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Global-Local and Trail-Making Tasks by Monolingual and Bilingual Children: Beyond Inhibition

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Abstract

In three experiments, a total of 151 monolingual and bilingual 6-year-olds performed similarly on measures of language and cognitive ability but bilinguals solved the global-local and trail-making tasks more rapidly than monolinguals. This bilingual advantage was found not only for the traditionally demanding conditions, incongruent global-local trials and Trails B, but also for the conditions not usually considered to be cognitively demanding, congruent global-local trials and Trails A. All the children performed similarly when congruent trials were presented in a single block or perceptually simple stimuli were used, ruling out speed differences between the groups. The results demonstrate a bilingual advantage in processing complex stimuli in tasks that require executive processing components for conflict resolution, including switching and updating, even when no inhibition appears to be involved. They also suggest that simple conditions of the trail-making and global-local tasks involve some level of effortful processing for young children. Finally, the bilingual advantage in the trail-making task suggests that the interpretation of standardized measures of executive control needs to be reconsidered for children with specific experiences such as bilingualism.

Keywords

bilingualism; executive function; global-local task; trail-making task; inhibition

A growing body of evidence has established that bilingualism enhances children's development of executive control, one of the most crucial aspects of cognitive development (e.g., Diamond, 2002; Zelazo, 2004). Although there is no single account of executive control, an influential model by Miyake et al. (2000) identifies inhibition, updating, and switching as its relevant components. An adaptation of this model by Garon, Bryson and Smith (2008) using the subcomponents working memory, response inhibition, and shifting provides a coherent framework for understanding executive function development in preschool children. However, progress in understanding how experience affects these developmental patterns and eventually explains modifications in the typical pattern requires precise evidence for the processes and subprocesses that are impacted and the conditions under which the effects are demonstrated. The usual interpretation of the bilingual advantage in executive control traces these effects to one of the three components, namely, enhanced inhibitory control (Abutalebi & Green,

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2007), but little evidence is available to evaluate this claim. At the same time, some tasks used for the assessment of executive control, such as the trail-making task (TMT), are also diagnostic of such conditions as attention-deficit/hyperactivity disorder (ADHD) (Wodka et al., 2008). Therefore, if bilingual advantages in executive control extend to neuropsychological assessment measures, then that information would be clinically relevant for diagnosis; ultimately it might be necessary for population norms on such tests to reflect such relevant experiences. The present studies contribute to research on the effect of bilingualism on development by comparing monolingual and bilingual children on two executive control tasks, one based on empirical constructs and the other used in more clinical applications. The purpose is to identify the component processes that are more advanced in bilinguals than in their monolingual peers and to explore whether there may be clinical implications of potential differences.

An important aspect of the bilingual advantage in executive control is that it is not confined to linguistic processing, an outcome that might be expected, but that it extends to nonverbal domains. Thus, some studies showing developmental differences in monolingual and bilingual children have used visual information processing tasks. In these cases, the bilingual advantage appears not to be in perceptual analysis, a central component of visual processing, but in the resolution of conflict inherent in visual stimuli; the visual modality, in other words, is not the important feature. Bialystok and Shapero (2005) presented two tasks to 6-year-old monolingual and bilingual children. In the Children's Embedded Figures Test (CEFT), children examined an image of a recognizable object (e.g., boat) that had been created out of component shapes (e.g., squares and triangles) to locate a target component. In the ambiguous figures task, children were shown a reversible figure (e.g., duck-rabbit) and were asked to identify the alternative image. Scoring reflected the amount of cuing needed to identify the second image. Both tasks require perceptual analysis of a complex drawing, but the meaning of that drawing is only relevant in the ambiguous figures task where there is a conflict between the two potential interpretations; the image cannot simultaneously be a rabbit and a duck. There is no conflict in the CEFT because the overall image continues to be a boat once the target component has been found. In two studies, monolingual and bilingual children obtained the same scores on the CEFT but bilingual children were better than monolinguals in reversing the ambiguous figure. The difference between the tasks is in the need to resolve perceptual conflict.

Similar results have been obtained using visual stimuli that present competing responses. For example, bilingual children were more successful than monolinguals (Bialystok, 1999; Bialystok & Martin, 2004) on the dimensional change card sort task (Zelazo, Frye, & Rapus, 1996), a written version (Pascual-Leone, 1969) of Piaget and Inhelder's (1956) water-level task (Bialystok & Majumder, 1998), the attentional networks test (ANT) (Rueda, Fan, McCandliss, Halparin, Gruber, Lercari, & Posner, 2004) (Mezzacappa, 2004; Yang, Shih, & Lust, 2005), and theory of mind tasks (Bialystok & Senman, 2004; Goetz, 2003; Kovacs, in press). In all these cases, attending to a different feature of the same stimulus would lead to a different response. Most of the studies included conditions with comparable tasks that did not include conflict, and these were solved similarly by all the children.

Important evidence for the interpretation that bilingual advantages are found under conditions of conflict was provided in a comprehensive study by Carlson and Meltzoff (2008). They administered ten executive function tasks that involved some type of inhibitory control to children who were monolingual, bilingual, or learning a second language. The tasks clustered onto two factors which they called delay (e.g., delay of gratification task) and conflict (e.g., ANT). Bilinguals outperformed the other children on conflict tasks but all children performed comparably on delay tasks. Similar results were reported by Martin-Rhee and Bialystok (2008): monolinguals and bilinguals performed tasks based on inhibition of a misleading cue (press a key showing the direction an arrow is pointing when it *conflicts* with stimulus position) and inhibition of executing a primed response (press a key showing the direction *opposite* to where a centrally presented arrow is pointing, where the display presents no conflict). Consistent with the results of Carlson and Meltzoff, bilinguals performed better than monolinguals when there was a misleading position cue creating conflict but there was no group difference when the task was to refrain from executing a salient response. Therefore, the interpretation that inhibition in general is responsible for the bilingual advantage in executive control is not consistent with these data.

Similar patterns have been reported in research with adults. Tasks in which responses are based on conflict, such as the Simon task (Bialystok, Craik, Klein, & Viswanathan, 2004), Stroop task (Bialystok, Craik, & Luk, 2008), and conflict conditions of the ANT (Costa, Hernández, & Sebastián-Gallés, 2008) are performed better by bilinguals. Colzato et al. (2008) reported comparable performance of monolinguals and bilinguals on a stop-signal task in which participants must refrain from responding, but bilingual advantages in an inhibition of return and attentional blink paradigms where there was conflict, parallel to the distinction demonstrated by Carlson and Meltzoff (2008). The authors concluded that bilinguals were better able than monolinguals to maintain goals and select goal-related information. As with children's research, the mechanism responsible for these effects is generally given as the need for inhibitory control to attend to the target language in the context of the activated irrelevant language (Green, 1998), although inhibition provides only a partial explanation for the results.

To summarize, bilingual advantages for children have been found in tasks or conditions containing perceptual conflict but not in comparable tasks for which no conflict is involved. Nonetheless, the components of executive control that are involved in the resolution of conflict remain to be determined. Several accounts have proposed that inhibition is one such process (e.g., Bialystok & Martin, 2004; Carlson & Meltzoff, 2008) but other components may also be relevant. It may be that using one language requires inhibiting attention to the other (Green, 1998), but bilinguals also demonstrate facilitation through activation of the non-target language (Costa, 2005), suggesting that inhibition alone is an incomplete explanation for the bilingual advantage in executive control. Further, these studies have used both research tasks, such as the ANT (Rueda et al., 2004) and assessment instruments that have clinical application, such as the CEFT. It is especially important to establish how bilinguals perform on tasks that carry diagnostic implications because of the clinical consequences that follow from the interpretation of these test results.

The present studies address these questions by examining monolingual and bilingual children performing two tasks that involve executive control. Both tasks require interpreting visually-presented symbols under varying degrees of conflict. The first task, the global-local task, has been used as a research tool to investigate the ability to inhibit attention to salient aspects of perceptual displays (Navon, 1977). The second task, TMT, is a neuropsychological test that involves motor speed and attentional control and is used diagnostically as a test of frontal lobe functioning (e.g., Demakis, 2004; Gouveia, Brucki, Malheiros, & Bueno, 2007). The children in the study are 6-years old. This is a critical age in the development of executive control (e.g., Diamond, 2002; Garon et al., 2008) and the age at which empirical data comparing monolingual and bilingual children on similar tasks has established group differences (e.g., Bialystok & Shapero, 2005). Therefore, the data will contribute to a more complete profile of the development of executive control in these young children.

The global-local task demonstrates the dominance of attending to global configuration rather than compositional detail in perceiving spatial patterns (Navon, 1977). In the standard paradigm, participants are shown a global stimulus (usually a capital letter H or S) that is constituted from smaller letters that are either the same as (congruent trials) or different from (incongruent trials) the larger letter. The task is to identify either the global or local stimulus.

The usual finding is that global level information is processed faster and more accurately than local information and interferes with identification of the local elements.

Evidence for sensitivity to the difference between local and global features of a visual stimulus has been reported from infancy (Bhatt, Rovee-Collier, & Shyi, 1994; Rovee-Collier, Schechter, Shyi, & Shields, 1992). For example, Colombo, Freeseman, Coldren, and Frick (1995) found a preference for novelty at the global level in 4-month-old infants and suggested that this was the more salient form of information, and Ghim and Eimas (1988) reported that even 3-month-old infants preferred global patterns. However, the superiority of global level responding is less reliable in studies with children. Some investigators have reported no global advantage in young children, claiming that both global and local stimulus components are equally salient (Kemler Nelson, 1988), but others have demonstrated the asymmetry in this group (Feeney & Stiles, 1996; Kimchi, 1992; Moses et al., 2002). Stiles, Delis, and Tada (1991) reported two studies using an orientation judgment task in which 3- and 4-year-olds responded like adults to both global and local features of hierarchical stimuli, although the effect was smaller for the children. A closer approximation to adult responses was found with 6-year-old children (Dukette & Stiles, 1996; Tada & Stiles,1996).

Because the global-local task requires perceptual processing of the overall and component features of a complex stimulus, it superficially resembles the CEFT. However, unlike the CEFT, there is potential conflict between the two levels in that they are created from the same set of forms, making the processing demands more similar to the ambiguous figures task. Moreover, the locus of attention shifts between these levels, requiring monitoring and switching. As in the ambiguous figures test, taking a different perspective, in this case, the global or local level, changes the interpretation of the stimulus. In the study by Bialystok and Shapero (2005), bilingual children were more able to solve the ambiguous figures task than monolingual children but all the children performed similarly on the CEFT.

The TMT consists of two conditions called Trails A and Trails B. In Trails A, a sequence of numbers, usually from 1 to 25, is arranged on a page and participants draw a continuous path through the numbers in sequential order beginning with 1. In Trails B, the page contains both numbers and letters, and the task is to begin with 1 and alternate between numbers and letters (1 A 2 B, etc.). There are at least two standard versions of the task that are used clinically, although the basic structure is the same in both formats (Delis et al., 2001; Reitan & Wolfson, 1985). Each of Trails A and Trails B involves slightly different processes, with the more demanding Trails B taken as the critical test of executive functioning. The TMT is used diagnostically for a number of conditions, notably to detect attention deficit hyperactivity disorder (Houghton et al., 1999; Martel, Nikolas, & Nigg, 2007; Oades & Christiansen, 2008), even in adults (Murphy, 2001; Taylor & Miller, 1997). Performance has also been found to be associated with autism spectrum disorder (Kleinhans, Akshoomoff, & Delis, 2005), and schizophrenia in adults (Nakamura et al., 2008). According to Stuss et al. (2001), the TMT involves visual search, visual perceptual ability, and motor speed for both Trails A and Trails B; Trails B additionally requires task shifting, planning, working memory, attention, and inhibition (Wodka et al., 2008).

In both the global-local task and the TMT, the response requires interpreting a display of symbols by selectively attending to certain features and ignoring others, and sometimes switching between elements, while holding in mind a complex rule. To use the set of executive control components identified by Miyake et al. (2000), both tasks require inhibition (ignore misleading cues), updating (monitor display in the context of current instructions), and switching (adjusting response according to current rule). Moreover, in both tasks, the presence of conflict creates conditions in which the executive demands are greater (incongruent trials of global local and Trails B) or lesser (congruent trials and Trails B). If the source of the bilingual advantage is inhibition in conflict resolution, then bilingual children will only solve the more difficult conflict conditions better than monolinguals because there is little need for inhibition in congruent trials or Trails A. However, if bilinguals also have advantages in other aspects of executive control, such as updating and shifting, then both conditions will be handled better by bilinguals. Such an outcome would challenge the interpretation that the impact of bilingualism is simply in the inhibition component of executive control, as claimed by several researchers.

Previous research supports the latter prediction. In paradigms similar to the global-local task, bilingual children (Martin-Rhee & Bialystok, 2008; Yang, Shih, & Lust, 2005) and adults (Bialystok et al., 2004; Costa et al., 2008) responded more rapidly than monolinguals to both congruent and incongruent trials presented in mixed blocks; however, if congruent trials were presented alone in single blocks, then bilinguals and monolinguals registered the same response speed (Bialystok, Craik, & Ryan, 2006). Similarly, frontal patients perform more poorly than controls in both Trails A and Trails B, suggesting some need for effortful processing or executive control even in the simpler version, even though inhibition is an unlikely candidate (Demakis, 2004; Stuss et al., 2001). Therefore, it is expected that in the early stages of developing executive control, both conditions of these tasks will be effortful for young children and that bilingual children will be more precocious than monolinguals on both conditions.

The results will contribute to three issues. First, they will extend previous research demonstrating executive control differences in monolingual and bilingual children to two spatial tasks that require the interpretation and processing of complex displays. Second, if bilinguals outperform monolinguals on the simple conditions, then the interpretation of the executive function differences between these groups needs to include processing components beyond inhibition. Third, evidence for differences between monolinguals and bilinguals in the TMT would raise issues about the diagnostic accuracy of executive control tasks for bilingual children.

Study 1

Method

Participants—There were 51 children, of whom 25 were monolingual (mean age = 6.1 years, 14 males) and 26 were bilingual (mean age = 6.0 years, 17 males). All the children attended the same public schools in a middle-class neighborhood but the bilingual children spoke a language other than English at home, including Cantonese, French, Russian, Mandarin, Urdu, Hindi, and Spanish. English was the only language used in school, and all extra-curricular activities were conducted in English for all the children. The schools were all located in a suburb where parents worked primarily in professional and management occupations.

Children's language background was reported through a Language Background Questionnaire completed by the parents with the consent form (see Results). The questions included the other languages the child was exposed to, the nature and extent of the exposure, and the child's competence in that language. In addition, parents rated statements about language use on a scale of 1-5, in which 1 represented "mostly in the other language" and 5 "mostly in English". Thus, a perfect balance between the two languages was indicated by a score of 3.

Tasks

Peabody Picture Vocabulary Test (Third Edition-Form IIIA): In this standardized test of receptive vocabulary, children indicate the named item from a set of four pictures. The items become increasingly difficult, and testing continues until the child makes 8 or more errors in a set of 12 items. The score is standardized for age. The test was administered in English to all participants and took approximately 10 minutes.

Category Fluency: This is a test of verbal productivity and word generation to provide an additional measure of English fluency. Children were asked to name as many animals as they could in 60 seconds, and the score was the total number of appropriate responses produced in this time. The testing time for this task, including instructions, was less than 3 minutes.

Digit Span: This is a test of short-term memory. The experimenter read a list of single digit numbers in English at the rate of one digit per second, and the child was asked to repeat the digits in the same order. The test started with two digits, with one digit added after every second trial. Testing stopped when the child was unable to reproduce both trials at a particular level. Digit span was calculated as the longest string length in which the child could reproduce at least one of the trials without error. The task took approximately 6 minutes to administer.

Trail-Making Test (TMT): This neuropsychological test consists of two parts, Trails A and Trails B. In Trails A, numbers from 1 to 25 are distributed across the page and children are asked to draw lines connecting the numbers in order beginning with 1, without lifting the pencil from the page. In Trails B, the page contains the numbers from 1 to 12 and letters from A to L and children must connect the symbols by alternating the sequence between numbers and letters, that is, 1-A-2-B-3-C…12-L. The experimenter explained each task and children completed a practice version containing fewer items. The score is the time in seconds required to complete each section. The task took less than 5 minutes to administer.

Global-Local Task: The experiment was based on a design developed by Andres and Fernandes (2006) and was presented on a PC notebook with a viewing aspect of 30.5 cm × 18.3 cm, and controlled by SuperLab Pro (version 2.0.4). Each trial began with a fixation cross (+) in the center of the screen that remained visible for 500 ms. This was followed by a stimulus in the center of the screen, which remained until a response was made. The fixation for the next trial began immediately after the response. The stimuli were approximately 6 cm high.

There were two tasks, each based on a different type of stimulus. This replication of the design across two types of stimuli was done both to maximize the possibility of finding an effect and to assess the generalizability of the effect if it were found (cf., Andres & Fernandes, 2006), particularly since Dukette and Stiles (1996) suggested that shapes are more familiar than letters to 6-year-olds. The stimuli are shown in Figure 1. In the letter task, the stimuli were the letters H or S (or X for neutral). In global trials, the instruction was to identify the large letter and for local trials, to respond to the small letters. In the shape task, the stimuli were circles or squares (or Xs for neutral).

Children indicated the identity of the relevant stimulus level by pressing the outer key on one of two mouse pads placed one on each side of the computer monitor. Each response key was assigned to one of the two stimuli (e.g., press left for H and right for S, or left for circle and right for square), with key assignments counterbalanced. Instructions preceding each block explained whether the global or local features were targeted. The neutral stimuli were never a response option; for example, a global H composed of small Xs presented only one stimulus for which there was an assigned response, namely H. Similarly, a global X comprised of local Hs only had a response key associated with the H. In the study by Dukette and Stiles (1996) using a forced-choice similarity task, the neutral cues reduced the conflict.

There were 4 types of experimental blocks: global letters, local letters, global shapes, and local shapes. Each of these blocks was presented 4 times, for a total of 16 experimental blocks. There were breaks between the presentation of each block and the instructions preceding the start of the next block. Testing continued when children said they were ready to go on.

Each block contained 12 trials consisting of congruent, incongruent, and neutral trials yielding 192 experimental trials across 16 blocks. In congruent trials, the global and local level matched, for example, both were Hs or squares. In incongruent trials, the two levels conflicted, for example, a global H comprised of local Ss or a global circle comprised of local squares. In neutral trials, the unattended dimension (local stimuli in the case of global trials and global shape in the case of local trials) were Xs rather than the opposite response choice, so attending to the wrong dimension did not provide a possible response. The instructions for the global or local conditions were given by an animated character called Floppy the Rabbit who appeared on the screen before each block. The child was told that when Floppy was big (6 cm high) then press the key to indicate the big letter (or shape); when Floppy was little (2 cm high), then press the key to indicate the little letters (or shapes) that were inside the bigger picture. There were 12 practice trials for each of the four types of blocks. The task took about 20 minutes.

Design and Procedure—Children were tested individually in a quiet room in their school. The tasks were presented in a fixed order in a single session that lasted between 45 minutes and one hour including as many breaks between tasks as children wished to take. The order of tests was: PPVT, category fluency, global-local, digit span, Trails A, and Trails B.

Results

Each of the statements in the Language Background Questionnaire was assigned a value between 1 and 5, with completely balanced use of both languages represented by 3. The mean values obtained for each of these questions is reported in Table 1. Combining these scores, the use of spoken language in the home was biased to the non-English language (M = 15.20, cf., 18 for balanced use), t (25) = −3.11, $p < .0005$ and the use of media was biased to English (M = 16.69, cf., 15 for balanced use), t (25) = 2.67, $p < .01$. This profile indicates an environment in which children are proficient in both languages and use both languages every day.

The mean scores for the background measures and the TMT are reported in Table 2. There were no differences between children in the two language groups for PPVT standard scores, t (49) = 1.8, n.s., category fluency, t (49) = 1.7, n.s., or digit span, $t < 1$. In the TMT, bilinguals completed both Trails A, t (49) = 2.7, $p < .01$, Cohen's $d = 0.76$, and Trails B, t (49) = 2.8, $p < .008$, Cohen's $d = 0.77$, faster than monolinguals.

The error data on the global-local task, reported in Table 3, were analyzed by a 4-way ANOVA for language group, task (letter, shape), condition (global, local), and trial (congruent, incongruent, neutral). There were few errors and large variance, so the data may reflect floor effects with artifactual differences and therefore must be interpreted cautiously. There were no effects of task, $F < 1$, and no interactions between task and any other variable, so the data in Table 3 are collapsed across task. Surprisingly, there were more errors in global conditions than in local conditions, F (1,49) = 35.01, $p < .0001$, a difference that interacted with language group, F (1,49) = 5.50, $p < .02$, because the two groups made similar numbers of errors on the local condition but monolinguals committed more errors on the global condition. There was also a difference in errors by trial type, F (2, 98) = 78.06, $p < .0001$, with the largest number on incongruent trials (M = 12.76, SD = 8.4), next for neutral trials (M = 4.18, SD = 4.5), and fewest for congruent trials (M = 2.55, SD = 2.2), with all contrasts significant. This effect interacted with condition, F (2, 98) = 22.78, $p < .0001$, because the difference between congruent and neutral trials was not significant in the local condition, F (1, 49) = 2.74, n.s., but was significant in the global condition, F (1, 49) = 6.67, $p < .01$.

RT data are reported for correct trials only, excluding trials with RT less than 250 ms or greater than 2500 ms. The mean RTs are plotted in Figure 2a for the letter task and Figure 2b for the shape task. A 4-way ANOVA for group, task, condition, and trial showed that bilingual children performed faster than monolinguals on all conditions, F (1, 49) = 8.59, $p < .005$, Cohen's d =

0.82, with no interactions. There was no effect of task, $F(1, 49) = 1.15$, n.s., or condition, $F(1, 49) = 1.38$, n.s., but an interaction between them, $F(1, 49) = 6.45$, $p < .02$. In the shape task there was no difference between global (M = 1268 ms, SD = 281) and local (M = 1250 ms, SD = 256) conditions, $F < 1$, but in the letter task the global (M = 1203 ms, SD = 255) was faster than the local condition (M = 1276 ms, SD = 283), $F(1, 50) = 5.75$, $p < .02$.

Because the global condition elicited the most errors and the fastest RT (at least for the letter task), a correlation between errors and RT was conducted to determine whether there was a speed-accuracy trade-off. There was no correlation for the local condition, $r(51) = .02$, n.s., but a *positive* relation for the global condition, $r(51) = .39$, $p < .005$, that was restricted to the monolinguals, $r(25) = .50$, $p < .01$, with no correlation for bilinguals, $r(26) = -.05$, n.s. There is no apparent explanation for why faster monolinguals made fewer errors in the global conditions.

The RTs for the three trial types were all different from each other, $F(2, 98) = 36.01$, $p < .0001$, all contrasts being significant. The order of difficulty in which congruent trials were fastest (M = 1162 ms, SD = 232), neutral trials next (M = 1268 ms, SD = 245), and incongruent slowest (M = 1318 ms, SD = 273) paralleled the order obtained for the error data. There was no interaction between trial type and any other factor, including language group.

The relationship between the TMT and global-local task was investigated by examining the correlations among their conditions. These correlations, reported in Table 4, show strong inter-correlations for all conditions. These relations are pursued in more detail across all three studies using regression analysis and are reported in the Results section of Study 3.

Discussion

All the children performed comparably on measures of vocabulary and working memory but the bilinguals completed the executive control tasks more rapidly than the monolinguals. This speed advantage was found not only for the conflict conditions, Trails B and incongruent trials, but also for Trails A and congruent trials which are not considered to involve conflict. This bilingual advantage in the simpler conditions is consistent with the counterintuitive results of previous research in which bilingual children (Martin-Rhee & Bialystok, 2008) and adults (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Ryan, 2006; Costa et al., 2008) outperformed monolinguals on both congruent and incongruent trials of conflict tasks. There is no inhibition required in the simpler conditions, but other demands, such as maintaining two response sets and switching between trial types in the mixed block, may also be handled better by bilinguals. This interpretation is considered in more detail in the General Discussion.

There were two main results from the global-local task. First, the three trial types were different from each other, with the congruent trials being easiest and the incongruent trials the most difficult, confirming that the task was effective in demanding greater control in the more difficult conditions. In the neutral trials, the “X” was not a response option, but since it is both a letter and a shape and attracts attention to the opposite level (global or local), it provides a moderate level of interference, replicating the results of Dukette and Stiles (1996). Second, there was limited evidence for a global advantage: the global condition was faster in the letter task, but surprisingly there were also more errors.

The primary result was that the bilinguals responded more rapidly than monolinguals on both the global-local task and the trail-making task. Therefore, it is possible that bilinguals are simply faster than monolinguals on speeded tasks. In that case, the group differences could not be attributed to differences in executive control and the relation between the TMT and the global-local task may simply reflect their common reliance on speed. This possibility was examined in the next two studies.

Study 2

Study 2 included a control condition using simple stimuli to determine the role of response speed in the results of Study 1. In Study 1, all the stimuli that produced language group differences were based on spatially arranged components (TMT) or hierarchically constructed constituents (global-local). If the bilingual advantage found in that study reflects differences in processing speed, then bilinguals will also perform faster on a simple classification task; if the difference reflects executive control, then there will be no group difference with simple stimuli.

Participants

The study included 50 children, comprised of 25 monolinguals (5.8 years, 12 males) and 25 bilinguals (5.8 years, 13 males) who attended the same schools. The non-English languages spoken by the bilingual children were Cantonese, French, Russian, Mandarin, Hebrew, Hindi, and Italian. As in Study 1, parents completed the Language Background Questionnaire, and the results indicate an environment that is fully bilingual (see Results). The schools involved in this study were public schools similar to those in Study 1 in that they were located in economically homogeneous middle-class neighborhoods.

Design and Procedure

The tasks were the same as those used in Study 1 but with two modifications to the global-local task. First, a control condition was included in which the stimuli were thick line drawings of the same letters or shapes used in Study 1 that were approximately halfway between the size of the global and local stimuli, about 3.5 cm high. Second, there were fewer trials for each condition; instead of 192 experimental trials, there was a total of 134 trials in this study. The total testing time was similar to that in Study 1.

The experiment began with two control blocks of 12 trials each, one for each of the shape and letter tasks in counterbalanced order. Each block was preceded by 6 practice trials with feedback. After the control blocks, Floppy the Rabbit was introduced, the task was explained, and there were 12 practice trials with feedback for each of the letter and shape tasks in each of the global and local conditions. The experimental conditions included 2 blocks of global shape, 2 blocks of local shape, 2 blocks of global letter, and 2 blocks of local letter, counterbalanced as in Study 1. After the first presentation of each of the block types, the remaining blocks were repeated in the reverse. In total there were 48 control trials (24 per task), and 24 trials for each of global letter, local letter, global shape and local shape.

Results

The results from the Language Background Questionnaire, reported in Table 1, confirmed that both languages were used in the bilingual homes. The pattern of mixed language use in the home, in conjunction with the children's schooling in English, indicates that these children are fully bilingual.

The mean scores for the background measures and TMT are presented in Table 2. As in Study 1, there was no difference between groups in PPVT vocabulary, $t < 1$, category fluency, $t < 1$, or digit span, $t\ (24) = 1.9$, n.s. Also replicating Study 1, the bilinguals performed faster than the monolinguals on both Trails A, $t\ (24) = 2.65$, $p < .02$, Cohen's $d = 1.27$, and Trails B, $t\ (24) = 2.96$, $p < .01$, Cohen's $d = 1.14$.

RT data were trimmed using the procedure described in Study 1. The mean errors and RT for the control condition of the global-local task are reported in Table 5. There were few errors, but more committed in the shape task than the letter task, F (1, 48) = 17.32, $p < .0001$, with no difference between language groups, $F = 0$, and no interaction, $F = 0$. Consistent with this, the letter task was faster than the shape task, F (1, 48) = 17.86, $p < .0001$, with no difference between the two language groups, $F = 0$, and no interaction, $F = 0$.

A 4-way ANOVA for language, task, condition, and trial type on the experimental errors reported in Table 3 showed no effect of task, $F < 1$, or language group, $F = 0$. There were more errors in the global than local, F (1, 48) = 25.70, $p < .0001$ condition, replicating Study 1, and a difference by trial type, F (2, 96) = 27.41, $p < .0001$, with fewer errors in congruent than in either neutral or incongruent trials. As in Study 1, these results for the error data are only suggestive rather than conclusive.

The mean RTs for correct experimental trials are plotted in Figure 3. A 4-way ANOVA for language group, task, condition, and trial type, showed that the bilingual children were faster than monolinguals on all conditions, F (1, 47) = 32.15, $p < .0001$, Cohen's $d = 1.26$, with no interactions between language group and any other factor. There was no difference between the letter and shape tasks, $F < 1$, but there was a slight speed advantage for the local (M = 1115 ms, SD = 153) over the global (M = 1140 ms, SD = 205) conditions, F (1, 47) = 4.88, $p < .04$, contrary to the global advantage. There was also an effect of trial type, F (2, 94) = 5.40, $p < .006$, with congruent trials (M = 1064 ms, SD = 164) faster than either the neutral (M = 1125 ms, SD = 168) or incongruent (M = 1121 ms, SD =152) trials. This difference interacted with global or local condition, F (2, 94) = 24.45, $p < .0001$. In the global condition, the incongruent trials were slower than the congruent or neutral trials, which did not differ from each other; in the local condition, the neutral trials were slower than the other two, which again did not differ from each other. These effects did not interact with language group, $F < 1$.

The correlations among the three types of experimental trials and the two conditions of the TMT are reported in Table 4, showing again a relationship between all conditions.

Discussion

The control condition designed to assess the role of response speed in these tasks elicited precisely the same RT from children in both language groups. It is therefore unlikely that speed was responsible for the bilingual advantage in the global-local task. In addition, bilingual children again solved both TMT conditions and all global-local conditions more rapidly than monolinguals. An unexpected finding was that the incongruent trials in the local condition were faster than the neutral trials. Although puzzling, this difference did not interact with language group or task, so the results might be an anomaly rather than a real effect.

The final step pursued in Study 3 is to incorporate measures of response speed that were more similar to the experimental tasks in order to rule out more conclusively the possibility that the bilingual advantage is primarily attributable to differences in speed and not executive control.

Study 3

The purpose was to provide more direct evidence for the role of speed in performance on the executive control tasks. There were two additional conditions: a single block presentation of congruent trials in the global-local task to establish speed on a simple version of the experimental task, and a test of speed in a written task to control for speed in the TMT.

Participants

There were 50 children, comprised of 25 monolinguals (6.0 years, 10 males) and 25 bilinguals (6.1 years, 15 males). The non-English languages were Vietnamese, Tamil, Cantonese, Hindi, Urdu, Arabic, Italian, Hungarian, Gujarati, Russian, and Japanese. The questionnaires confirmed that the bilingual children lived in bilingual environments. Monolingual and bilingual children attended the same schools. These schools were also public schools located in middle-class neighborhoods, but the neighborhoods were less affluent than those involved in the first two studies. Importantly, however, the monolingual and bilingual children in this study attended the same schools, as they did in the previous studies, and were comparable in socio-economic status.

Design and Procedure

The procedures followed those used in Study 2 with two additions: the box completion task to assess speed of processing in a written task and single block presentations of the congruent global-local trials. There were also two changes to the background measures used in Study 2. First, the backward digit span was included to provide a better assessment of working memory, since forward digit span is a test of short-term verbal recall. Second, the category fluency task was excluded because there was no evidence of group difference in the previous two studies. The total testing time was again about 45 minutes.

Backward Digit Span—The procedures and scoring were identical to the forward digit span except that children repeated the digits in the reverse order from their presentation.

Box Completion Task (Salthouse, 1994)—The task measures the time to complete a set of three-sided boxes by adding the fourth side. The task began with a practice page of 15 boxes arranged in 5 rows, in which the first row boxes were already complete. Children were told to fill in the missing side on each of the other boxes so they looked like the ones on the top and that the boxes did not need to be perfect but that they needed to work as quickly as possible. The test sheet contained 35 three-sided boxes arranged in 7 rows of 5 boxes each. The score was the time in seconds required to complete all the boxes on the page.

Global-Local Task—The task was the same as in Study 2 but included separate blocks of congruent trials for each of the global and local conditions. In total, there were 14 blocks (2 control, 2 global congruent, 2 local congruent, 8 mixed experimental) with 12 trials in each, for a total of 168 trials. Four presentation orders were counterbalanced across participants.

Results

The results of the Language Background Questionnaire confirmed the bilingual environment for children in the bilingual group and are reported in Table 1.

Table 2 shows that monolinguals had marginally significant higher vocabulary scores than bilinguals, F (1, 48) = 4.01, p = .05, and higher scores on the forward digit span, F (1, 48) = 4.21, $p < .05$. There were no group differences in backward digit span, or box completion, Fs < 1. As in the previous two studies, the bilinguals completed both Trails A, F (1, 48) = 4.16, $p < .05$, Cohen's d = 0.51, and Trails B, F (1, 48) = 7.00, $p < .01$, Cohen's d = 0.76, faster than monolinguals.

The results for the control condition (Table 5) show that as in Study 2, there were no group differences on errors, F (1, 48) = 2.5, n.s., or reaction time, $F < 1$. In the blocked presentation of congruent trials in the global condition, there was no difference in errors between monolinguals (M = 0.84, SD = .98) and bilinguals (M = 0.60, SD = 1.04), $F < 1$, or reaction time between monolinguals (M = 1118 ms, SD = 51) and bilinguals (M = 1075 ms, SD = 36),

$F < 1$. Similar results were found for the blocked presentation of congruent trials in the local condition: there was no difference between monolinguals (M = 0.68, SD = 1.06) and bilinguals (M = 0.52, SD = 0.87) for errors, $F < 1$, or between monolinguals (M = 1079 ms, SD = 41) and bilinguals (M = 1104 ms, SD = 31) for reaction time, $F < 1$.

A 3-way ANOVA for group, condition, and trial type on the experimental errors, presented in Table 3, indicated no effect of group, $F = 0$, or task, F (1, 48) = 2.58, n.s., but more errors on the incongruent trials than on the other two, F (2, 96) = 112.60, $p < .0001$.

The mean RTs for the correct experimental trials are plotted in Figure 4. Data were trimmed following the same procedures used in the two previous studies. A 3-way ANOVA for group, condition, and trial type showed that bilinguals performed faster than monolinguals, F (1, 48) = 6.91, $p < .01$, Cohen's $d = 0.74$, with no interaction between language group and any other factor. There was an effect of condition, F (1, 48) = 11.58, $p < .002$, in which the global condition (M = 1215 ms, SD = 176) was faster than the local condition (M = 1302 ms, SD = 214), and an effect of trial type, F (2, 96) = 15.12, $p < .0001$, in which the congruent trials (M = 1193 ms, SD = 180) were faster than either the neutral (M = 1309 ms, SD = 173) or incongruent trials (M = 1275 ms, SD = 226), with no difference between the latter two. Trial type interacted with condition, F (2, 96) = 3.88, $p < .02$: In the global condition, F (2, 98) = 11.35, $p < .0001$, congruent and incongruent trials were faster than the neutral trials but in the local condition, F (2, 98) = 8.22, $p < .0005$, congruent trials were faster than the neutral and incongruent trials.

Because the trials in the blocked conditions are the same as those in the experimental conditions, it is possible to calculate an estimate of mixing costs as the difference between these trials when they were presented alone or in the mixed experimental condition. For monolinguals, the mixing cost was 96 ms (SD = 157) for global and 198 ms (SD = 230) for local conditions; for bilinguals, the mixing cost was 46 ms (SD = 175) for global and 58 ms (SD = 211) for local conditions. A 2-way ANOVA showed no difference for condition, F (1, 48) = 1.38, n.s., but a smaller cost for bilinguals, F (1, 48) = 5.15, $p < .02$, Cohen's $d = 0.63$.

As in the previous studies, there were inter-correlations among all conditions, shown in Table 4. The nature of these relationships was pursued through linear regression analyses, reported in Table 6. The purpose was to explore the relation between the executive control tasks as a means of understanding the pattern of language group effects found through the ANOVAs in the three studies, rather than to uncover differences between language groups. Therefore, language group was not entered into the model. Only tasks which had been administered under similar procedures were included in these analyses. An overall mean RT for each of the congruent, incongruent, and neutral trials for the letter task was calculated across all three studies. The independent variables were PPVT, forward digit span, Trails A, and Trails B, because these tasks were used in all the studies. For the congruent trials, the model was significant, F (4, 140) = 10.02, $p < .0001$, and accounted for 23% of the variance. The only variable that accounted for unique variance was Trails A. For the incongruent trials, the model was significant, F (4, 139) = 7.10, $p < .0001$, and accounted for 27% of the variance, with both Trails A and Trails B contributing equivalently. For the neutral trials, the model was significant, F (4,139) = 13.73, $p < .0001$, and accounted for 28% of the variance.

To confirm the relation between Trails A and congruent trials because correlation does not indicate direction of influence, an additional model was examined in which Trails A was the dependent variable and the independent variables were PPVT, forward digit span, neutral trials to account for speed on the global-local task, incongruent trials, and finally congruent trials. The model was significant, F (5, 91) = 9.57, $p < .0001$, and accounted for 34% of the variance. The two factors explaining unique variance were neutral trials, $t = 3.30$, $p < .002$, and congruent trials, $t = 2.07$, $p < .04$. Hence, the relationship between Trails A and congruent trials in the global-local task is deeper than a simple account of response speed.

Finally, the regression analysis can be conducted with group as a dummy variable to determine whether the regression slope is different for the two groups. Using this procedure, there was a significant effect of group in the analysis based on both congruent, $t = -2.08$, $p < .03$, B = −70.9, SE B = 34.1, and incongruent, $t = -2.84$, $p < .005$, B = −116.5, SE B = 41.1, trials set as the independent variable. This confirms the results of the ANOVAs showing that the performance of the participants in the two groups was different for both measures.

Discussion

The bilinguals in this study obtained lower scores than the monolinguals on vocabulary and forward digit span but performed better than monolinguals on both the TMT and global-local tasks, replicating the results of Studies 1 and 2. The two new control measures, box completion and blocked presentation of congruent global-local, were solved similarly by children in both language groups, supporting the interpretation that speed of processing is not responsible for group differences in the experimental tasks. A comparison of RT on congruent trials in the blocked and experimental conditions also showed that the mixing costs were greater for monolinguals than bilinguals. This supports the interpretation that part of the bilingual advantage is on the switching demands of the mixed block presentation.

General Discussion

In three studies, bilingual children outperformed monolinguals on all conditions of the trail-making test and the global-local task. This pattern extends previously reported differences in performance by bilinguals to two new tasks, one of which is commonly used for neuropsychological assessment. Differences between groups remained with increasing controls for simple response speed, and combined regression analyses pointed to an underlying commonality in the two relevant tasks. These results have implications both for our interpretation of what is being measured by these tasks and our understanding of how the experience of bilingualism influences children’s cognitive development.

The bilingual children in the three studies spoke different non-English languages but they all used two languages on a regular basis and were comparable to their monolingual classmates in socioeconomic level, community context, and educational experience. The monolingual and bilingual children performed similarly on tests of receptive vocabulary, digit span, verbal fluency, and box completion, but where there were differences, it was the monolinguals who obtained higher scores. Nonetheless, the bilingual children completed the trail-making task and the global-local task more rapidly than the monolinguals. Since both of these are speeded tasks, the most obvious explanation for the group difference is that the bilinguals are simply faster responders, but all the children completed the control conditions based on simpler stimuli (Studies 2 and 3) or simpler processing demands (Study 3) at the same speed, ruling out basic response speed as the sole explanation for the group differences.

An important finding in all three studies was that the bilingual children outperformed monolinguals in the two critical tasks not only on the conflict conditions but also on the conditions for which no apparent conflict was involved. Although counterintuitive, this replicates research with executive control tasks such as the Simon task in which bilinguals perform faster than monolinguals on both congruent and incongruent trials (e.g., Martin-Rhee & Bialystok, 2008) and extends that pattern to the TMT in which Trails A also distinguished between the groups. To understand this result, we need to examine the cognitive demands of each of these tasks.

Consider first the global-local task. As in previous research with children, the global precedence effect was not strongly demonstrated (e.g., Kemler Nelson, 1988): There were more errors in the global than the local conditions in Studies 1 and 2, and the global precedence effect in RT was only found for the letters task in Study 1 and in Study 3. These task effects, however, never interacted with language group. Importantly, when the three trial types were randomly combined in a mixed block, bilinguals were faster at responding to all of them, even though strictly it is only the incongruent trials (and to a lesser extent the neutral trials) that require inhibition. Single block presentations of congruent trials were not performed differently by the two language groups, so the need to monitor the trials by holding several plans in mind and switching between trial types made the task more difficult, including the congruent trials, and was easier for the bilinguals. Supporting this interpretation, the mixing costs calculated in Study 3 showed larger costs for monolinguals than for bilinguals. Thus, these data provide no direct evidence for bilingual advantages in inhibition but show instead a bilingual advantage in those aspects of executive control concerned with monitoring and shifting.

In the TMT, the stimuli are not hierarchical as in the global-local task, but they are compositional, and again bilinguals performed both conditions of the task more efficiently than monolinguals. However, even Trails A incorporates demands for executive control: children need to hold in mind the current place in the sequence (e.g., 4) while searching for the next element (i.e., 5) through a distracting space filled with other digits. This process is not effortful for adults for whom the counting sequence is deeply ingrained and the digits extremely familiar but it is considerably less automatized for 6-year-olds. Segalowitz and Hulstijn (2005) point out that letter recognition is less automatic for adult second-language learners than it is for native speakers familiar with that alphabet; the process of automatization of these forms is undoubtedly not yet complete for 6-year-olds. Thus, even the simple condition requires working memory to maintain the goal, selectivity to ignore distracting elements, and switching. Moreover, even the simple version of these tasks is novel for 6-year-olds, and Normal and Shallice (1986) have argued that any novel task requires executive control, even for adults.

The interpretation that all conditions of the global-local and TMT involve elements of executive control predicts commonality among these conditions. This was demonstrated in each of the studies through the correlation matrix in which there were significant interrelations among all conditions. However, a stronger test of the interpretation was found in the regression analyses in which congruent trials of the global-local task were significantly predicted by Trails A and incongruent trials by both Trails A and Trails B; thus the incongruent trials are related to the same set of abilities as congruent trials with the addition of a component related to conflict. The relation between congruent trials and Trails A was confirmed by setting Trails A as the dependent variable and showing that once speed was explained through the neutral trials, there was still a significant role for the congruent trials. What is common is that both tasks are based on compositional stimuli: for TMT they are spatially-arranged components and for global-local they are hierarchically constructed images, and processing these stimuli requires some level of control. Although the processing demands for the simple conditions such as Trails A are trivial for adults, they present a challenge to children, and bilingual children are better able to deal with that challenge, at least at 6-years old.

In the study by Bialystok and Shapero (2005), bilingual children outperformed monolinguals in the ambiguous figures task based on perceptual conflict but not on the CEFT for which there was a complex perceptual display but no conflict. However, the explanation for those results was too narrow. The CEFT presents a global image constructed of individual parts, but unlike global-local stimuli, the meaning of the picture does not interfere — finding a triangle is not hindered by the fact that the image represents a boat — and unlike Trails A, the search for the component part does not require holding a plan in mind and monitoring its progress. Both the global-local and trail-making tasks, in contrast, require working memory and monitoring because both levels of meaning *are* relevant. At 6-years of age, all the children are equally proficient at CEFT, but the bilinguals are making greater progress in Trails A and congruent global-local trials because even those conditions involve executive control. Thus, tasks that are assumed to be baseline assessments for adults present significant challenges to young children. However, the reason these tasks are difficult for children is not simply because they contain conflict and require inhibition, as originally proposed, but because they require effortful attention to complex stimuli as well as monitoring and shifting, invoking executive control.

These results suggest that the interpretation of the TMT may need to be modified in two ways when it is used diagnostically in children's development: first, Trails A is complex for young children and shares processing requirements with other executive control tasks, and second, both Trails A and Trails B are solved more easily by bilingual children than monolinguals, all else being equal.

The present studies extend previous research demonstrating the precocious development of executive control in bilingual children and contribute to our understanding of the processes involved in children's performance in some simple tasks. Bilingual children outperformed monolingual children in processing perceptual information from complex stimuli, even when the components of the stimuli presented no explicit conflict. On closer inspection, however, these tasks made significant demands on executive control, even in the simple conditions. Thus, bilingual children are developing executive control over a broad range of processes, not only inhibition and conflict resolution as previously suggested (Bialystok, 2001). More research is needed to determine how broadly this extends. In the study by Carlson and Meltzoff (2008), bilingual advantages were found for all tasks containing conflict but not for tasks requiring delay of responding. A closer analysis of those conflict tasks may reveal which aspects of the complex stimuli, working memory demands, or other processes may be responsible. Simple tasks such as Trails A are more effortful for children than for adults, and interpretations from those tasks need to consider their demands on aspects of executive control. Although the present results do not identify an explanatory mechanism for these effects, the breadth of the effect beyond inhibitory control indicates that the explanation will likely be broader than the bilingual need to inhibit the non-target language (cf., Green, 1998). New research shows bilingual differences in language perception in infancy, long before inhibition of an unwanted language can be relevant (Werker & Byers-Heinlein, 2008). Finally, our assumptions about standardized tasks used diagnostically for atypical development may need to be revisited if such common experiences as bilingualism can significantly modify children's performance.

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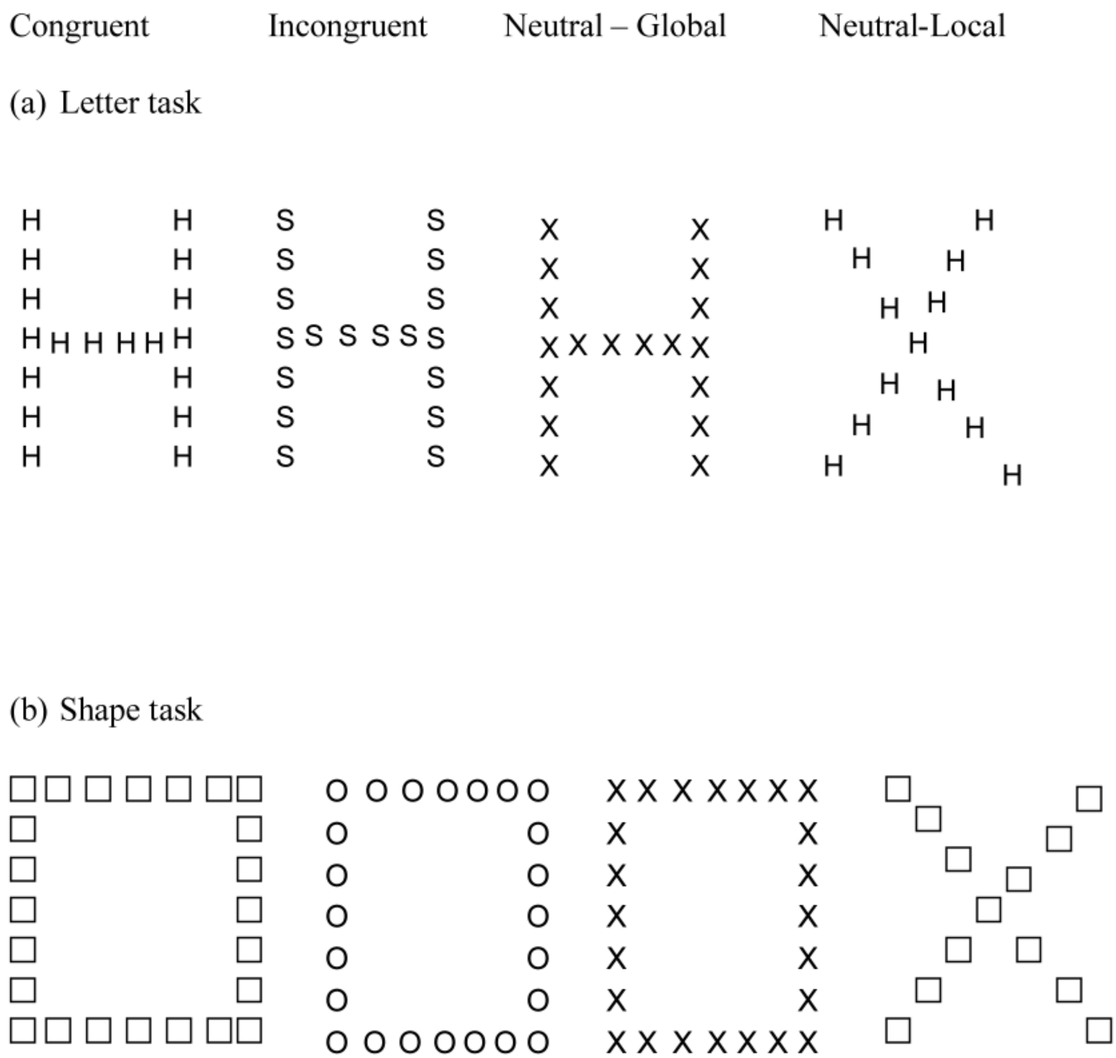
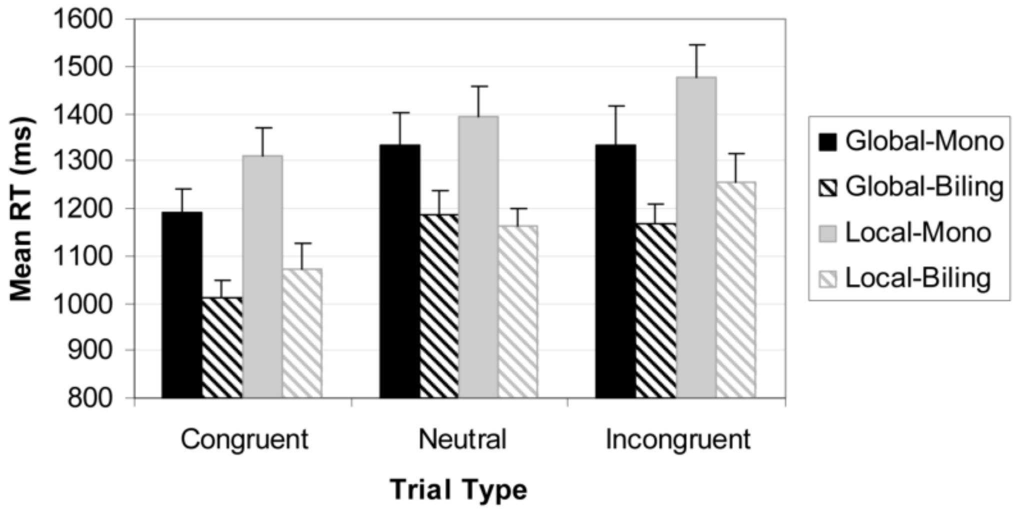


Figure 1.
Sample of stimuli used in the three trial types of the global-local paradigm for the (a) letter task and (b) shape task.

a)



b)

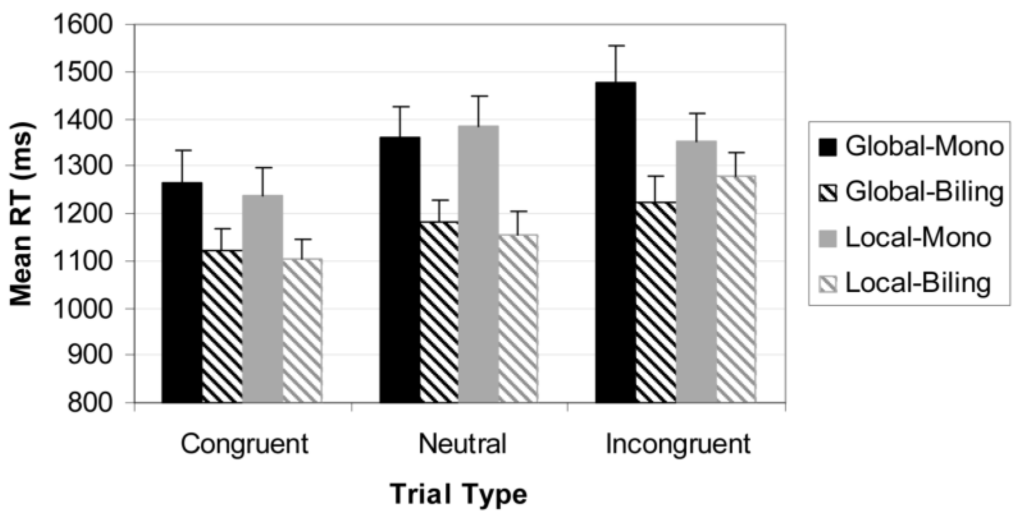
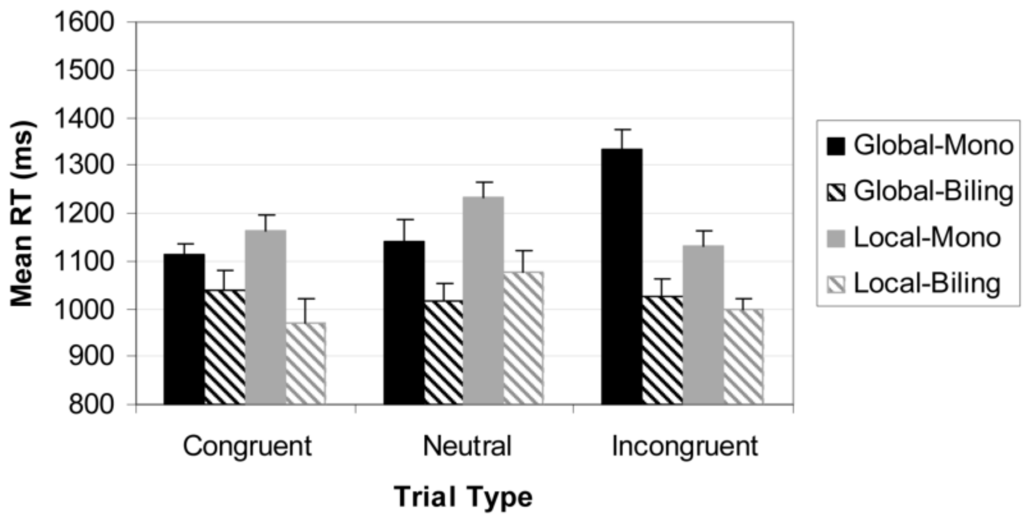


Figure 2.
Mean RT and standard error by trial type for monolinguals and bilinguals in Study 1 for (a) the letter task and (b) the shape task.

(a)



(b)

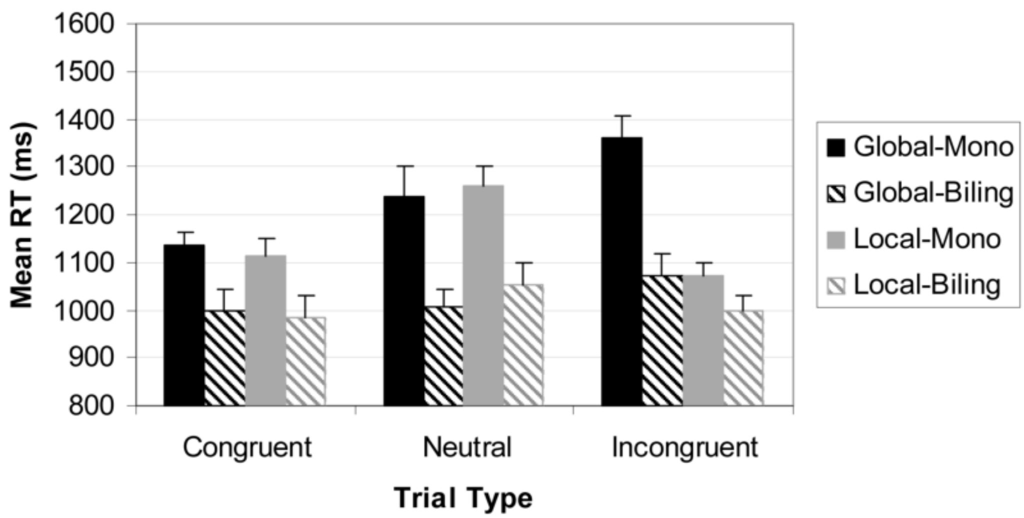


Figure 3.
Mean RT and standard error by trial type for monolinguals and bilinguals in Study 2 for (a) the letter task and (b) the shape task.

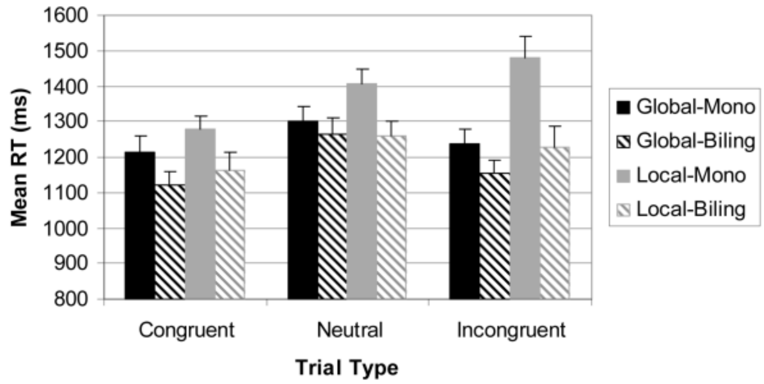


Figure 4.
Mean RT and standard error by trial type for monolinguals and bilinguals in Study 3 for the letter task

Table 1

Mean score (and standard deviation) for questions about home language use from the Language Background Questionnaire. The 5-point scale indicates the dominant language used for hat activity in the home, with 1 being use of the non-English language and 5 the use of English, and 3 representing balanced use of both languages. T-tests compared each score to the balanced mean of 3.0.

Question	Study 1	Study 2	Study 3
Child speaks	3.15 (0.8)	3.20 (0.4) *	2.00 (0.7) **
Adults to each other	1.76 (0.8) **	2.04 (0.7) **	1.10 (0.9) **
Adults to child	2.62 (1.2)	2.40 (0.6) **	1.00 (0.9) **
Siblings	3.64 (1.3) *	3.47 (0.7) **	2.11 (1.2) **
Adults TV/video	2.73 (1.2)	2.36 (0.6) **	2.21 (1.0) **
Child TV/video	4.27 (0.9) **	3.76 (0.7) **	2.8 (1.1)
Adults read	2.69 (1.3)	2.44 (0.7) **	2.36 (1.2) *
Stories to child[1]	4.46 (0.8) **	---	---

[1] This question was only asked in Study 1.

* $p < .05$

** $p < .001$

Table 2

Mean score (SD) and 95% confident interval (CI) for background measures by language group in the three studies.

Task	Study 1		Study 2		Study 3	
	Monolingual	Bilingual	Monolingual	Bilingual	Monolingual	Bilingual
PPVT standard	107.8 (7.5)	104.2 (6.6)	105.0 (12.0)	104.3 (11.2)	107.7 (12.6)	100.9 (11.1)
CI	±2.9	±2.5	±4.7	±4.4	±5.0	±4.4
Category fluency	12.4 (3.2)	11.0 (2.6)	10.3 (2.0)	10.2 (1.9)	---	---
CI	±1.3	±1.0	±0.8	±0.8		
Forward digit span	5.0 (0.7)	4.9 (0.7)	5.5 (0.6)	5.4 (0.6)	6.1 (2.2)	5.0 (1.6)
CI	±0.3	±0.3	±0.2	±0.2	±0.9	±0.7
Backward digit span	---	---	---	---	2.9 (1.4)	3.2 (1.1)
CI					±0.6	±0.4
Box completion (sec)	---	---	---	---	60.1 (27.1)	57.4 (16.7)
CI					±10.6	±6.6
Trails A (sec)	83.1 (53.7)	52.9 (16.5)	74.8 (18.8)	51.9 (16.8)	88.7 (45.7)	70.1 (23.3)
CI	±21.0	±6.3	±7.4	±6.6	±18.7	±9.1
Trails B (sec)	192.1 (78.7)	142.7 (46.4)	201.2 (45.7)	140.6 (59.6)	220.8 (98.7)	162.1 (47.6)
CI	±30.8	±17.8	±17.9	±23.4	±41.3	±18.7

Table 3

Mean number of errors, standard deviation, and 95% Confidence Interval (CI) for condition and trial type in the three studies by language group. The errors are collapsed across the letter and shape tasks for Studies 1 and 2.

Task	Study 1		Study 2		Study 3	
	Monolingual	Bilingual	Monolingual	Bilingual	Monolingual	Bilingual
Global Congruent	1.9 (1.9)	0.9 (1.0)	1.1 (1.0)	1.2 (1.5)	1.3 (1.0)	1.0 (1.2)
CI	±0.8	±0.4	±0.4	±0.6	±0.4	±0.5
Global Neutral	2.9 (3.1)	1.9 (2.1)	2.2 (1.3)	2.4 (1.4)	1.0 (1.7)	1.9 (2.5)
CI	±1.2	±0.8	±0.5	±0.6	±0.7	±1.0
Global Incongruent	10.1 (7.6)	7.4 (5.6)	2.0 (1.6)	1.8 (1.4)	3.9 (2.6)	5.6 (3.9)
CI	±3.0	±2.2	±0.7	±0.5	±1.0	±1.5
Local Congruent	1.4 (1.4)	0.9 (1.1)	0.3 (0.6)	0.6 (0.8)	0.6 (0.8)	0.6 (1.2)
CI	±0.6	±0.4	±0.2	±0.3	±0.3	±0.5
Local Neutral	1.7 (2.1)	1.8 (3.3)	1.1 (0.8)	0.9 (0.9)	1.5 (1.9)	1.0 (1.2)
CI	±0.8	±1.3	±0.3	±0.4	±0.8	±0.5
Local Incongruent	3.4 (2.9)	4.6 (3.1)	1.0 (1.1)	0.8 (1.0)	5.1 (3.2)	3.3 (2.1)
CI	±1.1	±1.2	±0.4	±0.4	±1.2	±0.8

Table 4

Correlation coefficients between Trails A and B and each of the three experimental trial types in Study 1 and Study 2.

Task	Congruent	Neutral	Incongruent
		Study One	
Trails A	.48***	.49***	.34**
Trails B	.57***	.52***	.50***
		Study Two	
Trails A	.39**	.42**	.44**
Trails B	.29*	.53***	.47***
		Study Three	
Trails A	.50***	.58***	.33**
Trails B	.28*	.34**	.37**

* $p < .05$

** $p < .01$

*** $p < .001$

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Table 5

Mean number of errors (and standard deviation) and mean RT (and standard deviation) for control condition in Studies 2 and 3.

Task	Group	Mean Errors	Mean RT (ms)
Study 2			
Letter	Monolingual	0.4 (0.6)	703 (100)
	Bilingual	0.4 (0.8)	703 (108)
Shape	Monolingual	1.2 (1.5)	778 (115)
	Bilingual	1.3 (1.7)	779 (127)
Study 3			
Letter	Monolingual	1.4 (1.5)	896 (157)
	Bilingual	2.1 (1.9)	887 (170)

Table 6

Linear regression models conducted for aggregate data from the three studiesusing (a) congruent trials, (b) incongruent trials, and (c) neutral trials for the letter task collapsed across global and local conditions.

Variable	B	SE B	β	ΔR^2	t
(a) Dependent variable: Congruent trials					
PPVT	1.39	1.43	0.07	.02	0.97
Digit span	4.47	11.91	0.03	.00	0.38
Trails A	2.24	0.60	0.34	.17	3.75**
Trails B	0.49	0.26	0.17	.04	1.88
(b) Dependent variable: Incongruent trials					
PPVT	1.83	1.79	0.08	.01	1.02
Digit span	−2.36	14.96	−0.01	.00	−0.16
Trails A	1.79	0.74	0.22	.13	2.39*
Trails B	0.79	0.33	0.23	.13	2.41*
(c) Dependent variable: Neutral trials					
PPVT	1.12	1.47	0.05	.01	0.76
Digit span	−6.93	12.27	−0.04	.00	−0.56
Trails A	2.49	0.61	0.35	.24	4.06**
Trails B	0.72	0.46	0.18	.03	1.70

* $p < .01$

** $p < .001$