas. This makes the model responsive to the demands of each individual situation. The task schemas determine output by controlling the activation levels of the competing responses from the two languages and inhibiting the lemmas that belong to the language incorrect for that situation. The basic notion is that each of a bilingual’s two languages can be described on a continuum of activation in a specific context (cf., Grosjean, 1997; Paradis, 1997), and not through a binary switch as earlier models had posited. The central mechanism of this model is inhibition of competing lexical representations. Green cites evidence showing that PET studies of translation indicate increased activity in the anterior cingulate, an area activated during Stroop tasks and associated with the inhibition of prepotent responses (Posner & DiGirolamo, 2000), whereas comparable scans of performance while reading (but not translating) do not invoke activity in this area. This pattern was confirmed in a study by Price, Green, and von Studnitz (1999) who showed separate brain activation patterns for switching and translating, with translating again activating the anterior cingulate.

Green's explanation depends on accepting inhibition as the primary mechanism for negotiating the language used in specific contexts, and independent evidence has supported the plausibility of this interpretation. Juncos-Rabadan and colleagues (1994; Juncos-Rabadan & Iglesias, 1994) have shown that language deterioration in the elderly is attributable to declines in attentional abilities, and that bilinguals suffer loss in attentional processing on both their languages. They attribute the changes to problems with inhibition mechanisms and demonstrate these processing changes to occur equally with both languages in bilinguals.

Studies by Hernandez and colleagues, also examining aging and bilingualism, provide further evidence for the role of inhibitory control mechanisms in language processing for bilinguals (Hernandez & Kohnert, 1999; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Hernandez, Martinez, & Kohnert, 2000). They presented older and younger Spanish-English bilinguals with a switching task in which the participant was required to name simple line drawings in one or the other language. A cue preceding each trial indicated the language in which the response was required. The interesting results come from mixed block presentations in which the two languages were combined into a single block, requiring rapid monitoring and switching between languages. These conditions were more difficult for the older bilinguals than the younger ones, evidenced by a significant increase in the reaction time. More interesting, however, is that an fMRI study of a small number of (young) bilingual individuals performing this task showed that switching between languages was accompanied by activation in the dorsolateral prefrontal cortex, an area involved in task switching and control of attention. Finally, a study by Rodriguez-Fornells, Rotte, Heinze, Nosselt and Munte (2002) used fMRI to locate the ability of bilinguals to prevent interference from the other language through an inhibition mechanism in regions of the frontal lobes.

If the inhibitory control model of Green is correct, then bilingualism, by its very nature, results in greater use of inhibitory control because it is invoked every time language is used. Bilingual children, therefore, experience extensive practice of this executive function in the first few years of life, at least once both languages are known to a sufficient level of proficiency to offer viable processing systems. If this practice in inhibiting linguistic processing carries over to processing in disparate cognitive domains, then bilinguals should be more able than monolinguals to perform tasks that require the inhibition of irrelevant information (see Meuter and also Michael & Gollan, this volume, for related discussion concerning adult bilingual performance).

The prefrontal cortex is the last brain area to mature in development, a possible reason that many of the tasks that require switching attention or ignoring conflicting information are difficult for young children to solve. The bilingual experience of negotiating two language representations, switching attention between them on a constant basis, and selecting subtle features of linguistic input to guide performance in choosing the correct response language may accelerate the development of the responsible cortical areas. Thus, bilingualism may provide the occasion for a more rapid development of an essential cortical center, and the consequence of that development influences a wide range of cognitive activities.

This explanation is based on the assumption that cortical organization is plastic and that it can be altered with experience. Both presumptions are supported in neuroscience research.

Studies by Recanzone, Merzenich, Jenkins, Grajski, and Dinse (1992) comparing finger sensitivity in monkeys that did or did not receive a stimulating learning experience, and Ebert, Pantev, Wienbruch, Rockstroth, and Taub (1995) comparing finger sensitivity in violin players and non musicians, reported cortical reorganization and enhancement in the representation area responsible for those fingers. In both cases, an environmental experience that offered massive practice in an activity resulted in a reorganization of a significant cortical region. In rehabilitation research, Taub (2001) has been successful in reestablishing motor control in areas paralyzed through stroke. Patients who lose control over some area, for example, an arm, have the spared arm immobilized and are trained to use the paralyzed arm through massive practice, an experience which results in the motor control for that arm being transferred to an undamaged cortical region. Bilingualism may provide another example of this kind of reorganizational process. The environmental experience of using two languages from childhood provides massive practice in the attention and inhibition centers of the prefrontal cortex and promotes their development.

The Bilingual Impact

Speculations about the manner in which bilingualism may influence cognitive functioning are rarely couched in terms of detailed processes like control of attention and inhibition. Instead, the descriptions are pitched at the level of overall intelligence, claiming enhancements (e.g., Peal & Lambert, 1962) or deficits (e.g., Saer, 1923), but broad in their implications. How can the processing descriptions proposed here be reconciled with the claims made by these more global views?

In an early description of intelligence, Cattell (1963) distinguished between fluid and crystallized forms. Fluid intelligence declines with aging and is correlated with a range of frontal tasks (Kray & Lindenberger, 2000; Salthouse, Fristoe, McGuthry, & Hambrick, 1998). In contrast, crystallized intelligence remains relatively stable across the lifespan, if anything increasing with the accretion of knowledge and experience, and does not correlate with those tasks that demand on-line processing and attention. In Duncan's (1996) model, described above, he posits a relation between *g* and performance in a variety of frontal tasks, but it is possible that his equation could be made more precise by considering only fluid intelligence rather than the commonality across all forms of intellectual assessment. If bilingualism has an impact on a general form of intelligence, then based on the performance on specific tasks, it is likely that the impact is confined to fluid intelligence, those aspects of performance most dependent on executive control. There is, of course, no evidence that bilingualism *does* affect intelligence. The claim here is more simply that the specific cognitive processes that do appear to be enhanced by bilingualism would most likely impact upon only one aspect of general intelligence, namely fluid intelligence.

The most general aspect of cognition that Peal and Lambert (1962) identified as the locus of bilingual influence was creative thinking and flexibility of thought, a conclusion shared by others as well (cf. MacNab, 1979). The usual explanation for this advantage is that having two linguistic systems and two names for things endows bilinguals with the capacity to see things from different perspectives, in both aspects, and switch between these designations. For example, creativity tasks, such as requiring the participant to generate unusual uses for common objects, requires individuals to suppress the usual use or appearance of these objects, freeing oneself to entertain alternatives. The nonverbal tests in which Peal and Lambert's (1962) bilinguals excelled all required a degree of manipulation as opposed to more straightforward concept formation or computation. These measures are aspects of fluid intelligence. Moreover, they frequently require the ability to ignore misleading information, such as the usual use of a common object, in order to attend to a more subtle feature and propose a novel function. If indeed bilinguals perform these tasks better than monolinguals, it would be attributable to precisely the same processes that ensured their advantage in the other executive function tasks described throughout. In that sense, creativity may indeed be an indirect beneficiary of bilingualism, at least in the way it is assessed on psychological tests.

Bilingualism changes something fundamental about the way cognitive processes are shaped by young children. How extensive these changes are in either cognitive space or developmental time are questions that are still being investigated. Even if these advantages prove to be more transient or more fragile than some of the more optimistic data suggests they might, their role in discarding old fears that bilingualism confuses children and retards their intellectual growth has been a worthy outcome.

References

Astington, J.W. (1993). *The child's discovery of the mind.* Cambridge, MA: Harvard University Press.

Bain, B.C. (1974). Bilingualism and cognition: Toward a general theory. In S.T. Carey (Ed.), *Bilingualism, biculturalism, and education: Proceedings from the conference at College Universitaire Saint Jean.* (pp. 119-128). Edmonton: University of Alberta.

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

Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual mind. *Child Development, 70,* 636-644.

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

Bialystok, E. (2002). Acquisition of literacy in bilingual children: A framework for research. *Language Learning, 52,* 159-199.

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., & Martin, M. (submitted). *Attention and inhibition in bilingual children*.

Brauer, M. (1998). Stroop interference in bilinguals: The role of similarity between the two languages. In A.F. Healy & L.E. Bourne, Jr. (Eds.), *Foreign language learning: Psycholinguistic studies on training and retention* (pp. 317-337). Mahwah, NJ: Erlbaum.

Burgess, P.W., & Shallice, T. (1996). Response suppression, initiation and strategy use following frontal lobe lesions. *Neuropsychologia, 34*, 263-272.

Carlson, S. M., Moses, L. J., & Hix, H. R. (1998). The role of inhibitory control in young children's difficulties with deception and false belief. *Child Development*, *69*, 672-691.

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, *72*, 1032-1053.

Cattell, R.B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology, 54,* 1 – 22.

Chee, M.W.L., Tan, E.W.L., & Thiel, T. (1999). Mandarin and English single word processing studied with functional magnetic resonance imaging. *Journal of Neuroscience, 19,* 3050-3056.

Chen, H.C., & Ng, N.L. (1989). Semantic facilitation and translation priming effects in Chinese-English bilinguals. *Memory and Cognition, 18,* 279-288.

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

Darcy, N.T. (1963). Bilingualism and the measurement of intelligence: A review of a decade of research. *Journal of Genetic Psychology, 103,* 259-282.

Dehaene, S., Dupoux, E., Mehler, J., Cohen, L., Paulesu, E., Perani, D., van de Moortele, P., Lehericy, S., & Le Bihan, D. (1997). Anatomical variability in the cortical representation of first and second language. *NeuroReport, 8,* 3809-3815.

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. (in press). 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.* London: Oxford University Press.

Diamond, A., & Taylor, C. (1996). Development of an aspect of executive control: Development of the abilities to remember what I said and to "do as I say, not as I do". *Developmental Psychology, 29,* 315-334.

Duncan, J. (1996). Attention, intelligence, and the frontal lobes. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 721-733). Cambridge, MA: MIT Press.

Duncan, S.E., & De Avila, E.A. (1979). Bilingualism and cognition: Some recent findings. *Journal of the National Association for Bilingual Education, 4,* 15-50.

Durgunoglu, A.Y., & Roediger, H.L (1987). Test differences in accessing bilingual memory. *Journal of Memory and Language, 26,* 377-391.

Ebert, T., Pantev, C., Wienbruch, C., Rockstroth, B., & Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science, 270,* 305-306.

Ellis, N.C. (1992). Linguistic relativity revisited: The bilingual word-length effect in working memory during counting, remembering numbers, and mental calculation. In R.J. Harris (Ed.), *Cognitive processing in bilinguals* (pp. 137–155). Amsterdam: North-Holland.

Francis, W.S. (1999a). Analogical transfer of problem solutions within and between languages in Spanish-English bilinguals. *Journal of Memory and language, 40,* 301-329.

Francis, W.S. (1999b). Cognitive integration of language and memory in bilinguals; semantic representation. *Psychological Bulletin, 125,* 193-222.

Frenck-Mestre, C., & Vaid, J. (1993). Activation of number facts in bilinguals. *Memory and Cognition, 21,* 809-818.

Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule based reasoning. Cognitive *Development, 10*, 483-527.

Fuson, K. C. (1988). *Children's counting and concepts of number*. New York: Springer-Verlag.

Geary, D.C., Cormier, P., Goggin, J.P., Estrada, P., & Lunn, M.C.E. (1993). *International Journal of Psychology, 28,* 185-201.

Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge, MA: Harvard University Press.

Gould, S. J. (1981). *The mismeasure of man.* New York: Norton.

Grainger, J. (1993). Visual word recognition in bilinguals. In R. Schreuder & B. Weltens (Eds.), *The bilingual lexicon* (pp. 11-25). Amsterdam: John Benjamins.

Green, D.W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1,* 67-81.

Grosjean, F. (1997). Processing mixed languages: Issues, findings, and models. In A.M. B. De Groot & J.F. Kroll (Eds.), *Tutorials in bilingualism: Psycholinguistic perspectives.* (pp. 225-254). Mahwah, NJ: Erlbaum.

Guttentag, R.E., Haith, M.M., Goodman, G.S., & Hauch, J. (1984). Semantic processing of unattended words in bilinguals: A test of the input switch mechanism. *Journal of Verbal Learning and Verbal Behavior, 23,* 178-188.

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

Hakuta, K., Ferdman, B.M., & Diaz, R. (1987). Bilingualism and cognitive development: three perspectives. In S. Rosenberg (Ed.), *Advances in applied psycholinguistics: Reading, writing, and language learning, Volume 2* (pp. 284-319). New York: Cambridge University Press.

Hala, S., & Russell, J. (2001). Executive control with strategic deception: A window on early cognitive development? *Journal of Experimental Child Psychology, 80,* 112-141

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.P. (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.

Hermans, D., Bongaerts, T., de Bot K., & Schreuder, R. (1998). Producing words in a foreign language: Can speakers prevent interference from their first language? *Bilingualism: Language and Cognition, 1,* 213-229.

Hernandez, A.E., Dapretto, M., Mazziotta, J., & Bookheimer, S. (2001). Language switching and language representation in Spanish-English bilinguals: An fMRI study. *NeuroImage, 14,* 510-520.

Hernandez, A.E., & Kohnert, K.J. (1999). Aging and language switching in bilinguals. Aging, Neuropsychology, and Cognition, 6, 69-83.

Hernandez, A.E., Martinez, A., & Kohnert, K. (2000). In search of the language switch: An fMRI study of picture naming in Spanish-English bilinguals. *Brain and Language, 73,* 421-431.

Hughes, C. (1998). Executive function in preschoolers: Links with theory of mind and verbal ability. *British Journal of Developmental Psychology*, 16, 233-253.

Illes, J., Francis, W.S., Desmond, J.E., Gabrieli, J.D.E., Glover, G.H., Poldrack, R., Lee, C.J., &

Wagner, A.D. (1999). Convergent cortical representation of semantic processing in bilinguals. *Brain and language, 70,* 347-363.

Jacques, S., Zelazo, P.D., Kirkham, N.Z., & Semcesen, T.K. (1999). Rule selection versus rule execution in preschoolers: An error-detection approach. *Developmental Psychology, 35,* 770-780.

Juncos-Rabadan, O. (1994). The assessment of bilingualism in normal aging with the Bilingual Aphasia Test. *Journal of Neurolinguistics, 8,* 67-73.

Juncos-Rabadan, O., & Iglesias, F.J. (1994). Decline in the elderly's language: Evidence from cross-linguistic data. *Journal of Neurolinguistics, 8,* 183-190.

Kim, K.H.S., Relkin, N., Lee, K., & Hirsch, J. (1997). Distinct cortical areas associated with native and second languages. *Nature, 388,* 171-174.

Kimberg, D. Y., D'Esposito, M., & Farah, M. J. (1997). Effects of bromocriptine on human subjects depend on working memory capacity. *Neuroreport, 8*, 3581-3585.

Kirkham, N., Cruess, L, & Diamond, A. (in press). Helping children apply their knowledge to their behavior on a dimension-switching task. *Cognition*.

Klein, D., Zatorre, R.J., Milner, B., Meyer, E., & Evans, A.C. (1995). The neural substrates of bilingual language processing: evidence from positron emission tomography. In M. Paradis (Ed.), *Aspects of bilingual aphasia* (pp. 23-36). Oxford: Pergamon.

Klein, D., Milner, B., Zatorre, R.J., Zhao, V., & Nikelski, J. (1999). Cerebral organization in bilinguals: A PET study of Chinese-English verb generation. *NeuroReport, 10,* 2841-2846.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15,* 126-147.

Kroll, J.F., & de Groot, A.M.B. (1997). Lexical and conceptual memory in the bilingual: Mapping form to meaning in two languages. In A.M.B. de Groot & J.F. Kroll (Eds.), *Tutorials in bilingualism.* (pp. 169-199). Mahwah, NJ: Erlbaum.

Kroll, J.F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language, 33,* 149-174.

Luria, A.R. (1966). *Higher cortical functions in man.* London: Tavistock.

MacNab, G.L. (1979). Cognition and bilingualism: A reanalysis of studies. *Linguistics, 17,* 231-255.

Macnamara, J. (1966). *Bilingualism and primary education.* Edinburgh: Edinburgh University Press.

Macnamara, J. (1967). The effect of instruction in a weaker language. *Journal of Social Issues, 23,* 121-135.

Macnamara, J., & Kushnir, S. (1971). Linguistic independence of bilinguals: The input switch. *Journal of Verbal Learning and Verbal Behavior, 10,* 480-487.

Mägiste, E. (1980). Arithmetical calculations in monolinguals and bilinguals. *Psychological Research, 42,* 363-373.

Marsh, L.G, & Maki, R.H. (1976). Efficiency of arithmetic operations in bilinguals as a function of language. *Memory & Cognition, 4,* 459-464.

McClain, L., & Huang, J.Y.S. (1982). Speed of simple arithmetic in bilinguals. *Memory & Cognition, 10,* 591-596.

Mestre, J.P. (1988). The role of language comprehension in mathematics and problem solving. In R.R. Cocking & J.P. Mestre (Eds.), *Linguistic and cultural influences on learning* *mathematics* (pp. 201-220). Hillsdale, NJ: Erlbaum.

Morales, R.V., Shute, V.J., & Pellegrino, J.W. (1985). Developmental differences in understanding and solving simple mathematics word problems. *Cognition and Instruction, 2,* 41-57.

Norman, D.A., & Shallice, T. (1986). Attention in action: Willed and automatic control of behavior. In R.J. Davidson, G.E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation, Volume 4* (pp. 1 – 18). New York: Plenum Press.

Paradis, M. (1997). The cognitive neuropsychology of bilingualism. In A.M.B. de Groot & J.F. Kroll (Eds.), *Tutorials in bilingualism: Psycholinguistic perspectives* (pp. 331-354). Mahwah, NJ: Erlbaum.

Peal, E., & Lambert, W. (1962). The relation of bilingualism to intelligence. *Psychological Monographs, 76* (Whole No. 546). 1-23.

Perani, D., Paulesu, E., Galles, N.S., Dupoux, E., Dehaene, S., Bettinardi, V., Cappa, S.F., Fazio, F., & Mehler, J. (1998). The bilingual brain: Proficiency and age of acquisition of the second language. *Brain, 121,* 1841-1852.

Perner, J. (1991). *Understanding the representational mind*. Cambridge, MA: MIT Press.

Perner, J., Stummer, S., & Lang, B. (1998). Executive functions and theory of mind: Cognitive complexity or functional dependence? In P. D. Zelazo, J. W. Astington, & D. R. Olson (Eds.), *Developing theories of intention: Social understanding and self-control* (pp.133-152). Mahwah, NJ: Erlbaum.

Perrett, E. (1974). The left frontal lobe of man and the suppression of habitual responses in verbal categorical behavior. *Neuropsychologia, 12,* 323-330.

Pinker, S. (1994). *The language instinct.* New York: W. Morrow and Co.

Posner, M.I., & DiGirolamo, G.J. (2000). Executive attention: Conflict, target detection, and cognitive control. In R. Parasuraman (Ed.), *The attentive brain* (pp.401-423). Cambridge, Mass: MIT press.

Pouratian, N., Bookheimer, S.Y., O'Farrell, A.M., Sicotte, N.L., Cannestra, A.F., Becker, D., & Toga, A. (2000). Optical imaging of bilingual cortical representations. *Journal of Neurosurgery, 93,* 676-681.

Price, C.J., Green, D.W., & von Studnitz, R. (1999). A functional imaging study of translation and language switching. *Brain, 122,* 2221-2235.

Recanzone, G.H., Merzenich, M.M., Jenkins, WM., Grajski, K.A., & Dinse, H.R. (1992). Topographic reorganization of the hand representation in cortical area 3b of owl monkeys trained in a frequency-discrimination task. *Journal of Neurophysiology, 67,* 1031-1056.

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

Ricciardelli, L.A. (1992). Bilingualism and cognitive development in relation to threshold theory. *Journal of Psycholinguistic Research, 21,* 301-316.

Rodriguez-Fornells, A., Rotte, M., Heinze, H-J., Nosselt, T.M, & Munte, T.F. (2002). Brain potential and functional MRI evidence for how to handle two languages with one brain. *Nature, 415,* 1026-1029.

Saer, D.J. (1923). The effects of bilingualism on intelligence. *British Journal of Psychology, 14,* 25-38.

Salthouse, T.A., Fristoe, N.M., McGuthry, K.E., & Hambrick, D.Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychology and Aging, 13,* 445-461.

Secada, W.G. (1991). Degree of bilingualism and arithmetic problem solving in Hispanic first graders. *The Elementary School Journal, 92,* 213-231.

Shallice, T. (1988). *From neuropsychology to mental structure.* Cambridge: Cambridge University Press.

Smith, M.C. (1997). How do bilinguals access lexical information? In A.M.B. de Groot & J.F. Kroll (Eds.), *Tutorials in bilingualism* (pp. 145-168). Mahwah, NJ: Erlbaum.

Spearman, C. (1927). *The abilities of man.* New York: Macmillan.

Spelke, E.S., & Tsivkin, S. (2001). Language and number: A bilingual training study. *Cognition, 78,* 45-88.

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

Taub, E. (2001, April). *Adult brain plasticity: Unlearning paralysis.* Paper presented in symposium, "Beyond the myth: Experience expectant and experience dependent brain plasticity", at the biennial meeting of the Society for Research in Child Development, Minneapolis, Minnesota.

Tipper, S.P., Bourque, T.A., Anderson, S.H., & Brehaut, J.C. (1989). Mechanisms of attention: A developmental study. *Journal of Experimental Child Psychology, 48,* 353-378.

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.

Torrance, E.P., Wu, J.J., Gowan, J.C., & Aliotti, N.C. (1970). Creative functioning of monolingual and bilingual children in Singapore. *Journal of Educational Psychology, 61,* 72-75.

Towse, J.N., Redbond, J., Houston-Price, C.M.T., & Cook, S. (2000). Understanding the dimensional change card sort: Perspectives from task success and failure. *Cognitive Development, 15,* 347-365.

Van Hell, J.G., & de Groot, A.M.B. (1998). Conceptual representation in bilingual memory: Effects of concreteness and cognate status in word association. *Bilingualism: Language and Cognition, 1,* 193-211.

Wellman, H.M. (1990). *Child's theory of mind.* Cambridge, MA: MIT Press.

Wynn, K. (1992). Children's acquisition of the number words and the counting system. *Cognitive Psychology, 24*, 220-251.

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 & Philadelphia: John Benjamins.

Zelazo, P.D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11*, 37-63.

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