6-2016

Bilingual effects on deployment of the attention system in linguistically and culturally homogeneous children and adults

Sujin YANG
Ewha Women's University

Hwajin YANG
Singapore Management University, hjyang@smu.edu.sg

Published in Journal of Experimental Child Psychology, 2016 June, Volume 146, Pages 121-136
http://doi.org/10.1016/j.jecp.2016.01.011

Bilingual effects on deployment of the attention system in linguistically and culturally homogeneous children and adults

Sujin Yang [a,*], Hwajin Yang [b]

[a] Department of Psychology, Ewha Womans University, Seoul 03760, South Korea
[b] Faculty of Social Sciences, Singapore Management University, Singapore 178903, Singapore

A R T I C L E I N F O

Keywords:
Bilingual advantages
Attention system
Attention Network Test
Global–local processing efficiency
Alerting
Orienting
Executive control

A B S T R A C T

We investigated the impact of early childhood and adulthood bilingualism on the attention system in a group of linguistically and culturally homogeneous children (5- and 6-year olds) and young adults. We administered the child Attention Network Test (ANT) to 63 English monolingual and Korean–English bilingual children and administered the adult ANT to 39 language- and culture-matched college students. Advantageous bilingual effects on attention were observed for both children and adults in global processing levels of inverse efficiency, response time, and accuracy at a magnitude more pronounced for children than for adults. Differential bilingualism effects were evident at the local network level of executive control and orienting in favor of the adult bilinguals only. Notably, however, bilingual children achieved an adult level of accuracy in the incongruent flanker condition, implying enhanced attentional skills to cope with interferences. Our findings suggest that although both child and adult bilinguals share cognitive advantages in attentional functioning, age-related cognitive and linguistic maturation differentially shapes the outcomes of attentional processing at a local network level.

* Corresponding author.
E-mail address: sy98@cornell.edu (S. Yang).

Introduction

Individuals differ in their ability to selectively attend to preferred information and allocate attentional resources while inhibiting interference (see Posner & Rothbart, 2007, for a review). Interestingly, attentional skills seem to be more rigorously honed in bilinguals, whose dual linguistic systems constantly compete for selection at varying levels of representation (e.g., phonology, syntax, lexico-semantics, morphology, orthography, pragmatics; Kroll & Stewart, 1994; Rodriguez-Fornells, De Diego Balaguer, & Münte, 2006). Unlike monolinguals, bilinguals are required to continually alternate between two languages in response to contextual demands and to attentively monitor incoming and outgoing information so that the two languages will not be confused. The literature that supports bilinguals' cognitive advantages asserts that bilinguals' regular use of two language systems is a major contributor to cognitive benefits in general control processing (i.e., executive function skills), as measured by a variety of different behavioral tasks (e.g., Bialystok, 1999; Bialystok, Craik, Klein, & Viswanathan, 2004; Carlson & Meltzoff, 2008).

Along this line, a number of studies have centered on bilingual benefits in executive function skills, particularly inhibitory control, to cope with interferences due to language coactivation (Garbin et al., 2010; Kroll & Bialystok, 2013). However, despite bilinguals' potentially unique capacity to exert attentional control in a manner different from that of monolinguals (e.g., see Friesen, Latman, Calvo, & Bialystok, 2015, for bilinguals' superior performance in the conjunction condition of a visual search task), relatively few studies have investigated how bilinguals deploy their attention system, which refers to a multidimensional construct of attention networks for goal-directed behavior (Posner & Petersen, 1990). To close this gap, we set out to examine bilinguals' attention skills and efficiency in a cross-sectional design that compared two age groups (children aged 5 or 6 years and young adults) at different maturational stages of attention.

Development of the attention system in children and adults

In the field of cognitive neuroscience, attention is commonly described as a multidimensional dynamic model that encompasses three network scores that are employed concurrently to assist the overall attention system in selective processes that guard against distraction (Posner & Fan, 2004; see Diamond, 2013, for a different conceptualization of executive attention as a unitary selective attention or inhibitory control). According to Posner, Sheese, Odludaş, and Tang (2006), the framework for attention as a networked system is based on an integrated "cue-by-flanker" paradigm in a visual field (Eriksen & Eriksen, 1974; Posner, 1980). The attention system in the brain is theorized to include three regulatory components: *alerting* for maintenance of vigilance to increase readiness to respond to impending stimuli; *orienting* for fast target detection, selection of information, and either engagement or disengagement of attention by shifting attentional resources; and *executive control* for conflict resolution when distracting stimuli interfere with the correct choice of response (for reviews, see Mezzacappa, 2004; Posner & Fan, 2004; Posner & Rothbart, 2007; Raz & Buhle, 2006). Although separate anatomical locations in the brain are implicated, suggesting the networks' reasonably independent operation (Fan, McCandliss, Sommer, Raz, & Posner, 2002), interactions among the three networks have been reported elsewhere based on cue-by-flanker interactions (Callejas, Lupiáñez, & Tudela, 2004; Fan et al., 2009; MacLeod et al., 2010; McConnell & Shore, 2011). These three network efficiency scores (alerting, orienting, and executive control) are believed to reflect attentional processing on a local level due to their computational methods. Three local network scores are obtained by contrasting two cue types (e.g., no cue vs. double cue) or flankers (congruent vs. incongruent) to reflect a narrowly defined area of attention. In contrast, global processing efficiency such as overall reaction time (RT), accuracy, and inverse efficiency score—which is a combined measure of both RT and accuracy—is computed by collapsing over all cue and flanker conditions to measure attentional performance from a holistic perspective.

Based on Posner and Petersen's (1990) theory of the attention system, reliable individual differences in attention capacity have been documented as measured by the Attention Network Test (ANT; e.g., see Rueda, Fan, et al., 2004a, for developmental differences; see Mezzacappa, 2004, for developmental and other sociodemographic differences; see Fernandez-Duque & Black, 2006, for aging effects). For both children and adults, development of the attention system—based on global indexes such as more effective inverse efficiency scores, faster RT, and higher accuracy and more efficient use of the executive control network—is greater in bilinguals than in monolinguals. For instance, using the child's version of the ANT, 4-year-old Korean–English bilingual immigrant children surpassed their English- or Korean-speaking monolingual counterparts in inverse efficiency scores, RT, accuracy, and network scores for executive control (Yang, Yang, & Lust, 2011). In a like manner, school-aged Spanish–English bilingual children (ages 5–8 and 11–14 years) outperformed monolinguals in overall RT on the child ANT when controlling for age and verbal skills (Kapa & Colombo, 2013). In addition, adult bilinguals' superior performance on the adult version of the ANT has been documented by Costa, Hernández, and Sebastián-Gallés (2008), who found more efficient attentional functioning (e.g., faster RT and higher network efficiency in executive control) among adult Catalan–Spanish bilinguals than among Spanish monolinguals. In addition, adult bilinguals' superior performance on the ANT has been observed in terms of RT and network scores for executive control among bilinguals of different language combinations (i.e., Korean–English and Chinese–English; Yang & Lust, 2007), even when using a lateralized ANT (LANT) task—in which stimuli are arranged vertically—to investigate hemispheric lateralization (Tao, Marzecová, Taft, Asanowicz, & Woodniecka, 2011). Although a bilingual advantage in global RT is sometimes absent on the LANT (e.g., Marzecová, Asanowicz, Krivá, & Woodniecka, 2013), significantly better performance on the executive control network has been demonstrated (Marzecová et al., 2013).

In contrast to these findings in favor of bilingual advantages in attentional functioning, other studies have failed to find evidence for a facilitating effect of bilingualism on attention. For instance, Antón et al. (2014) observed no bilingual effects in Basque–Spanish children in three age groups (7, 9, and 11 years) as measured by the child ANT. Paap and Greenberg (2013), using a flanker task, also found no effects in their bilingual adults of mixed language pairs. Based on a large sample size ($N = 360$ for Antón et al. (2014) and $N = 110$ for Paap and Greenberg (2013)), these studies argue that any bilingual cognitive advantage may be due to uncontrolled factors or manipulation of experimental conditions. However, these counterarguments contain confounding factors. For instance, Antón and colleagues' bilingual participants were not equally proficient bilingually ($M_{\text{Spanish}} = 8.65$, $SD = 1.17$, and $M_{\text{Basque}} = 5.95$, $SD = 1.63$, on a 10-point scale). In addition, because they were older, potential schooling effects could have played a role. Paap and Greenberg's study could have been confounded by the use of 30 different bilingual language pairs and diverse language-associated culture groups. It has been shown in the literature that formal schooling in reading and math (e.g., Best, Miller, & Naglieri, 2011), bilingual proficiency (e.g., Singh & Mishra, 2013), and bilingual language pairs (e.g., Coderre & van Heuven, 2014; Yang et al., 2011), among all others, affects executive functioning independent of bilingualism. Lack of control over these factors, therefore, could dilute bilingual advantages toward null effects in Antón and colleagues' and Paap and Greenberg's studies. To respond to these issues more systematically, a more refined design that controls for potentially important balanced bilingualism, age, and linguistic and cultural homogeneity is warranted.

In view of these inconsistencies concerning bilingual effects on the attention system, it is evident that three limitations in prior studies should be addressed. First, relatively less is known about bilingual effects on the two other local networks, alerting and orienting, compared with the network of executive control. Regarding alerting efficiency, both Costa and colleagues (2008) and Marzecová and colleagues (2013) have shown that bilingual adults experience significantly greater alerting effects than monolinguals, suggesting that bilinguals are quicker to increase their alert state when alerting cues pop up on the screen. These findings, however, were not successfully replicated in other adult studies except in the form of a trend (Tao et al., 2011; Yang & Lust, 2007). Moreover, developmental studies have reported no significant differences in alerting between bilingual and monolingual children (Kapa & Colombo, 2013; Yang et al., 2011), suggesting that age-dependent maturation might not significantly affect the use of alerting cues. Concerning the orienting network, the literature has seldom demonstrated a bilingual advantage (e.g., Kapa & Colombo, 2013) or even age-related changes among normally developing monolingual children and adults (Mezzacappa, 2004; Rueda, Fan, et al., 2004a).

The second limitation is that developmental studies have frequently failed to report network efficiency scores because of incompletion rates and high variability in RT-based data with younger bilingual children (e.g., Carlson & Meltzoff, 2008) or because a short version of the child ANT, rather than the full-length version, was used (e.g., Yoshida, Tran, Benitez, & Kuwabara, 2011). Lack of information about children's network efficiency makes it unfeasible to examine potential child–adult variations and performance compatibility. Children and adults differ substantially in many aspects of language and cognitive experience. Linguistically, bilingual children have not achieved the same level of bilingual mastery as adults—such as bilingual proficiency and biliteracy skills—in either breadth or depth. Cognitively, children are also more susceptible to interference and less efficient in reorienting their attention than adults, both of which are neurally supported by decreased brain activation in the areas of the temporoparietal junction and dorsolateral prefrontal cortex in children (Konrad et al., 2005). Without thoroughly investigating the three networks' effects, any attempt to draw conclusions about child–adult similarities and differences in attentional performance based on global indicators would fail to reveal mechanisms that may be more latent.

Lastly, given the paucity of research that directly compares the effects of bilingualism on child and adult attentional function—as well as lack of control over homogeneity when comparing children and adults from different studies—further studies are needed to examine the extent to which bilingualism exerts positive impacts on deployment of the attention system in a way that distinguishes children from adults. An age-comparable measure that is capable of assessing age-related execution demands and differential maturational speed is required to systematically examine how similarly or dissimilarly child and adult bilinguals coordinate the attention system at global and multicomponent local levels—such as alerting, orienting, and executive control.

The current study

Our primary goal was to investigate how bilingual children and adults differ from their monolingual counterparts in deployment of the attention system and to determine whether any potential positive effects due to bilingualism appear not only during early childhood but during adulthood as well. Employing a focused and integrative attention measure of the ANT, we differentiated our design from prior studies (Antón et al., 2014; Paap & Greenberg, 2013) in two major ways. First, we recruited younger children (aged 5–6 years) than Antón and colleagues (2014) to mitigate, as much as possible, the schooling effect, especially in terms of reading and math. Second, we recruited bilingual children and adults who were homogeneous in linguistic and cultural properties to avoid potential confounds linked to cross-linguistic or cultural effects (Yang & Lust, 2007; Yang et al., 2011).

Building on previous findings (Costa et al., 2008; Tao et al., 2011; Yang et al., 2011), we predicted that bilingual advantages would appear on the ANT for both children and adults at the overall performance level, as demonstrated by global measures of inverse efficiency scores, RT, and accuracy. Children and adults should similarly experience general cognitive changes in the brain that are caused by bilingualism (see, e.g., Moreno, Lee, Janus, & Bialystok, 2015, and Sullivan, Janus, Moreno, Astheimer, & Bialystok, 2014, for reviews of a causal link between short-term language training and changes in neural responses for both children and adults). They should differ, however, in cognitive maturation and the length and intensity of bilingual experience, factors that would modulate levels of attentional complexity at a more narrowly defined local level such as the three network components. Therefore, we expected that the local network of executive control would more readily reflect potentially divergent bilingual advantages in children and adults because its core processing of conflict resolution resembles bilinguals' control of two languages. However, given that the two other networks, alerting and orienting, are considered to be more stable and invariant throughout development (Rueda, Fan, et al., 2004a), it is possible that the two other networks may also be closely related to bilingual benefits and sufficiently sensitive to detect any age- or bilingualism-related changes.

Method

Participants

A total of 102 participants took part in the study: 63 5- and 6-year-old children, of whom 31 were English monolinguals (23 boys) and 32 were Korean–English bilinguals (19 boys), and 39 adults, of whom 19 were English monolinguals (2 men) and 20 were Korean–English bilinguals (5 men). Age did not differ between monolingual and bilingual children, but monolingual adults were younger than bilingual adults by 9.6 months ($M_{\text{monolinguals}}$ = 19.9 years vs. $M_{\text{bilinguals}}$ = 20.7 years), $t(37) = 2.3$, $p = .027$. Approximately a 1-year difference among adults, however, has not been associated with a significant outcome in executive functions (Yang & Yang, in press), so we did not consider age to be a covariate in subsequent analyses. Both children and adults were drawn from a healthy population and had normal or corrected-to-normal vision. Table 1 summarizes descriptive statistics for each age and language group.

English monolingual children were recruited in Ithaca, New York, and Korean–English bilingual children were recruited in Palisades Park, New Jersey, which is one of the largest Korean communities in the United States. A proxy measure of socioeconomic status was obtained by controlling parents' education level (minimum of a college education) and selecting day-care centers in both cities that were located in middle-class neighborhoods. All bilingual children were U.S.-born, second-generation Korean immigrants. Eligibility criteria for bilingual children were that (a) Korean had been acquired first and was spoken as a mother tongue (L1) and English was acquired later as a second language (L2), which qualified them as sequential bilinguals; (b) Korean was spoken at home and in the community, and English was spoken at the day-care center; (c) they were enrolled in a Korean–English bilingual program at the day-care center; and (d) they were neither English- nor Korean-dominant bilingual, which was determined by the parents' screening questionnaire. We adhered to strict selection criteria to ensure an adequate level of Korean proficiency that was not otherwise assessed on a standardized test.

For the adult group, undergraduate students at Cornell University were recruited from across the campus. Participants received either extra credit or $5. To approximate our Korean–English bilingual children's language profile, we recruited sequential bilingual adults who had learned their mother tongue (Korean) first and English later yet functioned proficiently in an English-speaking environment. Table 2 summarizes the characteristics reported on a language background questionnaire: bilingual experience such as self-rated proficiency levels, age on arrival in the United States, onset age of second-language acquisition, length of residence in the Korean-speaking country (L1: Korean) and the English-speaking country (L2: English), and level of comfort with and frequency of use of each language.

The average age of adult bilinguals on arrival in the United States was 10 years ($SD = 6.1$), which approximately coincides with the onset age of English learning ($M = 10.0$ years, $SD = 5.9$). Overall, residence was longer in Korea ($M = 11.7$ years, $SD = 4.3$) than in the United States ($M = 8.8$ years, $SD = 4.0$). Bilingual participants self-rated their proficiency levels in both languages (L1: Korean; L2: English) along four dimensions—comprehension, reading, speaking, and writing—using a 4-point Likert scale ranging from 1 (*scarcely*) to 4 (*perfectly*). A series of paired *t*-tests on these four domains produced no significant L1–L2 differences, which confirms that the Korean–English bilinguals were more likely to have L1–Korean skills commensurate with their L2–English skills. However, a repeated-measures analysis of variance (ANOVA) with the four language domains as a within-participant factor yielded a significant difference for Korean, $F(3, 57) = 7.55$, $p < .001$, $\eta_p^2 = .28$, whereas the result was not significant for English. A follow-up analysis further showed that Korean comprehension skills ($M = 3.8$) were significantly higher than writing skills ($M = 3.2$), $p < .01$, whereas linguistic skills in all of the other domains were approximately equal. Participant responses on a 3-point scale—1 (*L1 dominant*), 2 (*equally comfortable/equally frequent*), and 3 (*L2 dominant*)—showed that 40% felt equally comfortable with both languages and 60% used them equally frequently on a daily basis. The remaining participants reported language dominance, either L1 or L2, for level of comfort and frequency of use.

Tasks

Peabody Picture Vocabulary Test

The Peabody Picture Vocabulary Test–Third Edition (PPVT-III; Dunn & Dunn, 1997) is a standardized English test ($M_{\text{population}} = 100$, $SD = 15$; median Cronbach's alpha $r = .95$ for internal consistency) that is widely used to measure receptive vocabulary knowledge in ages ranging from 2.5 to 90 years. The concurrent validity of the PPVT-III has been established by comparison with a widely used

Table 1
Participants' descriptions (and standard deviations).

Category ($N = 102$)	Children ($n = 63$)			Adults ($n = 39$)		
	Monolinguals ($n = 31$)	Bilinguals ($n = 32$)	t-Statistic	Monolinguals ($n = 19$)	Bilinguals ($n = 20$)	t-Statistic
Age (years;months)[a]	5;10 (0.6)	5;10 (0.55)	−.007	19;11 (0.9)	20;8 (1.2)	2.3*
Gender (M:F)	23:8	19:13		2:17	5:15	
PPVT-III standard[b]	114 (12.8)	87 (14.8)	−7.7**	121 (10.4)	109 (8.6)	−4.2**
PPVT-III raw[c]	97 (15.5)	65 (23.4)	−6.6**	189 (5.3)	181 (6.9)	−4.2**
Age equivalents[d] (lower–upper)[e]	7;3 (6;10–7;8)	5;0 (4;10–5;6)		22+	22+	

[a] Standard deviations for age are in years.
[b] Standard scores are norm-referenced and converted from raw scores based on the participant's chronological age in years and months.
[c] Raw scores are calculated by subtracting the total number of errors from the ceiling item.
[d] Age equivalents correspond to raw scores with 68% confidence and were obtained from PPVT-III norms.
[e] Values in parentheses refer to age equivalents (lower limit and upper limit).
* $p < .05$.
** $p < .01$.

Table 2
Bilingual adults' basic language characteristics (means and standard deviations).

Category	Age at arrival (years)	Onset age (years)	Years in L1	Years in L2
Background[a]	10.0 (6.1)	10.0 (5.9)	11.7 (4.3)	8.8 (4.0)
Proficiency[b]	Comprehension	Speaking	Reading	Writing
L1	3.8 (0.4)*	3.6 (0.6)	3.5 (0.5)	3.2 (0.8)*
L2	3.4 (0.6)	3.1 (0.6)	3.4 (0.6)	3.3 (0.6)
Usage[c]	Comfort level		Frequency of use	
Equally	40% ($n = 8$)		60% ($n = 12$)	
L1 dominant	55% ($n = 11$)		25% ($n = 5$)	
L2 dominant	5% ($n = 1$)		15% ($n = 3$)	

[a] Age at arrival refers to first arrival in the United States. Onset age refers to the age at onset of second-language acquisition. Years in L1 and L2 refer to years spent in Korean (L1)-speaking and English (L2)-speaking countries.
[b] Proficiency was measured on a 4-point Likert scale ranging from 1 (*scarcely*) to 4 (*perfectly*).
[c] Percentiles were obtained by dividing the number of respondents in each cell by the total for each group.
* $p < .01$ for a comparison between L1 comprehension and L1 writing.

intelligence test such as the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 2004). Correlation coefficients between the PPVT and K-BIT are relatively strong, ranging from .86 (matrices) to .92 (composite) (Powell, Plamondon, & Retzlaff, 2002). Using receiver operating characteristic analysis, Campbell, Bell, and Keith (2001) tested the accuracy of the PPVT-III as a diagnostic indicator of intellectual and achievement skills. When the Kaufman Assessment Battery for Children (Kaufman & Kaufman, 1983) was used as a criterion for their analyses, the PPVT-III showed 82% probability to correctly classify children. Taken together, the PPVT-III is considered to be valid as a screening measure of intellectual achievement skills.

Attention Network Test–Child Version

The Attention Network Test–Child Version (ANT-C; Rueda, Fan, et al., 2004a) was adapted from the Adult ANT (Fan et al., 2002) by taking into consideration developmental constraints specific to children such as limited attention span and motor skills. The total number of trials was reduced to 168 for children from 288 for adults and was distributed over one training block of 24 trials and three experimental blocks of 48 trials each. Performance feedback was given for correct responses, using both sound ("Woohoo!") and animation (a target fish stimulus making bubbles and wagging its tail fin), whereas only audio feedback ("Huh?")[1] was given for incorrect responses. Stimuli for the ANT were presented visually on a 14.1-inch laptop computer, and children responded by pressing one of two input keys (left or right) on a keyboard to match the direction of a target fish swimming solo or in an array of five fish. Children took approximately 25 to 30 min to complete the task. Fig. 1 lists schematic details for the time course of a trial presentation and intervals among a fixation, a warning cue, a target and flankers, and auditory/visual feedback.

The ANT-C was designed to examine multidimensional functions of attention in a single integrated test using the cue-by-flanker paradigm (Eriksen & Eriksen, 1974; Posner, 1980). General processing abilities related to attention were measured in terms of inverse efficiency scores, RT (ms), accuracy (%), and three RT-based individual network efficiency scores. Four cue types (no cue, central cue, double cue, and spatial cue) and three flanker types (neutral, congruent, and incongruent) on the ANT-C were combined to present 12 different conditions and used as a platform to compute three attention network efficiency scores: alerting, orienting, and executive control. The alerting network for vigilance was manipulated by subtraction between conditions with either the presence (double cue) or absence (no cue) of warning cues. Typically, performance is faster when warning cues alert participants about an upcoming event than in the no-cue condition. The orienting network for detection of the target was obtained by contrasting performance between cue conditions with (spatial cue) or without (central cue) spatial information about the target location. Spatial cues commonly trigger better attentional processing than central cues, which appear in the middle of the screen with no hint of spatial location of a target. To compute performance of the executive control network, two flanker types (congruent vs. incongruent) were compared. A congruent condition presents an array in which a target and flankers face the same direction; in an incongruent condition, the target and flankers face different directions and, as a result, slow performance efficiency.

The test–retest reliabilities of the ANT-C, which were obtained by Rueda and colleagues (2004a) based on a sample of 28 children, were $r = .94$ for overall RT and $r = .93$ for error rate. Analyses were conducted based on correct trials only.

Attention Network Test–Adult Version

The Attention Network Test–Adult Version (ANT-A; Fan et al., 2002) uses the same conceptual framework as the ANT-C and measures multiple dependent variables (inverse efficiency scores, RT, accuracy, and three network efficiency scores) using the cue-by-flanker paradigm. The ANT-A, however, replaces the animated fish with arrow stimuli (← ← →← ←) without any visual or auditory feedback for responses except during practice trials, in which the word "Correct" or "Incorrect" appears. Fig. 1 includes more details about the ANT-A, which consists of a total of 288 trials over one training block of 24 trials and three experimental blocks of 96 trials each and takes approximately 20 to 25 min to complete. Test–retest reliability of the ANT-A ($N = 40$) provided by Fan and colleagues (2002) was $r = .87$ for overall raw RT.

Procedure

Language-matched bilingual experimenters were recruited to indirectly gauge whether participants were proficient in both languages. For the children's group, before the experiment began, the Korean–English bilingual experimenters joined the classroom on several occasions during circle time and free playtime to establish rapport and acclimate children to the experimental situation. Bilingual experimenters carried on a casual conversation in both languages to ensure that the children understood and could use both languages proficiently. The topics were of interest to children, for example, a birthday party and favorite toys or movies. Children were then invited by the same bilingual experimenter into a quiet room at the day-care center to complete the PPVT-III and

[1] We replaced the beep for incorrect responses in the original ANT with a spoken "Huh?" because the beep seemed to negatively influence affective and motivational aspects in younger participants with lower accuracy.

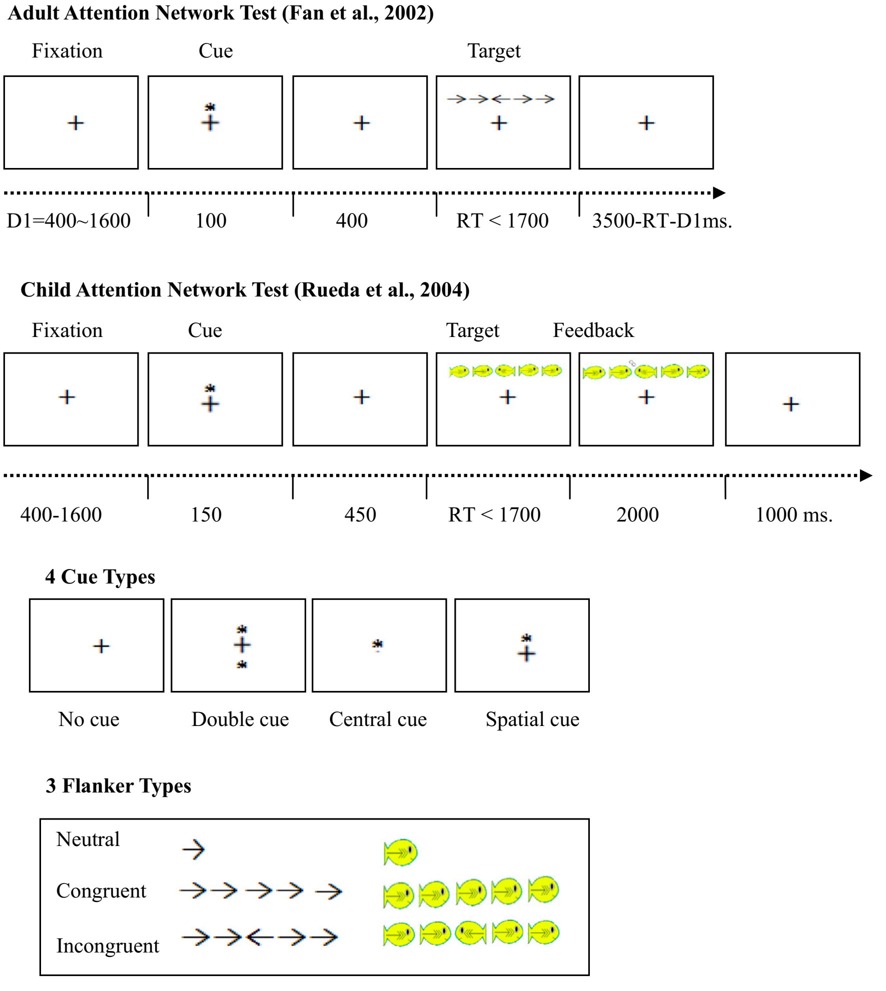

Fig. 1. Schematic representation of the Attention Network Test (ANT).

ANT-C. Adult participants completed the PPVT-III, ANT-A, and a short language background questionnaire in a quiet room. With adult participants, a brief linguistic interaction in both languages occurred during debriefing at the end of the session.

All instructions were given in English. The two tasks—the PPVT-III and ANT (Child or Adult Version)—were administered in a counterbalanced fashion to control for order effects (except for the language background questionnaire, which was given to all bilingual adults at the end of the session).

Results

Our initial analyses revealed no gender effects on any ANT-related measures (inverse efficiency scores, RT, accuracy, and network scores). Therefore, all subsequent analyses were carried out by collapsing across gender for the ANT results. For each dependent measure, we conducted a 2 (Bilingualism: monolinguals vs. bilinguals) × 2 (Age: children vs. adults) ANOVA as our primary analysis to directly compare children[2] and adults. Further analysis was performed, if necessary, to investigate bilingual benefits during early childhood and adulthood.

English receptive vocabulary (PPVT-III)

A two-way ANOVA with bilingualism and age as factors was performed on the age-referenced standardized PPVT-III scores. Significant main effects of bilingualism and age emerged, where monolinguals scored significantly higher than their bilingual peers, $F(1, 98) = 61.5$, $p = .001$, $\eta_p^2 = .39$, whereas adults were better than children, $F(1, 98) = 32.3$, $p = .001$, $\eta_p^2 = .25$. A significant interaction between bilingualism and age indicates that the effect of bilingualism differed between children and adults, $F(1, 98) = 7.7$, $p = .007$, $\eta_p^2 = .073$, with a more pronounced monolingual–bilingual gap in PPVT-III scores among children than among adults. A summary of descriptive statistics for the PPVT-III is provided in Table 1.

Attention Network Test

Table 3 shows the means of the three global indexes of inverse efficiency scores, RT, accuracy, and local indexes of the three attention network scores as functions of age and language group. We first present our results from three global measures in the order of inverse efficiency scores, RT, and accuracy and then report our results from local network efficiency scores. Follow-up analyses were performed, if necessary, to determine whether bilingualism effects were present during both early childhood and young adulthood.

Global inverse efficiency scores

To examine overall ANT performance, we employed the inverse efficiency score, which combines speed (RT) and accuracy in a single measure. The inverse efficiency score was computed by dividing mean RT by percentage of correct accuracy (Townsend & Honey, 2007). The two-way factorial ANOVA with bilingualism (monolinguals vs. bilinguals) and age (children vs. adults) revealed two main effects of bilingualism, $F(1, 98) = 18.35$, $p = .0001$, $\eta_p^2 = .16$, and age, $F(1, 98) = 164.9$, $p = .0001$, $\eta_p^2 = .63$. These results indicate that bilinguals were more effective than monolinguals ($M_{\text{bilinguals}} = 8.6$ vs. $M_{\text{monolinguals}} = 5.4$) and that adults were better than children ($M_{\text{monolinguals}} = 11.68$ vs. $M_{\text{children}} = 13.03$). A significant interaction between bilingualism and age appeared, $F(1, 98) = 12.54$, $p = .001$, $\eta_p^2 = .11$, suggesting that the effects of bilingualism on inverse efficiency scores were moderated by age. Follow-up *t*-tests were conducted separately for each (child and adult) group to test for bilingualism effects. Results confirmed that both children, $t(61) = -5.0$, $p = .001$, $d = -1.3$, and adults, $t(37) = -2.4$, $p = .02$, $d = -0.7$, experienced the same bilingual advantage. Notably, however, the beneficial effect of bilingualism seems to be more pronounced during childhood than during young adulthood; the effect size (Cohen's *d*) for children ($M_{\text{difference}} = 4.7$, $d = -1.26$) is approximately twice that for young adults ($M_{\text{difference}} = 0.4$, $d = -0.7$).

Global reaction time

RT data were entered into the same 2 (Bilingualism) × 2 (Age: children vs. adults) ANOVA model. We found two main effects of bilingualism, $F(1, 98) = 11.97$, $p = .001$, $\eta_p^2 = .11$, and age, $F(1, 98) = 269.14$, $p = .001$, $\eta_p^2 = .73$. In contrast to monolinguals ($M = 950.2$) and children ($M = 1095.8$), bilinguals ($M = 809.3$) and adults ($M = 527.2$) had faster RTs. A significant bilingualism and age was evident, $F(1, 98) = 4.94$, $p = .029$, η_p^2 interaction between $= .05$, demonstrating that the effect of bilingualism was moderated by age. In follow-up analyses, both children, $t(61) = -3.7$, $p = .001$, $d = -0.93$, and

[2] We combined the two age groups of children into one for our main ANT analyses because the age difference between these two groups is less than a year ($M_{5\text{years}} = 5.5$, $SD = 0.3$; $M_{6\text{years}} = 6.5$, $SD = 0.3$) and significant age differences were limited to the inverse efficiency scores, $t(61) = 3.26$, $p = .002$, $d = 0.86$, and RT, $t(61) = 4.50$, $p = .001$, $d = 1.17$, which favored 6-year-olds over 5-year-olds, as expected. To focus more on any potential effects of early childhood and adulthood bilingualism on attentional functioning, no further statistical comparisons between 5- and 6-year-olds were conducted.

Table 3
Global measures of ANT performance (and standard deviations) and network efficiency.

ANT performance	Children		t-Statistic	Adults		t-Statistic
	Monolinguals	Bilinguals		Monolinguals	Bilinguals	
Global attention measures						
Inverse efficiency[a]	15.4 (4.6)	10.7 (2.5)	−5.0**	5.6 (0.6)	5.2 (0.5)	−2.4*
RT (ms)	1196 (240)	999 (180)	−3.7**	549 (59)	506 (55)	−2.4*
Accuracy (%)	81 (13.3)	94 (4.9)	5.3**	97 (1.8)	97 (1.7)	−0.05
Attention network performance						
Alerting	101 (81.7)	102 (67.1)	0.05	36 (22)	45 (17)	1.3
Orienting	77 (65.9)	77 (42)	−0.1	44 (19)	28 (15)	−2.7*
Executive control	97 (42)	87 (49)	−0.8	133 (35)	96 (23)	−3.8**

[a] Higher inverse efficiency scores indicate poorer processing efficiency, and lower scores indicate greater processing efficiency.
* $p < .05$.
** $p < .01$.

adults, $t(37) = -2.4$, $p = .024$, $d = -0.75$, displayed a positive bilingualism effect on RT, but it was larger among children ($M_{difference} = 197$ ms) than among adults ($M_{difference} = 43$ ms).

Global accuracy

Consistent with RT analysis, the same ANOVA model showed that bilinguals outperformed monolinguals ($M_{bilinguals} = 95.76$, $SD = 1.13$; $M_{monolinguals} = 89.20$, $SD = 1.16$), $F(1, 98) = 16.69$, $p = .001$, $\eta_p^2 = .15$, whereas adults were superior to children ($M_{adults} = 95.56$, $SD = 1.27$; $M_{children} = 87.40$, $SD = 1.00$), $F(1, 98) = 39.95$, $p = .001$, $\eta_p^2 = .29$. An interaction between bilingualism and age was significant, $F(1, 98) = 16.84$, $p = .001$, $\eta_p^2 = .15$, suggesting that the effect of bilingualism is manifested differently during early childhood and adulthood. To test for bilingualism effects, a separate *t*-test was conducted for children and adults; results demonstrated that the positive effect of bilingualism on accuracy was evident in young children, $t(61) = 5.2$, $p = .001$, $d = 1.3$, but not in young adults. However, given that young adults' accuracy data typically allow for little variance—because they easily perform the task—the absence of bilingual benefits in their accuracy data is not surprising.

Together, our analyses of the three global measures (inverse efficiency scores, RT, and accuracy) of the ANT consistently suggest that bilingualism confers apparent benefits for global processing efficiency in attentional deployment during early childhood and young adulthood; critically, it is notable that bilingual benefits are more pronounced among children than among adults.

Network efficiency

The three network efficiency scores were computed using RTs. Alerting scores were obtained by subtracting RT for double-cue conditions from those for no-cue conditions. Orienting scores were obtained by subtracting RT for spatial-cue conditions from those for central-cue conditions. Executive control scores were obtained by subtracting RT for congruent conditions from those for incongruent conditions. Following the procedures described previously (Rueda, Fan, et al., 2004a), only positive values[3] were included. This resulted in the loss of 21.7% of children's data on average ($n = 11$ for alerting, $n = 20$ for orienting, and $n = 10$ for executive control out of 189 data points) and 3.4% of adults' data ($n = 2$ for alerting, $n = 2$ for orienting, and $n = 1$ for executive control out of 117 data points).

When a separate 2 × 2 ANOVA with bilingualism and age (children vs. adults) was performed for each of the three network scores, a significant main effect of bilingualism was apparent only in executive control scores, $F(1, 88) = 7.5$, $p = .008$, $\eta_p^2 = .08$ ($M_{bilinguals} = 90.8$, $SD = 40.9$;

[3] Negative network scores are more prevalent in young children than in older children (see Carlson & Meltzoff, 2008, for an example). Negative network scores are conventionally eliminated from the main analyses because they unduly lower average scores. Although clear reasons have not been presented, they may have resulted from the task–time setup for target processing (RT < 1700 ms; see Fig. 1), which was alleviated in another study where the interval was increased to 5000 ms (see Rueda, Posner, Rothbart, & Davis-Stober, 2004b).

Table 4
Mean RTs and accuracy (and standard deviations) as a function of cue and flanker condition.

Condition	Children		t-Statistic	Adults		t-Statistic
	Monolinguals	Bilinguals		Monolinguals	Bilinguals	
Reaction time (ms)						
No cue	1113 (178)	997 (169)	−2.7*	585 (53)	542 (59)	−2.3*
Double cue	1057 (199)	908 (174)	−3.2**	554 (62)	496 (51)	−3.1**
Central cue	1072 (201)	929 (165)	−3.1**	557 (60)	507 (58)	−2.6*
Spatial cue	1038 (197)	900 (161)	−3.0**	519 (67)	479 (55)	−2.0*
Neutral flanker	1042 (186)	884 (165)	−3.6**	481 (50)	450 (49)	−1.9
Congruent flanker	1056 (203)	915 (163)	−3.0**	524 (60)	486 (54)	−2.0*
Incongruent flanker	1113 (181)	1001 (163)	−2.6*	657 (76)	583 (65)	−3.2**
Accuracy (%)						
No cue	79 (15.4)	94 (7.2)	4.8**	98 (1.2)	98 (1.6)	−0.6
Double cue	83 (15)	94 (6.2)	4.0**	98 (1.6)	97 (2.8)	−0.8
Central cue	80 (14)	93 (6.0)	5.0**	97 (3.1)	97 (1.9)	−0.1
Spatial cue	83 (13.4)	96 (5.2)	5.0**	98 (1.7)	98 (2.0)	0.2
Neutral flanker	83 (14)	94 (5.7)	4.1**	99 (0.63)	99 (0.7)	0.1
Congruent flanker	84 (14)	95 (5.8)	4.3**	99 (0.43)	99 (0.6)	−0.9
Incongruent flanker	77 (16.3)	93 (5.6)	5.5**	95 (4.3)	95 (4.7)	−0.4

* $p < .05$.
** $p < .01$.

$M_{monolinguals}$ = 113.8, *SD* = 42.5), suggesting that of the three network scores, bilingual experiences had the most significant effect on the executive control network. All three networks were sensitive to age, favoring adults over children: alerting, $F(1, 85) = 23.11$, $p = .001$, $\eta_p^2 = .214$; orienting, $F(1, 76) = 18.33$, $p = .001$, $\eta_p^2 = .19$; executive control, $F(1, 88) = 7.31$, $p = .008$, $\eta_p^2 = .08$ (see Table 3). Although we did not find any interaction effect on the three network scores, there was a trend favoring bilinguals over monolinguals, which we further probed in follow-up analyses. When bilingual effects were examined separately in children and adults, significant bilingual effects emerged among young adults only for orienting, $t(35) = -2.73$, $p = .01$, $d = -0.88$, and executive control, $t(37) = -3.80$, $p = .001$, $d = -1.20$. For children's data, however, we found no bilingualism effects on any of the network efficiency scores. These findings imply that an important developmental difference between children and adults may modulate bilingual benefits in specific attentional deployment.

Cue and flanker effects

Table 4 summarizes RT and accuracy on flanker and cue conditions as a function of language and age groups. To examine cue and flanker effects on RT and accuracy, we performed two separate repeated-measures mixed-factor ANOVAs: 3 (Flanker: neutral, congruent, or incongruent) × 4 (Cue: no cue, double cue, central cue, or spatial cue) × 2 (Bilingualism: bilinguals vs. monolinguals) × 2 (Age: children vs. adults), with flanker and cue as within-participant factors and bilingualism and age as between-participant factors.

For RT, main effects of flanker and cue were significant (*ps* < .001), confirming that RT is susceptible to varying flanker and cue types (see Fig. 2). Significant main effects of bilingualism, $F(1, 98) = 10.26$, $p = .002$, $\eta_p^2 = .10$, and age, $F(1, 98) = 268.00$, $p = .001$, $\eta_p^2 = .73$, were also found, which favored bilinguals and adults over their respective counterparts. A significant flanker by cue interaction, $F(6, 588) = 83.6$, $p = .001$, $\eta_p^2 = .46$, and a significant flanker by age interaction, $F(2, 196) = 4.14$, $p = .017$, $\eta_p^2 = .04$, were also found.

For accuracy, three main effects emerged: flanker, $F(2, 196) = 9.43$, $p = .001$, $\eta_p^2 = .19$, bilingualism, $F(1, 98) = 15.47$, $p = .001$, $\eta_p^2 = .14$, and age, $F(1, 98) = 42.19$, $p = .001$, $\eta_p^2 = .30$. Two significant interactions were found: flanker by cue, $F(6, 588) = 1.55$, $p = .001$, $\eta_p^2 = .01$, and bilingualism by age, $F(1, 98) = 16.5$, $p = .001$, $\eta_p^2 = .14$. To evaluate the bilingualism by age interaction more closely, we performed an omnibus analysis with a 2 (Bilingualism) × 2 (Age) × 2 (Flanker: congruent vs. incongruent) repeated-measures mixed-factor ANOVA. All three main effects were significant

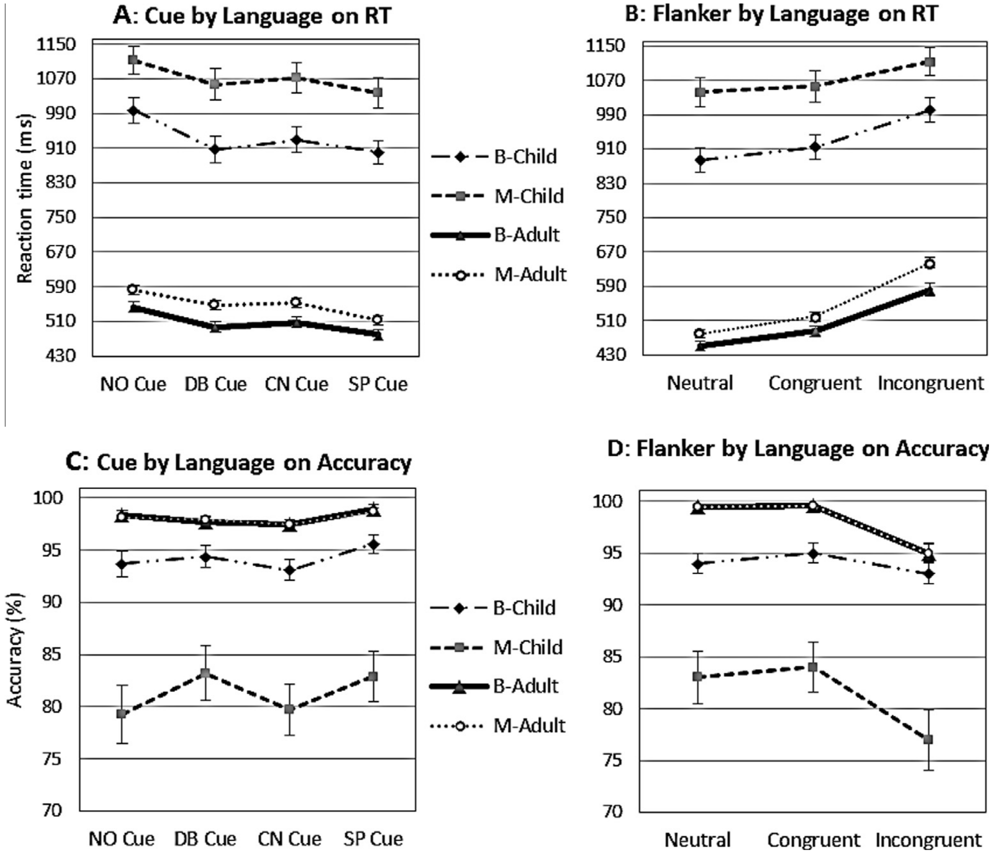

Fig. 2. Mean accuracy (%) and reaction times (ms) on the flanker and cue conditions as a function of bilingualism and age. NO Cue, no cue; DB Cue, double cue; CN Cue, central cue; SP Cue, spatial cue.

(*Fs* > 15, *ps* < .001), as was a bilingualism by age interaction, $F(1, 98) = 17.9$, $p = .001$, $\eta_p^2 = .16$, and a bilingualism by age by flanker interaction, $F(1, 98) = 4.11$, $p = .045$, $\eta_p^2 = .04$ (see Fig. 2D). Further follow-up analyses examining the three-way interaction revealed that the bilingualism by age interaction was significant for both congruent and incongruent conditions (*Fs* > 11, *ps* < .001). A series of the simple-effect tests showed that for both conditions, bilingual children were more accurate than their monolingual counterparts (*ps* < .001) and adults were superior to children (*ps* < .05), except for the incongruent flanker condition where bilingual children ($M = 93.4\%$, $SD = 5.6$) and bilingual adults ($M = 95.3\%$, $SD = 4.7$) performed equally well (see Table 4). This implies that bilingual children may develop an enhanced attentional skill early on to cope with interference, as shown in the incongruent condition.

In summary, global processing measures of inverse efficiency scores, RT, and accuracy, as well as a local measure of the executive control network, consistently demonstrated bilingual advantages in children and adults. Significant interactions between bilingual experience and age (children vs. adults) in inverse efficiency scores, RT, and accuracy confirmed that the positive effects of bilingualism were more pronounced during early childhood than during early adulthood. However, early childhood bilingual advantages were absent in results for network efficiency—as opposed to bilingual effects for adults that enhanced functioning in orienting and executive control. Nevertheless, it is notable that bilingual children achieved an adult level of accuracy in the incongruent flanker condition, implying that a bilingual experience for early childhood is an important enhancer for attentional control skills for interference.

Discussion

We investigated the scope of bilingual effects on deployment of the attention system in a group of linguistically and culturally homogeneous children and young adults. Using the integrative measure of the three-networked ANT, we found sizable bilingualism effects in all global measures of attention and at markedly larger magnitude for children than for adults. Children and adults were subject to differential influences due to bilingualism on orienting and executive control network efficiency, with advantages evident for adult bilinguals only. Notably, however, bilingual children achieved an adult level of accuracy in the incongruent flanker condition, implying that an early bilingual experience is advantageous in controlling interference.

Given that attention is a key function of basic and complex information processing and learning (Posner & Rothbart, 2007), our results confirm that bilingual experiences enhance attentional functioning—primarily in the global aspect—for both children and adults. Importantly, bilingual children as young as 5 or 6 years were able to achieve an adult level of accuracy when resolving conflicts and interference in the incongruent condition. Given that this phenomenon was not observed in monolingual children, this is a remarkable feat for bilingual children, whose executive control network is still developing and who may be at a disadvantage due to maturational constraints. Moreover, considering that conflict resolution in incongruent flanker conditions is closely related to the executive control network, our finding suggests that early bilingual experience is particularly advantageous to the development of executive control, which helps bilingual children to deal with interference better than their monolingual peers. This also corroborates previous findings that bilingualism enriches executive functioning in areas such as inhibitory control (e.g., Bialystok, 1999; Bialystok et al., 2004), whose operating principle is analogous to the executive control network.

Our findings of child–adult differences in two local network scores for orienting and executive control demonstrate how attentional functioning may be inherently different in both child and adult bilinguals compared with monolinguals. Given that children's bilingualism is likely to be shaped less than adults' bilingualism in many linguistic and cognitive aspects, adult bilinguals' richer language experience for a longer period of time than that of children may have prepared them to deal more adaptively with orienting information while simultaneously subduing distraction (e.g., acquisition of biliteracy skills; for a review, see Yang, Yang, & Kang, 2014). Alternatively, although no bilingual distinctions appeared in local attentional networks for children using the current ANT-C, they might emerge if a more rigorous task were administered. In a recent study, Yang and Yang (in press) suggested that varying task demands for controlled processing moderates bilinguals' task performance and that bilinguals excel only when distraction is at a substantial level. In line with this view, the latest version of the ANT (Pozuelos, Paz-Alonso, Castillo, Fuentes, & Rueda, 2014), which includes more complex and demanding features such as tonal/phasic alertness signals and valid/invalid orientation cues, has revealed significant age-related developmental changes in network scores among children aged 6 to 14 years that were not detected with the original ANT-C for children aged 6 to 12 years (Rueda, Fan, et al., 2004a). Future research should further explore a bilingual advantage in the three network scores, particularly in executive control, for children of varying ages and with a range of task demands.

In terms of adult bilingual advantages in specific network efficiency, our findings yielded different observations from those of Costa and colleagues (2008). Although both studies consistently found that bilingualism affords benefits to executive control, Costa and colleagues identified an additional advantage in alerting among Catalan–Spanish bilinguals compared with Catalan-speaking monolinguals; in contrast, we found an advantage in orienting. Although our data did not yield a significant result for alerting, we found a larger alerting effect trend for bilingual adults ($M_{\text{monolinguals}} = 36$, $SD = 22$; $M_{\text{bilinguals}} = 45$, $SD = 17$) and, thus, reexamined the specific relationship between bilingualism and use of alerting cues while controlling for the baseline RT in the absence of cue. To this end, we normalized our alerting data by dividing individuals' mean RT on the double-cue condition by the corresponding RT on the no-cue condition. This allowed us to understand how bilinguals and monolinguals employ alerting cues provided that baseline response speed is consistent. A *t*-test revealed a significant difference, as Costa and colleagues found, indicating that adult bilinguals ($M_{\text{bilinguals}} = .92$) maximized alerting cues in the double-cue condition—compared with the no-cue condition—more than their monolingual counterparts ($M_{\text{monolingual}} = .95$), $t(37) = -2.4$, $p = .02$, $d = -0.07$. Although different degrees of bilingualism and bilingual profiles may differentially intensify degrees of alerting effects, our data further suggest that bilinguals' typical responsiveness to daily contextual demands regarding language choice and use could positively reinforce the use of alerting cues.

Given our finding of bilingual advantages in the orienting network—which were absent in Costa and colleagues' (2008) study—a different aspect of bilingualism (e.g., different language pairs, varying degrees of bilingual proficiency, frequency of language use, switching demands), which in turn leads to adaptively varied control levels, could have affected the results of three local networks in the attention system (for reviews, see Green & Abutalebi, 2013; Kroll, 2015; Luk, 2015; Yang & Yang, 2013). For instance, orthographic differences between the two language families (e.g., Indo-European [Spanish, Catalan, and English] vs. Altaic [Korean]) could have an independent effect on the two bilingual groups' visuospatial analysis abilities, particularly for adults whose knowledge of print is more extensive than that of children. Research on the neural mechanisms that underlie Korean word reading demonstrates that the right hemispheric BA 8 (the posterior area of the right dorsolateral prefrontal cortex) is strongly activated in addition to areas generally identified with alphabetic word reading (Yoon, Cho, Chung, & Park, 2005). Yoon and colleagues (2005) proposed that this area, which has been implicated in higher order visual control, may be specialized in the visuospatial processing of Korean word reading. Given the nonlinear orientation of Korean orthography—as opposed to alphabetic Catalan or Spanish—orienting network efficiency may be enhanced for Korean–English bilinguals, who require spatially more precise processing skills for correct phonemic and semantic mapping and efficient reading. Future research should be designed to determine how disparate linguistic properties in bilingual language combinations modify attentional processing outcomes at network levels.

Questions that require more extensive investigation remain. First, despite clear evidence of bilingual advantages in global and local levels of attentional processing (i.e., overall RT, accuracy, and inverse efficiency scores), we still know very little about how the three individual networks—alerting, orienting, and executive control—are sculpted by and interact with specific bilingual experiences. Second, recent debate regarding the bilingual advantage, as measured by the ANT, should be tested using a more rigorously designed modified ANT task (e.g., Pozuelos et al., 2014) and varying age ranges of younger and older children. Factors that are known to interact with executive functioning, such as math and reading skills, should be carefully controlled, as should bilingual profile factors such as age of acquisition, onset age of active bilingualism, language pairings, and contextual demand for the language use (Yang, Hartanto, & Yang, 2016). Third, it would be worthwhile to determine whether specific orthographic knowledge or literacy levels in bilinguals could enhance visually oriented attentional efficiency as in the case of language pairing effects (e.g., Coderre & van Heuven, 2014; Tao et al., 2011). Lastly, although we sought to maintain the homogeneity of child and adult samples for language and culture, subtle intrinsic differences persist such as immigration status (i.e., second-generation children vs. 1.5-generation adults). For instance, late age on arrival in the United States for Korean–English adult bilinguals ($M = 10.0$ years, $SD = 6.1$) may reveal the effects of different educational systems in the United States and Korea. Therefore, the extent to which diverse educational systems across cultures foster attentional skills differentially deserves further investigation.

To conclude, our study confirms the positive impact of early childhood and adult bilingualism on the attention system and how bilingual experiences affect children and adults similarly and differentially. Our results contribute to the body of knowledge by demonstrating that an early childhood bilingual experience may operate as a cognitive enhancer for attentional functioning, particularly for handling interference and conflict. Potential interaction effects between bilinguals' varying linguistic experiences and the attention system should be investigated further. Given recent ERP/EEG (event-related potential/electroencephalogram) recordings in which short-term training in a second language (Moreno et al., 2015; Sullivan et al., 2014) revealed a direct causal link to brain changes in neural responses for both children and adults, our behavioral data offer an important avenue for future neuroimaging research (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Posner & Fan, 2004) to elucidate how functional and maturational characteristics of brain activation in the attention system are modified as a result of bilingual experiences and maturational constraints.

Acknowledgments

We thank Ellen Bialystok and two anonymous reviewers for their excellent comments. We are grateful to Gigi Luk, Trelani Chapman, and Andree Hartanto for their valuable comments and feedback on earlier versions of the manuscript. Data were collected when the first author worked in the Cornell Language Acquisition Laboratory. We thank Barbara Lust for her support. Special thanks go to the children and parents who made this study possible.

References

Antón, E., Duñabeitia, J. A., Estévez, A., Hernández, J. A., Castillo, A., Fuentes, L. J., ... Carreiras, M. (2014). Is there a bilingual advantage in the ANT task? Evidence from children. *Frontiers in Psychology, 5*. http://dx.doi.org/10.3389/fpsyg.2014.00398.
Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative, national sample. *Learning Individual Differences, 21*, 327–336.
Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual mind. *Child Development, 70*, 636–644.
Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging, 19*, 290–303.
Callejas, A., Lupiáñez, J., & Tudela, P. (2004). The three attentional networks: On their independence and interactions. *Brain and Cognition, 54*, 225–227.
Campbell, J. M., Bell, S. K., & Keith, L. K. (2001). Concurrent validity of the Peabody Picture Vocabulary Test-Third Edition as an intelligence and achievement screener for low SES African American children. *Assessment, 8*(1), 85–94.
Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science, 11*, 282–298.
Coderre, E. L., & van Heuven, W. J. B. (2014). The effect of script similarity on executive control in bilinguals. *Frontiers in Psychology, 5*. http://dx.doi.org/10.3389/fpsyg.2014.01070.
Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition, 106*, 59–86.
Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168.
Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test-Third Edition*.Circle Pines, MN: American Guidance Service.
Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*, 143–149.
Fan, J., Gu, X., Guise, K. G., Liu, X., Fossellla, J., Wang, H., et al (2009). Testing the behavioral interaction and integration of attentional networks. *Brain and Cognition, 70*, 209–220.
Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *NeuroImage, 26*, 471–479.
Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*, 340–347.
Fernandez-Duque, D., & Black, S. E. (2006). Attentional networks in normal aging and Alzheimer's disease. *Neuropsychology, 20*, 133–143.
Friesen, D. C., Latman, V., Calvo, A., & Bialystok, E. (2015). Attention during visual search: The benefit of bilingualism. *International Journal of Bilingualism, 19*, 693–702.
Garbin, G., Sanjuan, A., Forn, C., Bustanmante, J. C., Rodriguez-Pujadas, A., Belloch, V., ... Ávila, C. (2010). Bridging language and attention: Brain basis of the impact of bilingualism on cognitive control. *NeuroImage, 53*, 1272–1278.
Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology, 25*, 515–530.
Kapa, L. L., & Colombo, J. (2013). Attentional control in early and later bilingual children. *Cognitive Development, 28*, 233–246.
Kaufman, A. S., & Kaufman, N. L. (1983). *Kaufman Assessment Battery for Children administration and scoring manual*.Circle Pines, MN: American Guidance Service.
Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test-II*. Circle Pines, MN: American Guidance Service.
Konrad, K., Neufang, S., Thiel, C. M., Specht, K., Hanisch, C., Fan, J., ... Fink, G. R. (2005). Development of attentional networks: An fMRI study with children and adults. *NeuroImage, 28*, 429–439.
Kroll, J. F. (2015). On the consequences of bilingualism: We need language and the brain to understand cognition. *Bilingualism: Language and Cognition, 18*, 32–34.
Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition. *Journal of Cognitive Psychology, 25*, 497–514.
Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Language and Memory, 33*, 149–174.
Luk, G. (2015). Who are the bilinguals (and monolinguals)? *Bilingualism: Language and Cognition, 18*, 35–36.
MacLeod, J. W., Lawrence, M. A., McConnell, M. M., Eskes, G. A., Klein, Raymond M., & Shore, D. I. (2010). Appraising the ANT: Psychometric and theoretical consideration of the Attention Network Test. *Neuropsychology, 24*, 637–651.
Marzecová, A., Asanowicz, D., Krivá, L., & Woodniecka, Z. (2013). The effects of bilingualism and lateralization of attentional networks. *Bilingualism: Language and Cognition, 16*, 608–623.
McConnell, M. M., & Shore, D. I. (2011). Mixing measures: Testing an assumption of the Attention Network Test. *Attention, Perception, & Psychophysics, 73*, 1096–1107.
Mezzacappa, E. (2004). Alerting, orienting, and executive attention: Developmental properties and sociodemographic correlates in an epidemiological sample of young urban children. *Child Development, 75*, 1373–1386.

Moreno, S., Lee, Y., Janus, M., & Bialystok, E. (2015). Short-term second language and music training induces lasting functional brain changes in early childhood. *Child Development, 86*, 394–406.
Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology, 66*, 232–258.
Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3–25.
Posner, M. I., & Fan, J. (2004). Attention as an organ system. In J. Pomerantz (Ed.), *Neurobiology of perception and communication: From synapse to society (De Lange Conference IV)*. Cambridge UK: Cambridge University Press.
Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25–42.
Posner, M. I., & Rothbart, M. K. (2007). *Educating the human brain*. Washington, DC: American Psychological Association.
Posner, M. I., Sheese, B. E., Odludaş, Y., & Tang, Y. (2006). Analyzing and shaping human attentional networks. *Neural Networks, 19*, 1422–1429.
Powell, S., Plamondon, R., & Retzlaff, P. (2002). Screening cognitive abilities in adults with developmental disabilities: Correlations of the K-BIT, PPVT-3, WRAT-3, and CVLT. *Journal of Developmental and Physical Disabilities, 14*, 239–246.
Pozuelos, J. P., Paz-Alonso, P. M., Castillo, A., Fuentes, L. J., & Rueda, M. R. (2014). Development of attention networks and their interactions in childhood. *Developmental Psychology, 50*, 2405–2415.
Raz, A., & Buhle, J. (2006). Typologies of attentional networks. *Nature Reviews Neuroscience, 7*, 367–379.
Rodriguez-Fornells, A., De Diego Balaguer, R., & Münte, T. F. (2006). Executive control in bilingual language processing. *Language Learning, 56*, 133–190.
Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., et al (2004a). Development of attentional networks in childhood. *Neuropsychologia, 42*, 1029–1040.
Rueda, M. R., Posner, M. I., Rothbart, M. K., & Davis-Stober, C. (2004b). Development of the time course for processing conflict: An event-related potentials study with 4-year-olds and adults. *BMC Neuroscience, 5*, 39.
Singh, N., & Mishra, R. K. (2013). Second language proficiency modulated conflict-monitoring in an oculomotor Stroop task: Evidence from Hindi-English bilinguals. *Frontiers in Psychology, 4*. http://dx.doi.org/10.3389/fpsyg.2013.00322.
Sullivan, M. D., Janus, M., Moreno, S., Astheimer, L., & Bialystok, E. (2014). Early stage second-language learning improves executive control: Evidence from ERP. *Brain and Language, 139*, 84–98.
Tao, L., Marzecová, A., Taft, M., Asanowicz, D., & Woodniecka, Z. (2011). The efficiency of attentional networks in early and late bilinguals: The role of age of acquisition. *Frontiers in Psychology, 2*. http://dx.doi.org/10.3389/fpsyg.2011.00123.
Townsend, J. T., & Honey, C. J. (2007). Consequences of base time for redundant signals experiments. *Journal of Mathematical Psychology, 51*, 242–265.
Yang, H., Hartanto, A., & Yang, S. (2016). The importance of bilingual experience in assessing bilingual advantages in executive functions. *Cortex, 75*, 237–240.
Yang, H., & Yang, S. (in press). Are all interferences bad? Bilingual advantages in working memory are modulated by varying demands for controlled processing. *Bilingualism: Language and Cognition*. doi: http://dx.doi.org/10.1017/S1366728915000632.
Yang, H., Yang, S., & Kang, C. (2014). The relationship between phonological awareness and executive attention among Chinese-English bilingual children. *Cognitive Development, 30*, 65–80.
Yang, S., & Lust, B. (2007). Cross-linguistic differences in cognitive effects due to bilingualism: Experimental study of lexicon and executive attention in 2 typologically distinct language groups. In H. Caunt-Nulton, S. Kulatilake, & I-H. Woo (Eds.), BUCLD 31: Proceedings of the 31st annual Boston University Conference on Language Development (Vol. 2, pp. 602–703). Somerville, MA: Cascadilla.
Yang, S., & Yang, H. (2013). Does bilingual fluency moderate the disruptive effect of cultural cues on second-language processing? *Proceedings of the National Academy of Sciences of the United States of America, 110*, E4403.
Yang, S., Yang, H., & Lust, B. (2011). Early childhood bilingualism leads to advances in executive attention: Dissociating culture and language. *Bilingualism: Language and Cognition, 14*, 412–422.
Yoon, H. W., Cho, K.-D., Chung, J.-Y., & Park, H. W. (2005). Neural mechanisms of Korean word reading: A functional magnetic resonance imaging study. *Neuroscience Letters, 373*, 206–211.
Yoshida, H., Tran, D. N., Benitez, V., & Kuwabara, M. (2011). Inhibition and adjective learning in bilingual and monolingual children. *Frontiers in Psychology, 2*. http://dx.doi.org/10.3389/fpsyg.2011.00210.