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PAPER

Attention and inhibition in bilingual children: evidence from the dimensional change card sort task

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Abstract

In a previous study, a bilingual advantage for preschool children in solving the dimensional change card sort task was attributed to superiority in inhibition of attention (Bialystok, 1999). However, the task includes difficult representational demands to encode and interpret the task stimuli, and bilinguals may also have profited from superior representational abilities. This possibility is examined in three studies. In Study 1, bilinguals outperformed monolinguals on versions of the problem containing moderate representational demands but not on a more demanding condition. Studies 2 and 3 demonstrated that bilingual children were more skilled than monolinguals when the target dimensions were perceptual features of the stimulus and that the two groups were equivalent when the target dimensions were semantic features. The conclusions are that bilinguals have better inhibitory control for ignoring perceptual information than monolinguals do but are not more skilled in representation, confirming the results of the original study. The results also identify the ability to ignore an obsolete display feature as the critical difficulty in solving this task.

Introduction

Studies of the cognitive abilities of bilingual children have primarily been concerned with identifying developmental differences between monolinguals and bilinguals. However, the unique cognitive configuration for bilinguals in which two languages emerge and interact from a single conceptual system also provides a means for investigating aspects of cognitive development and cognitive organization itself. The present studies examine the ability of monolingual and bilingual children to solve a cognitive problem with the intention of understanding both the impact of bilingualism on children's solutions and the function of specific cognitive processes in development for both groups of children.

The basis for the investigation is a distinction between two cognitive processes that have been shown to diverge in the development of monolingual and bilingual children (Bialystok, 1993). Evidence for developmental differences by monolingual and bilingual children in these aspects of cognitive processing not only isolates the effect of bilingualism on children's cognition but also contributes to a broader understanding of the development of these cognitive processes (review in Bialystok, 2001).

The two processes are called analysis of representations and control of attention. Analysis is the process of constructing mental representations that are increasingly capable of recording information that is detailed, explicit and abstract. As mental representations become analysed, knowledge can be organized around abstract categories and details retrieved independently of their contexts. Analysis resembles the process of representational redescription proposed by Karmiloff-Smith (1992) as the primary mechanism of development. With development, mental representations increase in their explicitness, organization and abstractness, allowing access to more detailed knowledge and allowing children to break free of the modular constraints within which it was accrued.

Control of attention is the process by which attention is selectively directed to specific aspects of a representation, particularly in misleading situations. Problem solving inevitably requires intentional focus on some types of information and the exclusion of others. This selective attention is more difficult if a habitual or salient response contradicts the optimal one and must be overruled, making inhibition an essential component of control. Tipper and his colleagues (Tipper, 1992; Tipper & McLaren, 1990; Tipper, Bourque, Anderson & Brehaut, 1989) have argued

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that attention comprises independent and independently developing components, including a selection mechanism, along with a separate mechanism for ignoring conflicting, irrelevant stimuli. Tipper *et al.* (1989) point out that the ability to ignore conflicting, irrelevant information is common to a variety of different perceptual inputs and response outputs.

Several researchers have documented the development of inhibition in young children and demonstrated its central role in a variety of cognitive tasks (Dagenbach & Carr, 1994; Dempster, 1992; Diamond & Taylor, 1996; Harnishfeger & Bjorklund, 1993). Bunge, Dudukovic, Thomason, Vaidya and Gabrieli (2002) compared children's and adults' performance on an interference suppression (flanker) task and a response inhibition (go/no-go) task, both known to require inhibition. Children were less accurate and had longer reaction times than adults on both tasks, but fMRI data additionally revealed different loci of activation for children and adults. Bunge *et al.* (2002) concluded that immature prefrontal activation accounted for poor performance on inhibition tasks; development brings both improved performance and a shift in the brain areas associated with these functions. Diamond and Taylor (1996) made a similar but broader claim by adding the important observation that most cognitive tasks, such as those used in Piagetian research (e.g. conservation), require both inhibition *and* working memory in order to remember the rules and follow them in a distracting context. These demands are part of the executive function and both are aspects of the process of control.

Children who become bilingual in early childhood might differ from monolinguals in the development of either analysis of representations or control of attention (or both). The need to encode, interpret and associate words from two languages with a common concept of the world requires more advanced representation because the connections between the words exist at a higher or more abstract level than the connection between a particular word and its meaning. Therefore, the semantic structure of a bilingual might be more hierarchical than that of a monolingual, and the process of constructing this structure could enhance children's representational processes. Alternatively, the need to attend to one set of labels and ignore equally meaningful labels from the other language requires control of attention. Constant experience in attending to one of the languages and ignoring the other might enhance the ability of bilinguals to selectively attend to appropriate cues and inhibit attending to others.

Tasks across various cognitive domains have shown that bilingual children develop control over attention more efficiently than monolinguals but that there is no difference between the two groups in progress with analysis of representations (summary in Bialystok, 2001). In metalinguistic tasks, bilingual children were better than monolinguals at judging the grammaticality of sentences that contained distracting semantic anomalies (*Apples grow on noses*) but both groups were equivalent in detecting errors in sentences that had grammatical violations but no distracting information (*Apples on trees grow*) (Bialystok, 1986, 1988; Cromdal, 1999). In concepts of print tasks, bilingual children were better than monolinguals at understanding that the meaning of a printed word does not change if it is moved to accompany a different picture, requiring them to suppress attention to the picture name but not necessarily better in understanding the detailed rules that specify how the print corresponds to the spoken word (Bialystok, 1997, 1999; Bialystok, Shenfield & Codd, 2000). In tasks assessing number cardinality, bilingual children were better than monolinguals at judging absolute quantity in the presence of distracting perceptual information but both groups were the same in judging equivalence when there were no distracting perceptual cues (Bialystok & Codd, 1997).

A task that provides an incisive test of the hypothesis regarding a bilingual advantage in cognitive processing is the dimensional change card sort task, developed by Zelazo and his colleagues (Frye, Zelazo & Palfai, 1995; Zelazo, Frye & Rapus, 1996). The task requires children to sort a set of cards by one dimension and then to re-sort the same cards by a different dimension. Two compartments are provided for the sorted cards, and each compartment is marked by a target stimulus. For example, the set of cards could contain items that are either blue squares or red circles. The target stimuli on the sorting compartments would be a red square and a blue circle. Children are first told (pre-switch phase) to sort by one dimension, for example, colour, and place all the blue cards into the box indicated by a blue circle (although that description is not used) and all the red cards into the box indicated by a red square. In the post-switch phase, children are asked to sort by shape, so each card must now be re-assigned to the opposite box. The square cards must be placed into the box indicated by the red square (instead of the blue circle) and the circle cards into the box indicated by the blue circle. The finding is that preschool children persist in sorting the cards according to the first dimension (colour) and continue to put the blue squares into the box indicated by the blue circle.

Zelazo and his colleagues (Frye *et al.*, 1995; Jacques, Zelazo, Kirkham & Semcesen, 1999; Zelazo & Frye, 1997; Zelazo *et al.*, 1996) have argued that children perseverate on the first set of rules because they have not acquired the ability to represent a higher-order rule that embodies all the lower-order rules. The thrust of their explanation, called the cognitive complexity and control theory, is that the task requires children to construct complex embedded representations of rules and that they are unable to do this until they are about 5 years old. Three-year-olds fail this task because they are selecting the default rules they have already used in response to an experimenter's request that they sort cards.

This explanation places much of the burden for correct performance on the development of adequate representations of the rule structure of the task, the responsibility of analysis. The task requires that children's level of representational analysis is sufficient to encompass the hierarchical levels needed to solve the post-switch phase of the problem. Although previous studies have not found representational advantages for bilingual children, the representational demands of this problem are similar to those used by bilinguals to represent two languages in a hierarchy. In both cases, the selection of the correct sorting response or the correct language is determined by contextual instructions or circumstances. Therefore, if there is indeed a representational advantage for bilinguals, it should emerge on this problem. The task also imposes high demands on control of attention: Children must inhibit attention to a dimension that was previously valid and refocus on a different aspect of the same stimulus. These control demands resemble the processes in which bilingual children have been shown to excel using other tasks. In a study with children 4 and 5 years old solving the dimensional change card sort task, bilingual children solved the problem better than monolinguals, showing a performance advantage of about one year (Bialystok, 1999).

Both analysis and control are involved in the solution to this problem. Children need to conceptualize both the stimuli and the rules by constructing appropriate mental representations, and, as noted by Zelazo and Frye (1997), this is difficult for young children. The representational abilities needed to encode the relevant features of the stimuli and the necessary hierarchy of rules might not be the same, making different demands and developing at different times. Additionally, children need to inhibit the response tendency set up by the initial stage of sorting. Two forms of inhibition are required. The first, response inhibition, is needed to resist carrying out the familiar motor action that would place each card in the box with which it was first associated. The second, conceptual inhibition, is needed to resist attending to the previously relevant feature (e.g. colour) in order to represent the new feature (e.g. shape) as the classification criterion. By this definition, conceptual inhibition entails both the inhibitory control to avoid attending to the obsolete feature and the representational skill to designate the new feature as criterial. Our proposal is that the source of difficulty in the card sort problem is in conceptual inhibition, the ability to inhibit attention to a prepotent mental representation.

Two recent studies provide converging support for this interpretation. Typically, the experimenter names each card before passing it to the child to be sorted, but children persist in sorting it according to the obsolete dimension. Kirkham, Cruess and Diamond (2003) revised the procedure by requiring the child to name the 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 attention 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. These studies indicate that children persist in mentally encoding the cards according to the description relevant in the pre-switch phase. In the post-switch phase, they must inhibit those descriptions to reinterpret the card in terms of the new feature. This process is conceptual inhibition, and it is partly dependent upon children's ability to construct and manipulate the necessary mental representations of the task stimuli.

In sum, three processes are involved in the card sort task. Bilingual children may be better at representation (hierarchically encoding the rules and representing relevant features of the stimuli), response inhibition (resisting previous motor patterns) or conceptual inhibition (inhibiting attention to previous mental descriptions). The results of the previous study could not distinguish among these possibilities so the present studies were designed to disentangle them.

Study 1

The card sorting task was instantiated in a computer program and adapted to vary the representational demands of both the sorting rules and the stimuli by creating four conditions. Representational complexity was manipulated in the number of dimensions depicted in the stimulus and the semantic content of those dimensions. The first condition was based on one perceptual feature; the second on two dimensions depicting colours or shapes; the third on colour and object outlines; the fourth on semantic properties of objects. The hierarchical complexity of the sorting rules was the same for the last three conditions but simpler for the first condition in which only one dimension was involved. Stimulus complexity increased across successive conditions as stimuli became more detailed. Response inhibition was identical in all conditions because the post-switch phase always required refraining from making the same response as in the pre-switch phase. The major difference between the conditions was in conceptual inhibition, namely, the type of information in the original representation that needed to be ignored when performing in the post-switch phase.

It is important to be clear about the distinction between representation of the rules and representation of the stimuli. According to Zelazo and Frye (1997), the task is difficult because children cannot represent the rules as embedded components of a hierarchical structure. Our claim is that a further representational challenge is in properly selecting, encoding and representing features of the stimuli to match the previously represented features of the target. Aside from the inhibitory control needed to ignore the obsolete features, the representation itself is difficult. The present study disentangles the challenge posed by rule representation and stimulus representation by holding constant the complexity of the rules across three of the conditions while varying the complexity of the stimuli that must be categorized by those rules.

There are three possible outcomes. First, if the bilingual advantage in the previous study were from a greater representational ability, then that advantage should increase across the four conditions as the conceptual demands increase and present increasing challenges to children with weak representation abilities. It is more difficult to represent an object than a simple colour because the object first needs to be identified; it is more difficult to represent a semantic feature than an object because the identified object needs to be interpreted. Second, if the bilingual advantage reflected greater ability to execute response inhibition (i.e. inhibit a prepotent motor response), then the bilinguals should outperform the monolinguals on all four conditions equally because all four require that the response be reversed in the second phase. Third, if the bilingual advantage came from enhanced ability in conceptual inhibition, then the prediction depends on an interaction between representation and inhibition demands. All the children would be equally able to represent the target feature, but the bilinguals would be better able to ignore the original representation to create a new one. Therefore, a problem based on only one dimension will be solved equally by both groups because there is no conflicting dimension to ignore in constructing the rule for the post-switch phase. Problems based on two dimensions would be solved better by bilinguals because of their superior ability to ignore the dimension used in the pre-switch phase. The extra difficulty of the condition based on semantic properties may benefit bilinguals because of their ability to ignore the interpretation used in the pre-switch phase, but the additional representational burden may override this potential advantage, leaving both groups again equivalent on this last condition. Therefore, the three possible outcomes anticipate different interactions between the two language groups and the four conditions: the first predicts an increasing bilingual advantage, the second predicts a constant bilingual advantage, and the third predicts a bilingual advantage only on selected conditions.

Method

Participants

There were 67 children in the study, consisting of 36 English monolinguals (18 boys and 18 girls) with a mean age of 59.1 months and 31 Chinese-English bilinguals (21 boys and 10 girls) with a mean age of 58.9 months. The bilingual children spoke Cantonese at home and English in the community and at school and attended English-language childcare programmes in a neighbourhood where there is a large Chinese population. The communities in which the monolingual and bilingual children lived were geographically close and similar in socioeconomic status. Although the task is traditionally used with 3-year-olds, computerization of it made it appropriate for older children. The additional constraint for the present study was that 3-year-olds rarely have enough proficiency in two languages to be classifiable as bilingual.

Materials and procedure

Peabody Picture Vocabulary Test-Revised

The PPVT-R is a standardized test of English receptive vocabulary (Dunn & Dunn, 1981). Children are required to choose (either verbally or by pointing) one picture from a set of four that illustrates the word spoken by the experimenter. The items become more difficult as testing progresses. A basal score is established, and testing continues until the child makes six errors in eight consecutive responses. Standardized tables convert raw scores to percentiles, stanines and standard scores.

The test was administered to all the children to establish that the bilingual children had English proficiency that was similar to the monolingual children. Because they spoke Chinese at home, adequate English skills would confirm their status as bilingual. Children were eliminated if they had a stanine of less than 3, a procedure that was necessary to ensure that the participants were truly bilingual. In previous research, children with a weak knowledge of one of their languages, more appropriately called second-language learners, did not exhibit the same cognitive advantages as did children who were more balanced bilinguals (Bialystok, 1988). This process excluded 26 children intended for the bilingual group. The PPVT test was given first, so children who failed to meet this criterion did not proceed with the other tests.

Forward digit span

This task is similar to that in the WISC-R (Weschler, 1974), and was used as a rough measure of working memory capacity. Children were presented with a series of digits and were required to repeat the string of digits back to the experimenter in the same order they had heard it. Children were allowed a second chance at a string length if they made an error. The test ended when the child made two consecutive errors at the same string length and the child's digit span score was the number of digits in the last correct series.

Raven's Coloured Progressive Matrices

This 36-item test was originally designed as a measure of general intelligence (Raven, Court & Raven, 1986). It is considered a measure of reasoning by analogy, organizing spatial perceptions into semantically related wholes and forming comparisons (Sattler, 1988). The intention was not to measure the intelligence of the children but to assure that the groups were functioning at a similar intellectual level.

Computerized dimensional change card sort

The task consisted of four conditions, or games, each based on a different level of conceptualization for the sorting rule. The games were presented on an IBM Thinkpad computer. A black cover was placed over the keyboard exposing only three keys: the 'W', the 'P' and the spacebar. The 'W' and 'P' keys were selected for their symmetry to the monitor and were covered with labels marked 'X' and 'O', respectively, and the spacebar was covered with a white label. An animated character appeared on the screen before each new game and each switch phase in order to explain the rules to the child. In the colour game, a square appeared centrally, and the child was required to respond with a key press. For the other three games, small target stimuli, simulating boxes with pictures on them, also appeared near the bottom of the screen directly aligned with one of the response keys. The child was told to press the button closest to the box they wanted the item to go in. This configuration is illustrated in Figure 1 for each condition. Three practice trials with feedback preceded the presentation of the pre-switch rule for each game. If the child was incorrect on one of the practice trials, the rule was repeated automatically and the child was allowed three more tries. This continued until the child was able to perform the three practice trials accurately. No practice trials were allowed in the post-switch phase, and there was no feedback on the actual trials. The experimenter remained with the child and repeated instructions if necessary.

1. *Colour game*. The stimuli were five red squares and five blue squares presented in a random order. In one set of rules, children were told to press the button with the X on it when the red square appeared and to press the button with the O on it when the blue square appeared. Following completion of the 10 trials, children were told that the rule had changed. In this new game, they were to press the X button if the blue square appeared and the O button if the red square appeared. Again, there were 10 trials, and the squares were presented in a random order.

2. *Colour-shape game*. This condition is a computerized version of the task used by Bialystok (1999). The stimuli were red circles and blue squares. The screen showed two boxes at the bottom, each with a target stimulus over it. One box was indicated by a picture of a red square and the other by a picture of a blue circle. The stimulus to be sorted was presented in the centre of the screen. In the colour game, the child was told to put all the blue pictures in the box with the blue picture on it, and all the red pictures in the box with the red picture on it. Therefore, all the blue squares went into the blue box and the red circles into the red box. The child pressed the button (marked X or O) closest to the appropriate box and the picture visually 'dropped' into that space. There were 10 items in this phase.

At the end of this phase, the animated figure appeared again and explained the post-switch rules. In this example, the next phase was the shape game, and children were told to place the squares in the box with the square on it and the circles into the box with the circle on it. The same target pictures remained on the sorting boxes. Again, there were 10 trials including five circles and five squares presented in a random order.

3. *Colour-object game*. This was identical to the previous game except that meaningful objects were used instead of Cartesian shapes. Hence, the stimuli consisted of red flowers and blue rabbits and the target stimuli on the sorting boxes were red rabbits and blue flowers.

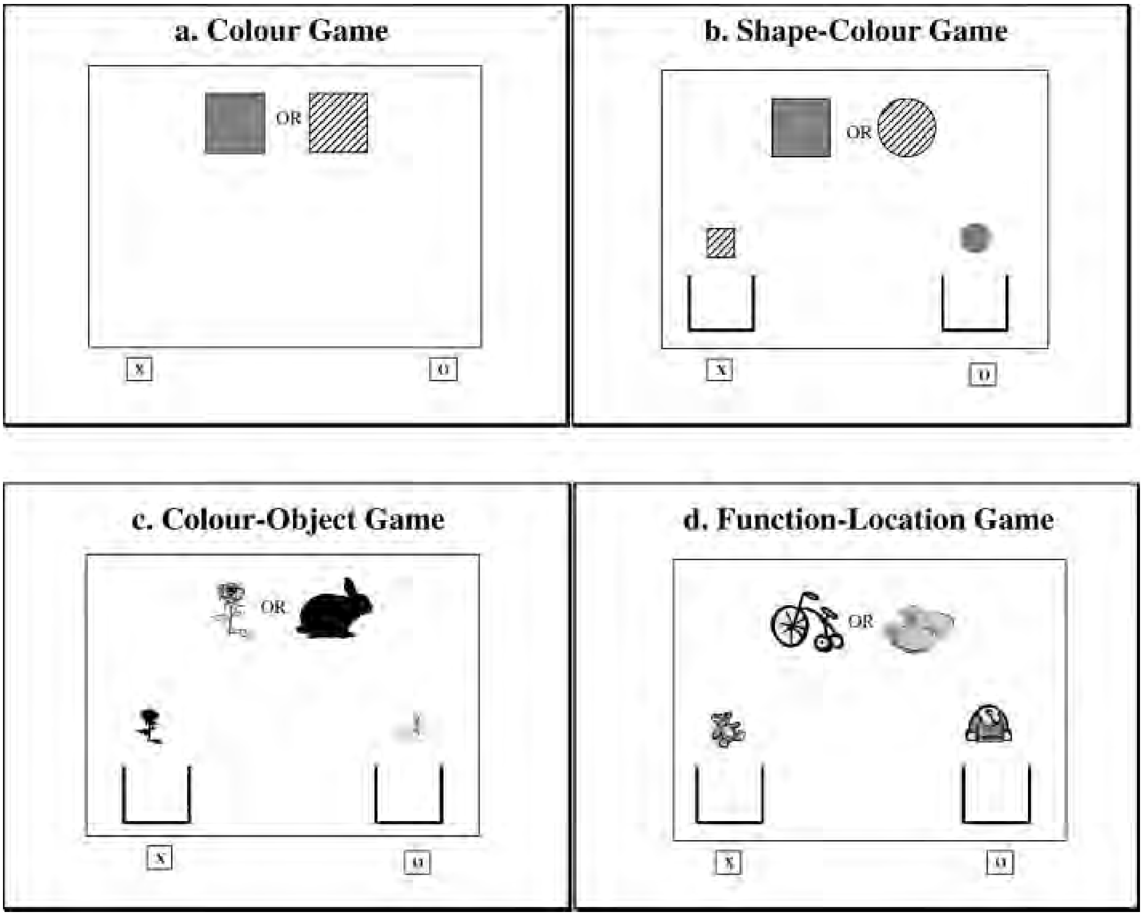

Figure 1 *Schematic illustration of four games in sorting task in Study 1.*

4. *Function-location game*. In this condition, the sorting dimensions were abstract properties of the stimuli instead of perceptual features. The stimulus items consisted of a functional property – things to play with or things to wear – and a location property – things that go inside the house or things that go outside the house. The set consisted of five things to play with that went outside the house (bicycle, skateboard, pail and shovel, skipping rope, kite) and five things to wear that went inside the house (slippers, nightgown, bib, ballet shoes, and baby pyjamas). The target pictures on the sorting boxes were a teddy bear (play-inside) and a winter jacket (wear-outside), reversing the dimensional pairings. In the function game, the instruction was to put all the things to play with in the box with the teddy bear and all the things to wear in the box with the jacket. In the location game, the rule was to put all the things that go inside the house in the box with the teddy bear and all the things that go outside the house in the box with the jacket.

The four games were presented in the fixed order of increasing difficulty that is listed above but the order in which the sorting rules were presented within each condition was counterbalanced. This was done to avoid the possibility of children doing worse on the most difficult game simply because it was first. The presentation order of the pictures was randomized for each game.

Children participated in two sessions separated by about a week. The first session consisted of the preliminary measures and the second was devoted to the computerized sorting tasks. Each session took approximately 20 minutes.

Results

A series of t-tests was carried out on each of the PPVT-R standard scores, forward digit span scores, and Raven's Matrices scores, to determine if there were differences between the groups. Despite a rigid selection criterion, the monolingual children ($M = 112.2$, SD = 15.2) outperformed the bilingual children ($M = 87.8$, SD = 10.6), on the PPVT, $t(65) = 7.09$, $p < .01$. There was no difference between the groups on digit span ($M = 4.5$, SD = 1.07),

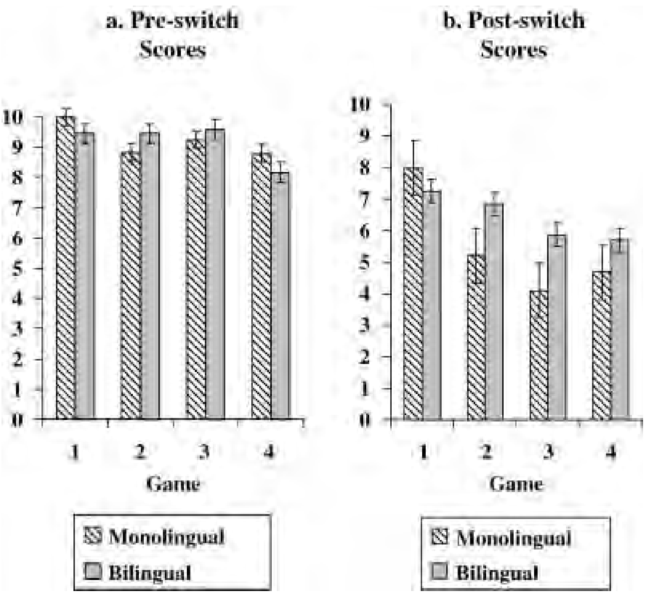

Figure 2 *Mean score by language group and phase in Study 1.*

$t < 1$, or Raven's Matrices ($M = 13.9$, SD = 4.6), $t < 1$, confirming that the children in the two groups were equivalent on basic cognitive skills.

Scores from the sorting task included a score out of 10 for each of the pre-switch and post-switch phases in each of the four games. The mean scores for these data are shown in Figure 2a for the pre-switch trials and Figure 2b for the post-switch trials.

These scores were examined in a three-way repeated measures ANOVA for game (4), phase (2) and language group (2).[1] Typically, the only relevant data in analysing performance in this task is the post-switch scores. In the present study, however, the pre-switch data are necessary to establish that the groups do not differ in this phase, ideally expressed as an interaction of phase and group. There were main effects of game, $F(3, 183) = 10.62$, $p < .001$, phase, $F(1, 65) = 116.05$, $p < .0001$, indicating better performance on pre-switch than post-switch trials, and group, $F(1, 65) = 6.84$, $p < .01$, showing higher scores for the bilinguals. Contrast analyses on the game factor revealed that the function-location game was more difficult than the other three, which did not differ from each other. There were two interactions with game: game and phase, $F(3, 183) = 5.84$, $p < .0008$, and game and group, $F(3, 183) = 2.71$, $p < .04$. The interaction of group and phase approached significance, $F(1, 65) = 3.02$, $p = .08$.

The interactions involving game were examined by a simple effects analysis holding the game factor constant. For the colour game, pre-switch scores ($M = 9.32$, SD = 1.25) were higher than post-switch ($M = 7.66$, SD = 3.15) items, $F(1, 65) = 19.74$, $p < .001$, with no effect of language group. For the colour-shape game, pre-switch ($M = 9.12$, SD = 1.62) items were better than post-switch ($M = 5.97$, SD = 3.87) scores, $F(1, 65) = 37.50$, $p < .001$, and bilingual children ($M = 8.15$, SD = 4.18) scored higher than monolinguals ($M = 7.02$, SD = 2.95), $F(1, 65) = 9.87$, $p < .002$. For the colour-object game, pre-switch items ($M = 9.40$, SD = 1.10) again were higher than post-switch items ($M = 4.93$, SD = 4.40), $F(1, 65) = 61.98$, $p < .001$, and bilinguals ($M = 7.73$, SD = 2.53) outperformed monolinguals ($M = 6.68$, SD = 2.78), $F(1, 63) = 6.34$, $p < .01$. Finally, for the function-location game, pre-switch scores ($M = 8.46$, SD = 1.75) were higher than post-switch scores ($M = 5.16$, SD = 3.69), $F(1, 65) = 46.09$, $p < .001$, and the interaction of phase and group approached significance, $F(1, 65) = 3.24$, $p = .07$.

The mean scores used in the ANOVA analyses are summary scores of all the children. Since some of the scores in the post-switch phase were approximately 50%, they might reflect chance responding as opposed to perseveration. This would indicate that the children had not encoded the stimuli in any particular way, but were randomly placing the cards into the compartments, a behaviour which cannot be properly interpreted. Therefore, an examination of individual performance based only on the post-switch scores was carried out to identify the possible role of guessing in children's performance. Three categories were created. Children who obtained between 0 and 3 correct answers on the post-switch phase of a game were called perseverators. Children who obtained between 4 and 6 correct responses were called guessers. Those who successfully completed 7 to 10 items were called correct responders. The distributions for this classification for each game by language group are shown in Table 1. Chi-square analyses were used to determine whether the number of guessers was comparable to the number of perseverators and the number of correct responders. In two of the analyses, the distribution was not different from chance: monolinguals in the colour-shape game and bilinguals in the function-location game. All other analyses were significantly different from chance, indicating that children were not guessing.

[1] We also analysed the data using only the post-switch scores in a two-way repeated measures ANOVA and obtained the same results. The overall bilingual advantage was significant, $F(1, 65) = 5.65$, $p < .02$, and the interaction showed that the advantage was only reliable for the colour-shape game, $F(1, 65) = 5.59$, $p < .02$, and the colour-object game, $F(1, 65) = 4.25$, $p < .04$. In addition, there was no difference between the two groups in the relative difficulty of the four games. In both cases, the colour game was easier than the other three with no difference among those conditions. An analysis of only the pre-switch scores revealed a game effect, $F(3, 186) = 8.09$, $p < .0001$, because the colour game was easier than the other three. There were no other significant results and no difference between the two language groups.

Table 1 *Distribution and chi-square analysis across three response categories for each game in Study 1*

Condition	Language group	Perseverators	Guessers	Correct	$\chi^2(2)$
Colour	Monolingual	4	4	28	32.00 $p = .001$
	Bilingual	6	4	21	16.71 $p = .001$
Colour-shape	Monolingual	14	6	16	4.67 n.s.
	Bilingual	8	2	21	18.26 $p = .001$
Colour-object	Monolingual	21	2	13	15.17 $p = .001$
	Bilingual	12	1	18	14.39 $p = .001$
Function-location	Monolingual	17	5	14	6.50 $p = .039$
	Bilingual	8	10	13	1.23 n.s.

Following the approach typically used in the literature, children were classified as passing or failing based on a criterion of 8/10 correct responses. From the sample of 36 monolinguals and 31 bilinguals, there were 25 monolinguals and 20 bilinguals who passed the colour game, 13 monolinguals and 20 bilinguals who passed the colour-shape game, 13 monolinguals and 17 bilinguals who passed the colour-object game, and 13 monolinguals and 10 bilinguals who passed the function-location game. The 13 monolinguals who passed these games were not always the same children. A chi-square analysis showed that the bilingual advantage was significant for the colour-shape game, $\chi^2(1) = 5.4$, $p < .02$.

Discussion

The children in the two language groups were comparable on several cognitive measures; if there was any bias, it was in favour of the monolingual children who obtained higher scores in receptive vocabulary. Research with preschoolers frequently indicates a vocabulary advantage for monolingual children in the language of testing (Ben-Zeev, 1977; Bialystok, 1988; Merriman & Kutlesic, 1993; Rosenblum & Pinker, 1983; Umbel, Pearson, Fernández & Oller, 1992). Nonetheless, the bilingual children who used Chinese at home still scored in a normal range of English functioning, even though it was lower than the monolinguals. More importantly, the scores from the Raven's Coloured Matrices and digit span demonstrated no cognitive difference between the children in the two groups.

In the card sort task, the bilinguals showed a selective advantage over the monolinguals in the colour-shape game in both analyses and in the colour-object game as well in the ANOVA. This is closest to the results predicted in the third hypothesized outcome in which the bilingual advantage is based on conceptual inhibition. The bilingual advantage was demonstrated by an ANOVA on the mean number of correct responses for both pre- and post-switch phases, and a chi-square comparing frequency of children passing in the post-switch phase.

There was no difference between the groups in the colour game involving a simple one-dimensional classification. The demands for response inhibition were constant in the four conditions, but the performance of the two groups diverged. In the colour game in which performance in the post-switch phase depended only on response inhibition, both groups were equally capable of suppressing a familiar motor response to execute the updated classification. This pattern rules out response inhibition as the source of task difficulty.

The prediction based on conceptual inhibition was that bilinguals would outperform monolinguals on the conditions involving two underlying dimensions. The results showed that this advantage was only reliable for the colour-shape and colour-object games. Why were the results different for the function-location game in spite of it having the same two-dimensional structure as the two previous games?

Conceptual inhibition depends on the complexity of the representation to which attention is directed. Children construct a mental description of the targets based on the rules in the pre-switch phase, for example, 'the red one' and 'the blue one'. The post-switch phase requires redescribing the same targets using different features, for example, 'the square one' and 'the round one'. This process of re-attributing the targets requires both inhibiting the original descriptions and representing the stimulus in a new way. It is easier to represent the target dimension in terms of a perceptual feature (red) than a semantic feature (toy), because it is more superficial, salient, and directly codable without the need for interpretation. The greater difficulty of the function-location game results reflects these aspects of representation.

Do bilingual children have greater representational ability than monolinguals? The prediction that tested this possibility was that the performance gap between the groups would increase as the stimulus displays required more detailed representations. This was not found, so the conclusion was that the groups were equivalent in their ability to represent the stimuli. Confirmation for this conclusion was sought using a paradigm in which the demands for attention and inhibition were separated from the demands for representation.

A pilot study was conducted in which the need for response inhibition and rule representation was kept constant but the need for conceptual inhibition was removed. The colour-shape and function-location games were used because of their contrast in representational complexity. The standard version of the task in which children manually place cards into the compartments was used to enhance the role of response inhibition. Conceptual inhibition was eliminated by removing the target feature used during the pre-switch phase. If the target is a red circle and 'red' is the criterion in the pre-switch phase, then switching the sorting criterion to 'circle' should be easy if the target changes from a red circle to a yellow circle. The card still needs to be classified into the opposite compartment, redefining it by shape rather than colour. Therefore, the demand for response inhibition remains intact.

This manipulation is similar to one used by Zelazo and colleagues (cited in Zelazo & Jacques, 1996) in a condition called total change that led to significant improvement in children's performance. In their study, children were asked to sort cards by either colour or shape, then in the post-switch phase, rather than having them re-sort the same cards, the deck was changed entirely. If the children began by sorting red flowers and blue trucks by colour, the second phase was sorting green stars and yellow triangles by shape. As Zelazo and Jacques (1996) argue, perseveration under these circumstances indicates that children were simply learning to sort a particular card into a particular box and not applying a classification rule to a set of stimuli. Performance on this version of the problem was good, indicating that children did conceptualize the stimuli in terms of the relevant features. Similarly, if children's difficulty with the task is caused by conceptual inhibition, then changing the target stimuli should improve performance because the need for this inhibition is eliminated.

Fifty $4^{1}/_{2}$-year-olds, half of whom were bilingual, were compared on this version of the card sort. All the children performed at ceiling when the target stimulus was changed to match only the post-switch sorting rule. Although ceiling performance is only suggestive, it helps to rule out the role of response inhibition in children's failure. Children did not execute the previously reinforced response when the distracting target cue was removed. Put another way, removing the demands for conceptual inhibition allowed children to solve the problem. In both the standard and altered versions, children had to construct a new representation for the target in the post-switch phase, but in Study 1 they had to do this while the feature in the original representation was still visible. Successful redescription required inhibiting attention to the obsolete feature; bilingual children could do this more successfully than monolinguals.

The results of Study 1 and the pilot study with the altered target cues help to rule out differences between monolinguals and bilinguals in both representational ability and response inhibition. Three of the conditions required conceptual inhibition, and bilinguals performed better than monolinguals in two of them. Study 2 was designed to explore the differences between them that led to or did not lead to a bilingual advantage.

Study 2

In Study 1, the function-location game was more difficult than the other three and both groups achieved lower scores in this condition. The function-location game differed from the other games in two ways. First, the pictures were more detailed than those used in the other conditions so they imposed a greater burden on representation. Instead of being simple shapes, the stimuli were complex objects that children needed to interpret before they could extract and code the relevant feature. Second, there was no perceptual basis for classification because each item was different. Therefore, children needed to identify each picture (e.g. bicycle) and then assign it to the two semantic categories (e.g. toy that goes outside). In this way, the basis of classification was different from that used in the other conditions where items could be directly assigned to categories on the basis of their perceptual properties (e.g. redness or roundness). This may be responsible for performance differences on these problems.

This explanation was pursued in Study 2 by comparing a new group of monolingual and bilingual children on two conditions that differed in this manner, the colour-shape game and the function-location game. The manual version was used to increase the need for inhibition.

Method

Participants

There were 15 English monolinguals with a mean age of 5;1 and 15 French-English bilinguals with a mean age of 4;6. The monolingual children were recruited from daycare centres in a metropolitan area. All parents indicated their children had no knowledge of any language other than English. The French-English bilingual children were recruited from childcare programmes in a French school board. Children attending these schools require fluent knowledge of French (English is not introduced into the curriculum until the 3rd grade) and typically speak French at home. These children live in predominantly English communities, participate in extra-curricular activities in English, and have monolingual English-speaking friends. The French-speaking community is less isolated from the English-speaking majority than the Chinese community was in Study 1, so no child fell below the threshold level for the PPVT scores. The socioeconomic and educational background of children in both groups was comparable – they lived in similar suburbs and attended schools in comparable areas of the city.

Materials and procedure

All the children were given the PPVT-R and the forward digit span. The bilingual children also completed the Échelle Vocabulaire en Images Peabody (EVIP), the standardized French version of the PPVT-R.

Two manual versions of the dimensional change card sort task were used – colour-shape and function-location. Children were shown a colourful box with two sorting compartments on which the target stimuli were adhered with a velcro tab. In the colour-shape game, the target cards were a red square and a blue circle and in the function-location game they were a teddy bear and a winter jacket. The rules were explained to the children and they were given 10 cards to be sorted, one at a time. Each card was placed face down in the selected box. Children were then told that the game was changed, the new rule was explained, and the 10 cards were again classified one at a time. The games were presented to the children in counterbalanced order, half beginning with the colour-shape version and the other with the function-location version.

Except for the EVIP for the bilinguals, all testing was conducted in English. Testing for the monolingual children occurred in one session and testing for the bilingual children occurred in two sessions to avoid giving both the PPVT-R and the EVIP on the same day.

Table 2 *Mean scores and standard deviation by language group in card sort task for Study 2*

Condition	Group	Pre-switch	Post-switch
Colour-shape	Monolingual	10 (0)	8.1 (3.7)
	Bilingual	10 (0)	10 (0)
Function-location	Monolingual	10 (0)	4.5 (4.2)
	Bilingual	9.8 (0.6)	7.9 (2.8)

Results

There was no difference between the digit span scores of the monolingual ($M = 6.1$, SD = 1.4) and bilingual children ($M = 6.0$, SD = 1.7), $F < 1$. As in Study 1, the monolinguals ($M = 110.8$, SD = 11.2) outscored the bilinguals ($M = 89.6$, SD = 24.9) on the PPVT-R, $F(1, 28) = 8.64$, $p < .006$. The bilingual children scored the same on the PPVT-R (89.6, SD = 24.9) and EVIP (98.8, SD = 15.4), $F < 1$.

The means scores out of 10 for the card sort task are reported in Table 2. The scores were analysed in a three-way ANOVA for game (2), phase (2) and language group (2). The function-location game was more difficult than the colour-shape game, $F(1, 28) = 13.89$, $p < .001$, and the post-switch phase was more difficult than the pre-switch phase, $F(1, 28) = 30.56$, $p < .001$. There was a main effect of group, $F(1, 28) = 8.52$, $p < .01$, with the bilinguals outscoring the monolinguals on both conditions, and an interaction of phase and group, $F(1, 28) = 10.49$, $p < .01$, confining that bilingual advantage to performance on the post-switch phase.

Because the mean scores were not close to 5/10, the three-way classification to detect guessing was not used. Instead, children were classified as passing or failing based on a pass criterion of 8/10 in the post-switch phase. Chi-square analyses revealed a significant bilingual advantage in the colour-shape game, $\chi^2 = 4.62$, $p < .05$ (monolinguals passing = 11; bilinguals passing = 15), but not for the function-location game, $\chi^2 = 2.14$, $p = .14$ (monolinguals passing = 6; bilinguals passing = 10).

Discussion

As in Study 1, bilingual children performed better overall, and the ANOVA indicated this superiority for both conditions. The group difference in the function-location game, however, was not reliable in the chi-square analysis, replicating the results of Study 1. Across the two studies, therefore, there is a clear bilingual advantage in the colour-shape game but a more sporadic advantage for the function-location game. The demands for response inhibition are the same in both games and the hierarchical rule structure identified by Zelazo and Frye (1997) is also the same. The difference is in the nature of the information that defines the sorting dimension. In the colour-shape game, the feature is perceptual and visible; classifications can be made by directly matching the correct visual property in the stimulus to the sorting target. In the function-location game, the feature is a semantic property of the item; classifications can be made only once the stimulus is labelled and then classified according to one of its properties. It is arguably more difficult to ignore a perceptual feature, like 'red', than a semantic property, like 'toy'. Since the two games are similar in every other respect, this difference must be responsible for the divergence in performance by the two groups. Study 3 attempts to confirm this explanation by expanding the conditions based on this distinction between perceptual and semantic classification.

Study 3

In the studies so far, there was a reliable bilingual advantage in conditions that require inhibiting attention to representations of perceptual information. The problem with the results of Study 2, however, is that all the children performed very well in the colour-shape game and the bilingual children were at ceiling. Therefore, Study 3 was designed to replicate this finding and to extend it by including two examples of each of the perceptual and semantic classification. The two perceptual games were the colour-shape game and the colour-object game from Study 1; the two semantic games were the function-location game and the kind-place game. This new game included 10 items that were either animals or vehicles (things to ride in), and were either things that go on land or things that go in the water. The target pictures were a sailboat (water vehicle) and a squirrel (land animal). Another feature makes this game slightly different from the function-location game. In the colour-shape and colour-object games, the sorting set consists of 10 cards, five of which are identical. In the function-location game, the sorting set involves 10 completely different cards (e.g. bib, skateboard, sled, slippers). The cards in the kind-place game represent an intermediate position between these extremes. Like the function-location game, each card depicts a unique object ruling out holistic template matching as a sorting strategy. Unlike the function-location game, however, the members of each category resemble each other: all the vehicles were car-like objects and all the animals were fish-like entities, even though no two were exactly the same. The similarity made this condition closer to the perceptual games but retained the need to label and interpret the cards.

Method

Participants

The participants were 27 English monolingual and 26 Chinese-English bilingual children. Both groups attended daycares in the same suburb of a large city. The bilingual children spoke Cantonese or Mandarin at home and English at school, using both languages daily. The Chinese community in this area is large, and it is possible to function entirely in Chinese. The bilingual children used Chinese regularly with their families but English outside the home. The monolingual children had no experience with any language other than English. The mean age of the children in the monolingual group was 4;2 years, and the mean age for the bilingual children was 4;4, a difference that was not significant.

Materials and procedure

All the children were administered the PPVT-R to test English receptive vocabulary and four conditions of the card sort task. The English-Cantonese children were also given a Cantonese translation of the PPVT-R (version L), but these results cannot be standardized so only provide a guideline for children's language competence. Fourteen of the bilingual children were Mandarin speaking and so did not complete the Cantonese PPVT-R.

The dimensional change card sort task was administered to the children manually. All the children completed all four versions in counterbalanced order.

Results

The monolinguals ($M = 109.7$, SD = 11.8) scored higher than the bilinguals ($M = 84.3$, SD = 16.0), $t(50) = 6.35$, $p < .0001$, on the PPVT-standard scores. The bilingual children who completed both PPVT versions obtained a mean standard score of 89.5 (12.5) on the PPVT in English and 70.8 (14.6) in Chinese, a difference that was also reliable, $t(12) = 2.93$, $p < .01$. The results for the Chinese test, however, likely underestimate children's knowledge of Cantonese. Because Cantonese is not strictly speaking a written language, different words (based on Mandarin) from those that are common in spoken language are often used in the written form. The translation of the PPVT tended to use the more formal written words for

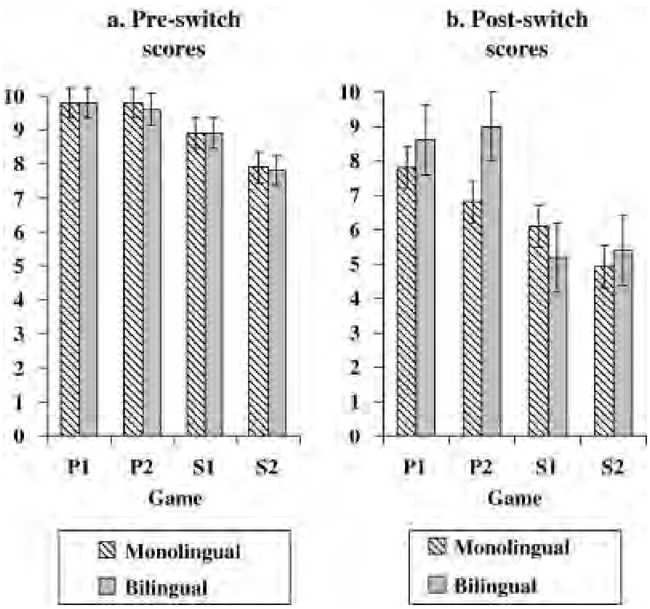

Figure 3 *Mean score by language group and phase in Study 3.*

many of the items, and these may have been unfamiliar to these young preliterate children.

A three-way ANOVA for condition (4), phase (2) and language group (2) was conducted on the mean number of correct classifications in the card sort task. These scores are presented in Figure 3. There were main effects of condition, $F(3, 153) = 34.55$, $p < .0001$, and phase, $F(1, 51) = 66.9$, $p < .0001$, indicating the superiority of the pre-switch phase. For condition, the two perceptual conditions were easier than the two semantic conditions ($p < .01$), with no differences between the two perceptual conditions, or between the two semantic conditions (both $F < 1$). For the perceptual conditions, the bilinguals were more successful than the monolinguals, $F(1, 48) = 5.46$, $p < .02$, but the interaction of language group and phase, $F(1, 51) = 6.36$, $p < .01$, restricted that advantage only to the post-switch condition. For the semantic conditions, the two groups were equivalent, $F(1, 48) = 2.42$, $p = .13$, and there was no interaction of language group and phase, $F < 1$.

Children were designated as perseverators (0–3), guessers (4–6) or correct responders (7–10) based on post-switch scores. Chi-square analyses showed that distributions were different from chance for both groups on the perceptual classifications but not for the semantic ones. The semantic classifications were much more difficult for the children in both language groups. The frequency table is reported in Table 3.

Finally, chi-square analyses compared the number of monolinguals and bilinguals passing each condition, using a criterion of 8/10 correct. From the 27 monolinguals and 26 bilinguals, 15 monolinguals and 21 bilinguals passed the colour-shape condition, 12 monolinguals and 23 bilinguals passed colour-object, 9 children from each group passed the kind-place game, and 3 children from each group passed the function-location game. The chi-square analysis was significant for colour-shape, $\chi^2(1) = 3.9$, $p < .05$, and for colour-object, $\chi^2(1) = 11.44$, $p < .001$, indicating that more bilinguals than monolinguals were successful in these problems.

Discussion

The results of this study replicated and extended those obtained in Study 2. The difference between conditions based on perceptual or semantic criteria was significant, and the two examples of each type of classification did not differ from each other. Both the ANOVA and

Table 3 *Distribution and chi-square analysis across three response categories for each game in Study 3*

Condition	Language group	Perseverators	Guessers	Correct	$\chi^2(2)$
Colour-shape	Monolingual	4	2	21	24.2 $p = .0001$
	Bilingual	3	2	21	26.3 $p = .0001$
Colour-object	Monolingual	6	5	16	8.2 $p = .02$
	Bilingual	2	1	23	35.6 $p = .0001$
Kind-place	Monolingual	6	9	12	2.0 n.s.
	Bilingual	11	4	11	3.8 n.s.
Function-location	Monolingual	7	11	9	0.9 n.s.
	Bilingual	8	7	11	1.0 n.s.

Table 4 *Summary of group comparisons for both ANOVA and chi-square analyses by condition*

Game	Study 1		Study 2		Study 3	
	ANOVA	χ^2	ANOVA	χ^2	ANOVA	χ^2
Colour-shape	B > M	B > M	B > M	B > M	B > M	B > M
Colour-object	B > M	B = M	–	–	B > M	B > M
Place-kind	–	–	–	–	B = M	B = M
Function-location	B = M	B = M	B > M	B = M	B = M	B = M

chi-square analyses indicated that bilingual children outperformed the monolinguals in both perceptual conditions and that there were no group differences for performance in the semantic conditions.

General discussion

There were three main goals for this series of studies. The first was to replicate the finding that bilingual children solve the dimensional change card sort problem more easily than comparable monolinguals. The second was to identify the component of the problem that was responsible for the bilingual advantage, considering the role of representation (both in terms of the task rules and the stimuli), response inhibition and conceptual inhibition. The third was to use group differences in performance to understand the cognitive demands of the task and children's development of those abilities.

Across the studies, different groups of bilingual children matched with comparable monolinguals solved the card sort problem better than monolinguals when the sorting dimension was a perceptual feature of the stimulus; the two groups were equivalent in carrying out the task using a semantic feature as the classifying dimension. A summary of the results for the three studies comparing performance on two-dimensional tasks based on perceptual and semantic features is shown in Table 4. In Study 1, a problem based on a single perceptual dimension was solved equally by both groups, but that condition is not included in the table. In two cases, the chi-square analysis produced more conservative results than the ANOVA. In the colour-object game in Study 1 and the function-location game in Study 2, the ANOVA indicated a bilingual advantage that was not replicated by the chi-square analysis. An important difference between these analyses is that the ANOVA uses all the data from both pre- and post-switch trials but the chi-square examines only post-switch performance.

The second purpose was to determine the reason for the bilingual advantage. A pilot study ruled out the role of differences in the ability to simply represent the stimuli and response inhibition. If representation ability were responsible, then bilinguals would outperform monolinguals when these demands increased in the semantic conditions and the bilinguals, but not the monolinguals, would find the task in this pilot study to be easy, since representation was manipulated but there were no inhibition demands. None of these results was found, leaving little support for the interpretation that the bilingual advantage is based on superior ability to represent complex stimuli. Response inhibition was excluded because the task required the same alteration in the motor response associated with each card as did the other versions of the problem but children were at ceiling because there was no misleading information in the display. Instead, the bilingual advantage was attributed to greater conceptual inhibition.

The third purpose was to identify the reason that the dimensional change card sort task is so difficult for children to solve. Our interpretation is that the source of the difficulty is in conceptual inhibition, the ability to inhibit attention to a mental representation and ignore misleading cues so that a new representation can be constructed. The new representation is the basis for sorting in the post-switch phase. The problem requires children to represent a target stimulus by reference to one type of feature, then to ignore that feature and re-represent the same stimulus in a different way. Representation is clearly involved, but the crucial step is the ability to ignore the feature that was previously the basis for identifying that stimulus. The representational demands required by stimulus complexity are part of conceptual inhibition, but the results of these studies do not support the conclusion that this ability is what distinguishes between the monolingual and bilingual children. When the stimuli were more complex and required interpretation in order to represent the appropriate feature, as in the semantic conditions, the two groups performed the same. The burden of representation presented the same challenge to all the children.

The most compelling argument against the interpretation that the ability to represent the rules in a hierarchical structure determines success is that the perceptual and semantic conditions presented structurally equivalent representational problems but led to reliably different outcomes. All the conditions match the same hierarchical tree structure set out by Zelazo and Frye (1997, p. 119), consisting of two setting conditions, each encompassing two antecedent conditions which led to specific consequences, but the semantic conditions were consistently more difficult. Representation certainly contributes to the solution – the rules and relations among the stimuli need to be properly interpreted and classified – but the ability to construct hierarchical representations is not sufficient to explain these results. Our interpretation is that the crucial step is in the ability to reinterpret the target stimulus for the post-switch phase, an achievement that requires ignoring its perceptual properties that had just been critical to the pre-switch phase. The lure of misleading information is most salient in the perceptual conditions, and it was in these that the bilinguals asserted an advantage.

Other studies have investigated the role of inhibition in the solution to this task but ruled it out as decisive. Jacques, Zelazo, Kirkham and Semcesen (1999) devised a version in which children observed as a puppet sorted the cards and then stated whether the puppet had sorted correctly. Thus, children did not need to inhibit their own prior response to a particular card in the post-switch phase. Nonetheless, children were no better in solving this version of the task than they were in the standard version. Therefore, Jacques *et al.* (1999) argued that inhibition was not central to the solution, leaving representation as the logical candidate for determining children's ability. However, the inhibition manipulated in their paradigm is response inhibition, the overuse of a familiar motor action or associative response. Their study provides important evidence that this type of inhibition is indeed irrelevant to performance. Eliminating conceptual inhibition, as in the pilot study reported above, restores performance for all children.

Our interpretation is compatible with evidence reported by Munakata and Yerys (2001). They hypothesized that the reason that children fail the post-switch phase but pass a set of knowledge questions (Where do the trucks go in the shape game?) is because of differences between the two measurements and not because of an action–knowledge dissociation, as proposed by Zelazo *et al.* (1996). The post-switch sorting is carried out in the presence of a misleading cue but the knowledge question is asked without any misleading information. Therefore, they introduced a misleading context to the knowledge question: Where do the red trucks go in the shape game? Their results replicated the findings reported by Zelazo *et al.* (1996) for the standard question, but the conflict knowledge question was just as difficult as the post-switch sorting. They conclude that the central problem in solving this task is in dealing with the conflict presented by the misleading information. Our results extend this interpretation by showing that children who are better at inhibiting conflicting information are also better at performing the card sort task.

Why would bilingualism alter the development of children's inhibitory control? In bilingual individuals for whom two language representations co-exist, one of the languages must be constantly inhibited to prevent ongoing intrusions (Green, 1998). This inhibition of the non-relevant language is controlled by the same cortical centres used to solve tasks with misleading information, and the early and massive exercise of that function appears to have generalized effects for young children. These arguments are elaborated elsewhere (Bialystok, 2001). Another possibility follows from research by Kroll and de Groot (1997). In their model, the two languages of a bilingual access a common conceptual store, creating both one-to-many and many-to-one mappings of words and concepts. This arrangement may result in greater cognitive flexibility and more acute attention strategies to select the appropriate option, both of which might generalize to problems such as the card sort. While this interpretation is compatible with the present studies, the data suggest that bilingual children's flexibility is limited to situations involving misleading perceptual information, favouring the conceptual inhibition hypothesis.

Results from these studies converge on the conclusion that the crucial feature in solving the dimensional change card sort task is the demand for attention and inhibition, the function of control. The results also contribute to previous evidence showing that early childhood bilingualism modifies children's development of control of attention while having little impact on their development of analysis of representations. The bilingual advantage was clearly asserted when the misleading context presented perceptual information that conflicted with the construction of a perception-based representation. This is an important result because of the pervasiveness of inhibition of attention for solving a wide variety of cognitive tasks. This methodology, then, is a means for understanding the distinctiveness of two essential cognitive processes and the experiences that can affect their development individually.

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