Testing effects of bilingualism on executive attention: comparison of cognitive performance on two non-verbal tests

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1. Introduction

Fundamental debates persist today regarding the question of whether or not there are beneficial cognitive effects of early bilingual acquisition, particularly in executive attention (Bialystok, 1992). In bilingual research of earlier years, bilingualism was often regarded as atypical and even abnormal when compared to monolingualism. In these cases, it was viewed as resulting in cognitive retardation, or causing detrimental effects on intelligence and language development. However, in 1962, Lambert and Peal discovered that previous research findings had been confounded by a failure to control methodological pitfalls such as sociodemographic factors, cognitive equivalence of the sample, and degree of bilingualism. Their results turned the direction to the opposite, positive cognitive outcomes of bilingualism (for review, Hakuta & Diaz, 1985; Bialystok, 1999). Since this turning point in 1962, bilingual research has actively sought to determine the aspects of cognitive domains—such as intelligence, creativity, concept formation, classification, analogical reasoning, and visual-spatial skill—bilinguals may excel in, how early such bilingual cognitive advantages appear (Yang, 2004), and how these cognitive advantages interact with the levels of bilingualism (Hakuta & Diaz, 1985; Bialystok, 1988). However, all these findings remain unconnected unless we understand the mechanisms that equip bilinguals to process the two linguistic systems – moving back and forth between them, and yet not confusing them. Efforts to find the higher-order cognitive control that enables bilinguals to command two systems have revealed that bilingual individuals resort to certain executive functions.

Back in 1977, Ben-zeeve assumed that a 'special facility' would distinguish bilinguals from monolinguals in resisting constant interlanguage interference. She tested her hypothesis in metalinguistic tasks that studied how well children can control interference between the combined semantic and syntactic processes, given a rule to ignore one of these two dimensions in testing sentences. In recent years, many bilingualism researchers, including Ben-zeeve, speculate that the underlying mechanism of bilingual cognitive advantage may stem from executive attention (Bialystok, 1999; Yang, 2004). In recent studies in neuropsychological science, Posner and Fan (2004) articulate the essential need for attentional resources in the human to select critical information in the flood of overwhelmingly massive amounts of environmental stimuli. They suggest that to select and respond to a target in the midst of distractions, humans must be equipped with a specialized system of networks in the brain, and this system is responsible for selective and conscious cognitive process defined as executive attention. In a more approachable definition, executive attention is a self-regulatory process that enables people to control thought and behavior.

To explain bilingual cognitive benefits in a domain-general way, a theory of Cognitive Complexity and Control (CCC; Zelazo & Frye, 1997) has been employed. This theory consists of a representational ability to construct a mental hierarchy among rules and a control ability to disregard irrelevant information and act on the rules. An example can be found in a rule-use paradigm like the Dimensional Change Card Sort (DCCS; Zelazo, Müller, Frye, & Marcovitch, 2003; Zelazo & Frye, 1997) task, in which children of varying ages show varying degrees of control. In the task, children are given two bi-dimensional (e.g., shape and color) target cards (e.g., a red square and a blue circle), and they are instructed to sort sets of test cards (e.g., a blue square and a red circle) by one dimension (called post-switch) after another dimension (pre-switch) (see Figure 1) (Bialystock, 1999). In other words, the two dimensions, shape and color, are given as two sorting rules, and the success and failure of correct card sort depends on whether the child is able to switch between the two incompatible rules that are always visually present together in one card causing conflicts and interference. Developmentally, most four years olds do not have difficulty in this paradigm but two to three years olds fail to switch rules.

Bialystok (1999) applied the DCCS task to test group differences between monolingual and bilingual preschoolers and suggested a specific advantageous link between executive attention and bilingualism in 4 and 5 year olds. Her findings showed that when linguistic and cognitive competences were controlled for both groups via the measure of receptive vocabulary knowledge and a memory span task, bilingual children earned significantly higher scores than monolingual children. However, these results deserve replication and generalization to confirm bilingual advantages in executive attention. First, the DCCS task assumes not only attentional processing to control interference from competing rules but also capability of representation of a hierarchically structured rule system as the mechanisms of children's cognitive development (Zelazo et al., 2003). The two cognitive abilities in the DCCS task are integrally united and must be simultaneously involved for success in this task. Children 2 to 3 years old who cannot represent a two-rule system, therefore, may fail. Because it is not clear how these two abilities are exploited in the DCCS task (Yang, 2004), the previous findings should be replicated and compared to other measures that test executive attention separately from other cognitive skills. Second, Bilaystok's findings (1999) may have been confounded by combining 3 years and 4 years in her group of younger children. The DCCS task is well-known to show age-related dichotomy; 3 year olds are unable to do it while most 4 year olds can do quite well. Proportional distribution in ages or standard deviations were not reported in Bialystok's (1999) results, and therefore bilingual superior performance may have been due to the inclusion of more 4 year olds than 3 year olds. Additionally, the DCCS task alone may not capture the accurate nature of executive attention. In the arguments made by neurocognitive scientists, executive attention must be organized in terms of several distinct networks involving alerting, orienting, and executive attention (conflict resolution) (Posner & Petersen, 1990; Posner & Fan, 2004). In the rule-use paradigm, however, the DCCS task can measure only one dimension of attentional networks in the brain, which overlaps executive attention. Therefore, by using the DCCS task, it is difficult to attribute the underlying mechanisms of bilingual cognitive advantages exclusively to control ability. In the present study, we employed another measure of executive attention to compare bilinguals' cognitive performance on the DCCS task. A computerized Attention Network Test (ANT) (Rueda, Fan, McCandliss, Halparin, Gruber, Lercari, & Posner, 2004), consists of four cue and three flanker conditions and is designed to probe developmental differences in attentional networks of alerting, orienting, and executive control in terms of percentage accuracy and reaction time (see Figure 2).

In the current investigation, we attempt to understand how early bilingualism at 4 years of age influences the development of executive attention via two non-verbal cognitive measures. We use the previously used DCCS task as a replication and the neuropsychological measure of the ANT to approach the issues of bilingual cognitive advantages in executive attention more precisely and adequately. We hypothesized that if bilingualism was beneficial to the development of executive attention, bilinguals would outperform monolinguals in the DCCS task and the ANT. Additionally, if the DCCS and the ANT's subcomponent of 'executive control' tested the same processing variance, we hypothesized that children's performance in the DCCS task and their ANT performance on 'executive control' would correlate.

2. Method

2.1. Participants

19 English monolinguals (11 girls) and 18 Korean-English bilingual children (9 girls), averaged 56 month olds (4;8) each participated in the DCCS. 6 monolingual girls, 2 bilingual boys and 3 bilingual girls were excluded from the analyses of the ANT due to literacy control (i.e., they had more developed literacy, N = 1), failure to complete the task (N = 9), or experimental error (N = 1). 13 monolinguals and 13 bilinguals completed the ANT and were included in the final analyses.

2.2. Procedures

Children were met by bilingual experimenters in a quiet room to participate in a receptive vocabulary test for English, the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1997), DCCS task, and the computerized executive attention task, ANT. To control socioeconomic factors, monolingual and bilingual children were recruited from a similar middle to upper-middle neighborhood in Ithaca, New York. The children's literacy was controlled by observing children at daycare centers or interviewing parents with a questionnaire. As literacy may influence executive attention development (Bialystok, 1999); no child in our sample has fully developed skills in reading and writing; without assistance from adults they are unable to read story books. Both monolingual and bilingual children have normal or corrected to normal vision.

The PPVT was used to measure language abilities in vocabulary knowledge for both English monolinguals and Korean-English bilingual children. Both groups took the PPVT in English.

In the DCCS task, children viewed two bi-dimensional (e.g., shape and color) target cards affixed in the wall of the containers (e.g., a red square and a blue circle) and were given 10 testing cards that were different from the target cards in one dimension (e.g., a blue square and a red circle). The two rules were to sort 10 cards twice (pre-switch and post-switch) by one dimension (e.g., shape rule) after another dimension (e.g., color rule) (see Figure 1) (Bialystock, 1999).

The ANT, a combined task of cued reaction time and the flanker task (Eriksen & Eriksen, 1974), was used to examine broad functions of attention in one integrated test (Fan et al., 2002; Rueda et al., 2004). Stimuli of the ANT ware presented visually on an IBM comparable laptop computer, and children were asked to respond to two input keys on a keyboard in the way that matches the direction of swimming hungry fish to feed them. Stimuli were composed of either a single fish (neutral condition) or a row of five animated fish (congruent or incongruent condition) swimming leftward or rightward with the center fish as a target to respond and the rest of four fish as flankers. When the five fish were swimming in the same direction, it is defined as congruent condition, and when the middle fish was swimming to a different direction from the rest, it is defined as incongruent condition. The stimuli appeared after the central fixation mark was presented, but the location of presentation (either above or below the fixation mark) and the presence of warning cue types (either nothing, or one cue in the center, or two cues both above and below the fixation mark or one spatial cue either above or below the fixation mark) differed. These three flanker types (congruent, incongruent, and neutral) and four warning cue types (no cue central cue, double cue and spatial cue) are combined to measure efficiency of the three networks of attention: alerting attention, orienting attention and executive attention (for review, Yang & Lust, in preparation).

The ANT scores of attention network efficiency were computed in terms of reaction time in milliseconds (Mezzacappa, 2004). Alerting efficiency subtracted reaction time in double cue types from no cue types, and orienting efficiency subtracted reaction time in central cue types from spatial cue types across all flanker types. Executive attention efficiency was obtained by subtracting reaction time in congruent types from incongruent types across all cue types. The duration to complete a task of 168 trials that was composed of a training block of 24 practice trials, and 3 experimental blocks of 48 trials was around 25 to 30 minutes. Children received feedback of 'Woohoo!" sound for correct responses and 'Huh!" sound for incorrect responses.

The Virtual Linguistic Lab's (VLL) Children's Multilingualism Questionnaire completed by the parents was employed to probe further into the experiential background of the bilingual children; [it was completed by parents] (Virtual Center for Language Acquisition, 2005). This questionnaire contains six parts: information about the child, family language background, child language background, child language use (code-switching), reading/writing ability, and summary and comments. The Korean version of the VLL Children's Multilingualism Questionnaire was translated by two Korean-English bilingual speakers and adjustments of translation differences were made to ensure as much linguistic equivalence as possible. This questionnaire allowed open-ended question types. Both of these measures were complementary in terms of obtaining balanced information about Korean and English languages from Korean-English bilinguals. According to the results of this questionnaire, all Korean-English bilingual children speak Korean at home and in the Korean community whereas they communicate in English at day care centers or outside home.

3. Results

Bilingual children in our study had significantly lower English proficiency than monolinguals according the PPVT results, $F(1, 33) = 24.033$, $p = .0000$. This significant difference in the PPVT scores persisted when analyzed separately for those who completed the ANT.

The DCCS task performance was not significant, $F(1, 33) = 1.809$, $p = .188$. During the pre-switch phase, children made no errors and during the post-switch phase, both groups performed at a ceiling level ($N = 9.5$ for monolingual vs. $N = 9.9$ for bilinguals). The current study failed to replicate Bialystok's results (1999).

However, bilingual children showed significant cognitive advantages in percentage ANT accuracy data, $F(1, 22) = 13.673$, $p = .001$, across all conditions (see Figure 3). Overall reaction times for correct responses were faster for bilinguals but did not reach significance, $F(1, 22) = 2.126$, $p = .159$ (see Figure 4). When networks subtractions were computed following the formulas, some of children's scores were negative whereby average scores were significantly lowered. After consulting the developer of the ANT (personal communication with Dr. Jin Fan in November, 2003), only positive values were considered for analyses resulting in only a small number of children's data in each network; for monolingual, 10 values for alerting, 6 values for orienting, and 7 values for executive attention were considered and for bilinguals, 10 values for alerting, 8 values for orienting and 13 values for executive attention were considered. A set of ANOVA was performed on three network efficiency scores (alerting, orienting, and conflict resolution). The results revealed no significant effects of bilingualism, ps > .229. There was no significant interaction between network efficiency and bilingualism, $F(1, 9) = 1.892$, $p =$ 999.

For correlation analyses, 26 children who completed the DCCS task and ANT were considered. Contrary to the previous results (Bialystok, 1999), the DCCS task failed to predict the ANT performance, $r = .126$, $p = .541$.

4. Discussion

The main objective of the current study was to investigate potential bilingual cognitive advantages in executive attention by using a non-verbal cognitive measure in early childhood as young as 4 years old. The DCCS task and the ANT were employed with purposes to measure executive attention and to compare the correlation between the two tasks. Bilingual and monolingual children in the present study did not posses similar levels of linguistic equivalence of English as measured by the PPVT. Bilingual children did not differ from monolingual children in the DCCS task. However, our results from the ANT support a positive relation between early childhood bilingualism and executive attention. Bilingual children were significantly more accurate than monolinguals though their response time was no greater. The reaction time yielded only a marginally significant difference in favor of bilinguals, but bilinguals were in fact faster across all conditions. Although the method of gauging executive attentional function was similar between the DCCS and the ANT in the presentation of situations where conflicts should be solved by inhibition of distracters and concentration on a rule or goal, the relation between the two tasks that were assumed to test executive attention was not supported by the non-significant correlational analysis.

In the DCCS task, the present results are not consistent with Bialystok's findings on bilingual advantages, showing no performance difference between the two groups. Reasons for this contrast can be traced to several differences in the characteristics of the recruited sample or the nature of the task (Yang, 2004).

First, two groups of monolingual and bilingual children in this study had significantly different levels of English proficiency in the PPVT, while Bialystok's two samples had comparable proficiency levels (1999). Although the influence of language proficiency on executive attention has not been studied systematically in the previous research, assumption that executive attention may develop with language proficiency can be made easily because as executive attention improves with ages, so does linguistic knowledge. Control of literacy in Bialystok's study (1999) also suggests the possible positive influence of advanced linguistic skills upon executive attention, although she did not develop this discussion in that study. Thus, monolinguals in the present study, who have acquired much higher levels of vocabulary knowledge, might have been able to reduce the performance gap on the DCCS task. The performance differences in the present study also shed light on the probable interrelation between language proficiency and bilingualism. When we focus on bilingual children's performance, rather than monolinguals', it is noteworthy to probe what helps them perform as equally well as monolingual peers despite their linguistic limits. If it were not for linguistic advancement that was assumed to be a key success factor for monolinguals, bilinguals must have relied on some other cognitive mechanism that was available to them to succeed in the task.

Second, the reason for the different performance scores in the DCCS task could be ascribed to the studied age range that does not match that of Bialystok's. The mean age of the both monolingual and bilingual groups in the present study is 56 months (4;8) and three years were not included. Bialystok studied 4.25 years for younger group and 5.5 years for older group and in her younger group, three years were integrated. However, this age difference cannot be a complete explanation of the current phenomenon because although the average age of the present sample falls between the two groups of

Bialystok's, the performance of the two groups in the present study was better than even the older groups in Bialystok's study.

Third, the language pairs that bilingual children have acquired in combination could have influenced the performance differences in the DCCS task. In many studies where bilingual cognitive advantages were evident, various language groups have compared to English monolingual control groups; they are Hebrew, Chinese, French, Swedish, and mainly Spanish to name a few. However, some of these languages are more similar to English either syntactically, phonologically or morphologically. It is speculative but if the magnitude of the earned cognitive advantages could differ depending on which of the first languages is combined to English (or vise versa), the contradicting findings between the present study and Bialystok's could be in part due to the differences or difficulties in the acquisition process of Korean and Chinese when they are paired with English.

Lastly, the task itself may be responsible for no performance difference on the DCCS task in the present study. The DCCS task has been replicated in much research and has reached a consensus of age sensitivity. For example, in most studies where the DCCS task was employed, the majority of three year olds had difficulty solving the conflicts inherent in the testing cards whereas more four year olds were able to overcome them. Thus, this clear distinction by ages between success and failure may have overridden the bilingualism effect that was measured otherwise in such task as the ANT.

To conclude, this study has supported a cognitive advantage in young bilinguals of 4 years in the ANT, a measure to capture the development of executive attention broadly but not in the DCCS task. Our findings raise issues about the relation between the tasks assumed to test an overlapping variance of executive attention. In the future, efforts and reexamination should be made to replicate the current findings and calibrate correlation among various tasks of executive attention.

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Figure 1. Sample target cards and testing cards in the DCCS task.

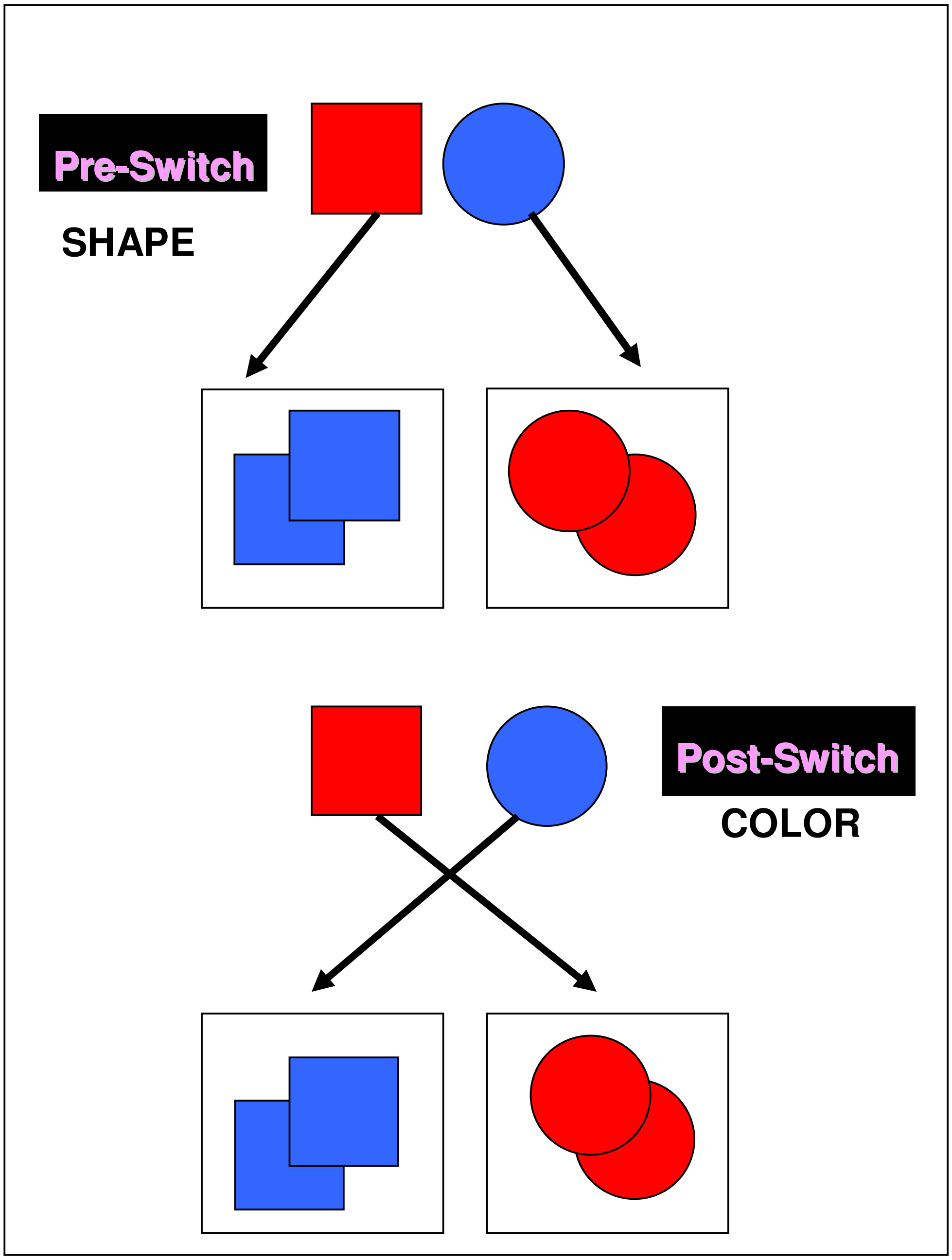

Figure 2. Attention Network Test (ANT): cue by flanker conditions

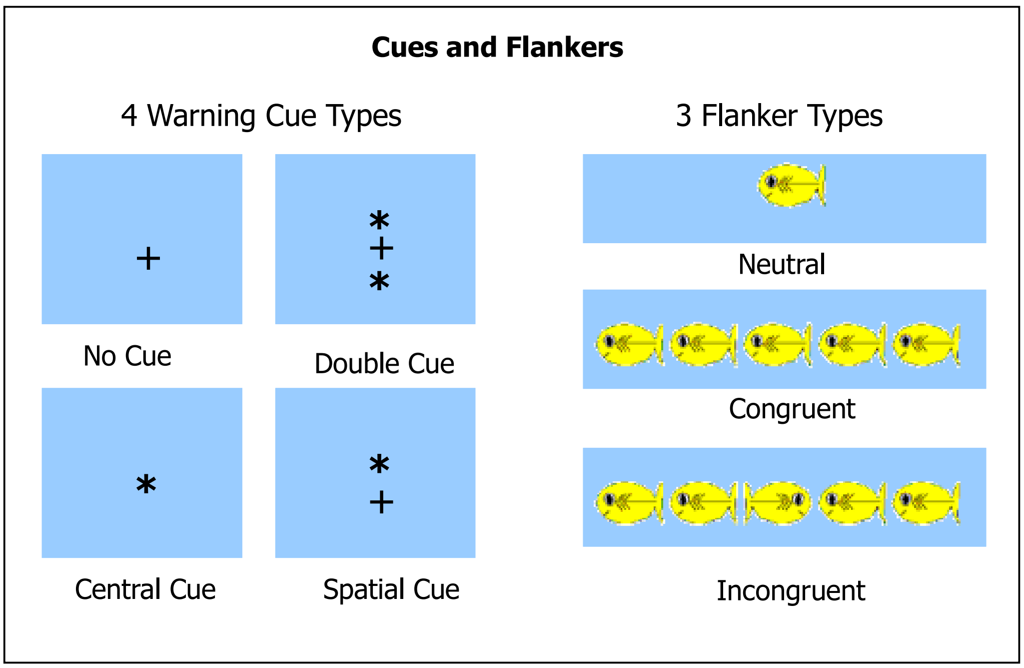

Figure 3. Overall ANT accuracy data in percentage

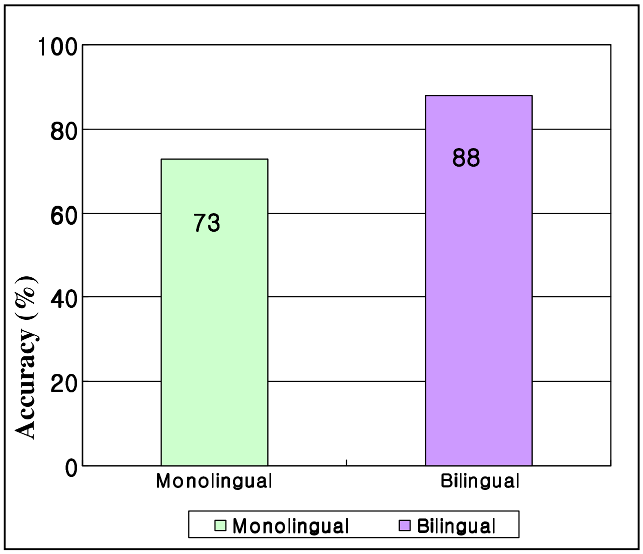

Figure 4. Overall ANT reaction time data in millisecond