Task Switching in English-Chinese Bilinguals: A Life Span Approach

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Task Switching in English-Chinese Bilinguals: A Life Span Approach

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Abstract

The current study investigated the developmental trajectory of 124 English-Chinese Singaporean bilinguals (41 6-9-year-olds, 44 18-26-year-olds, and 39 55-79-year-olds) with the Standard (SD), Total Change (TC), Positive Priming (PP), and Negative Priming (NP) versions of the Computerized Dimensional Change Card Sort task. Tasks were administrated in either English or Chinese. Additionally, participants were tested with both English and Chinese versions of the Peabody Picture Vocabulary Test. Separate curve fitting indicated that significant quadratic trends appeared in the local switch costs for accuracy only in the SD and the PP versions. Children had significantly larger local switch costs in all the versions compared to young adults and elderly adults, who had similar local switch costs. These findings suggest that bilingualism may slow down the decay of information maintaining, updating, disinhibition, and task set integration in elderly adults. Results imply that bilingual advantage may accumulate through childhood, and be preserved in late adulthood.

Introduction

Previous research has well documented the advantages of bilingualism as bilinguals tend to have superior flexibility and inhibitory control compared to monolinguals (see Bialystok, 2006 for a review). Nevertheless, research in the past mainly compares bilinguals with monolinguals. It is unclear whether the bilingual advantage develops at the early stage, accumulates over adulthood or is maintained in late adulthood. The current study took a different approach by examining the bilingual advantage across life span in proficient English-Chinese bilinguals with a task switching paradigm.

Bilingualism

Bilingual individuals have been widely reported to have advanced abilities in meta-linguistic awareness (Ianco-Worrall, 1972), analytic skills and logical reasoning (Ben-Zeev, 1977), flexibility and creativity (Ricciardelli, 1992), and understanding of theory of mind (Goetz, 2003), even though bilingual children have relatively smaller vocabularies than monolingual children (e.g., Ben-Zeev, 1977). In addition, bilingualism has been associated with superior inhibitory control after vocabulary is taken into consideration. For example, bilinguals are more able to ignore misleading and irrelevant features in meta-linguistic tasks such as a grammar detection task (e.g., Bialystok, 1986), a picture-name matching task (e.g., Bialystok, 1999), and an absolute quantity judgment task (e.g., Bialystok & Codd, 1997). Furthermore, bilinguals outperform monolinguals in cognitive control tasks such as an antisaccade task (Bialystok, Craik, & Ryan, 2006), the Simon task (Bialystok, 2006), and the Dimensional Change Card Sort (Bialystok & Shapero, 2005).

Such advantages are possibly related to the unique experience of bilinguals. An important and normal aspect of bilingualism is language alternation (Grosjean, 1982), consisting of code switching and code mixing. Code switching refers the use of language alternation within a single discourse accompanied by a shift in speech situation while code mixing refers to intrasentential alternations – language alternation within a sentence (Grosjean, 1982). During code switching, bilingual people need to constantly "overcome negative transfer between the languages" (Dopke, McNamara, & Quinn, 1991, p. 43). During code mixing, bilinguals need to activate both language systems simultaneously (Sridhar & Sridhar, 1980). Thus, compared to monolinguals,

bilinguals utilize their executive function more often. When communicating in one language, bilinguals need to continuously hold the relevant language in their minds and inhibit the irrelevant language (Bialystok, 2006). Indeed, compared to monolinguals, bilinguals appear to have enhanced brain activities in the left dorsolateral prefrontal cortex, an area essential for executive functioning and task switching (Rodriguez-Fornells, Balaguer, & Münte, 2006).

Task Switching

Switching between tasks is a key aspect of executive function (Miyake et al., 2000), and one that develops across a wide range of ages (Cepeda et al., 2001). In task switching paradigms, participants are required to switch from responding in one way to specific stimuli to responding in a different, incompatible, way. For example, participants need to switch between matching test stimuli to targets either according to shape or colour during a switching block of trials (Casey et al., 2004). Performance on trials that require participants to switch between tasks (switch trials) is compared to performance on trials that do not require participants to switch (repeat trials). Generally, participants take more time and make more errors on switch trials compared to repeat trials; the extra response time and errors are called local switch costs (Allport, Styles, Hsieh, 1994). In addition to the local switch costs, there are global switch costs, usually defined as the difference between performance on repeat trials during switch blocks and performance on trials during blocks in which no switching is required (Meiran, Gotler, Perlman, 2001). Global switch costs are associated with the ability to maintain and select appropriate task sets in a continuous switching context.

The task switching process involves various cognitive processes (e.g., Allport et al., 1994; Rogers & Monsell, 1995): information updating and maintaining the current task set in mind (e.g., Bojko, Kramer, & Peterson, 2004), the formulation and use of higher order rules for switching between task sets or the integration of task sets (e.g., Zelazo, Müller, Frye, & Marcovitch, 2003), and inhibition (e.g., Davidson, Amso, Anderson, & Diamond, 2006; Hasher & Zack, 1988). In particular, inhibition consists of the suppression of the previously activated task sets, and disinhibition of the previously suppressed task sets (e.g., Lustig, Hasher, & Zacks, 2007; Müller, Dick, Gela, Overton, & Zelazo, 2006).

These processes may influence children, young adults, and elderly adults differently. Lifespan studies on monolinguals have found that task switching improves during childhood and adolescence and declines during senescence (e.g., Cepeda et al., 2001). Age differences in local switch costs are observed when cognitive demands are large (e.g., Davidson et al., 2006) and they may decrease when the switch is highly predictable (e.g., Reimers & Maylor, 2005), or after age-related slowing is taken into consideration (e.g., Salthouse, Fristoe, McGuthry, & Hambrick, 1998). Age differences in global switch costs are often observed (e.g., Meiran et al., 2001), even when age differences in general speed are taken into account (e.g., Salthouse et al., 1998). Age differences may decrease and even disappear when the demands of working memory are reduced with the presentation of external cues (e.g., Chevalier & Blaye, 2009).

The current study used four versions of the Dimensional Change Card Sorting (DCCS) task to investigate the life-span development of task switching in English-Chinese bilinguals: the Standard (SD), Total Change (TC), Positive Priming (PP), and Negative Priming (NP) versions (Qu, Wijeya, Zelazo, & Craik, 2007; Zelazo et al., 2003). In the SD condition (see Figure 1a), participants are shown two target stimuli (e.g., a blue square and a red star) that vary along two dimensions (e.g., color and shape), and they are asked to sort a series of bivalent test stimuli (e.g., red squares and blue stars), first according to one dimension (e.g., color) and then according to the other. Hence, participants have to update, maintain and integrate the different task sets while inhibiting the previously activated pre-switch rules and activating of the previously inhibited post-switch rules in the trial following the switch. In the PP condition (see Figure 1b), the values of the dimension that are irrelevant in the pre-switch task are different in the post-switch task. In this case, during switch trials, participants' main challenge is to inhibit the previously activated rules. In the NP condition (see Figure 1c), the values of the dimension that are irrelevant in the pre-switch task are kept the same in the post-switch task. In this case, during switch, participants' main challenge is to activate the previously inhibited rules. In the TC condition (see Figure 1d), the values of both dimensions are changed between the pre- and post-switch tasks. Hence, during

switch, participants' main challenge is to activate the novel stimuli and there is no inhibition demand.

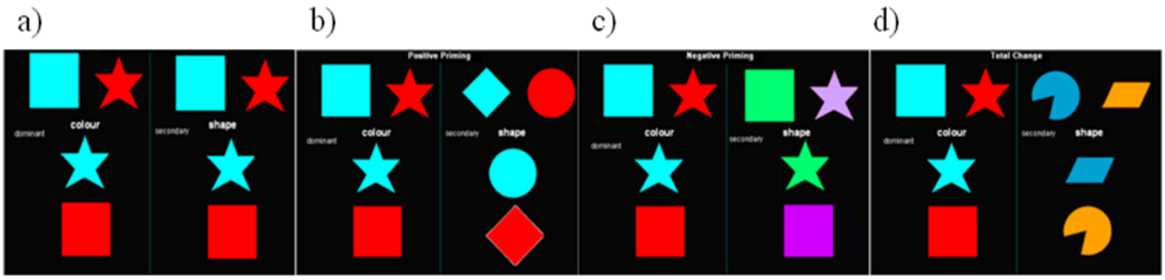

Figure 1. Target stimuli (top row) and test stimuli (bottom row) in the a) Standard version, b) Positive Priming version, c) Negative Priming version, and d) Total Change version. In each panel, the sorting task on the left side is the dominant task with colour as the dominant cue while the right side is the secondary task with shape as the secondary cue, in this example.

In addition, in this study, we used a pragmatic approach proposed by Grosjean (1989, 1998) to define a proficient bilingual as an individual who can function in either language according to the given needs of a situation. Thus proficient bilingual individuals have equivalent functional proficiency in both languages when they are able to carry out similar activities in both languages even though their formal proficiency in either language may not match that of a monolingual.

Method

Participants

One hundred and twenty-four English-Chinese Singaporean bilinguals (children: *N* = 41, *M* age = 7.3, *SD* = 0.8, *Median* = 7.3, *Range:* 6 – 8.8 years; young adults: *N* = 44, *M* age = 20.8, *SD* = 1.8, *Median* = 21, *Range:* 18 – 26 years; elderly adults: *N* = 39, *M* age = 62.0, *SD* = 6.0, *Median* = 60, *Range:* 55 – 79 years) participated the study. All participants were healthy and none of them was color-blind, as indicated by their performance on the Ishihara colour-blindness test (Ishihara, 1917). All children were recruited from a database of parents who expressed interest in participating in the research, and the children received stationery as tokens of appreciation. The young adult participants received academic credits while the elderly participants received $(SG) 15 for compensation.

Materials

Computerized Dimensional Change Card Sorting task (Qu et al., 2007). Twenty geometric shapes and 20 colors were used to construct 8 cm X 8 cm stimuli. For each participant, target and test stimuli were randomly chosen and the target or test stimuli were not repeated across different conditions. The task was programmed in E-Prime 1.1 software (Schneider, Eschman, & Zuccolotto, 2002) and run on a Pentium 4 laptop computer with a 12.5" X 9.5" monitor that was positioned approximately 50 cm away from the participant. Participants responded using the numerals 1 and 2 on the number pad of the standard keyboard. The task was presented in either English or Chinese.

The Ishihara Colour-Blindness Test (Ishihara, 1917). Participants were asked to identify digits embedded in 6 coloured plates.

The Peabody Picture Vocabulary Test, Fourth Edition (PPVT-IV; Dunn & Dunn, 2006). Participants were asked to select one picture out of four that best represents the meaning of a stimulus word presented orally. Both forms A and B of the PPVT were translated into Chinese by a native Chinese speaker. Participants were given one form in English and the other form in Chinese. The test order was counter-balanced between participants.

Design

All participants received all four versions of the DCCS and the order in which these four versions were presented was determined randomly. Different target and test stimuli were used in each version, and the order

in which specific test stimuli within each version were presented was determined randomly. In each version, there was a dominant task, presented on a majority (87%) of trials, and a secondary task presented on a minority (13%) of trials. In the dominant task, participants were instructed to sort test stimuli according to one dimension (i.e., the dominant dimension); in the secondary task, participants were instructed to switch to another dimension (i.e., the secondary dimension). The dominant dimension, color or shape, was counter-balanced between participants. Each version took less than 6 minutes, and there was a 2-minute break between each version. The whole DCCS took less than 45 minutes.

Procedure

Participants were first assigned to being tested in either Chinese or English. After completing the consent form and information sheet in their test language, they were tested for their colour-blindness using the Ishihara Colour-Blindness Test and for proficiency in the test language using either forms A or B of the PPVT. Then they were instructed to go through all versions of the DCCS task in their test language on a computer. Each version consisted of 2 blocks of trials: the first block served as a baseline of 40 trials which required participants to match stimuli by the dominant dimension while the second block – switching block – had a total of 78 trials with a mixture of 68 dominant trials and 10 secondary trials which required participants to switch to match stimuli by the secondary dimension. A cue word in the center of the screen instructed the participants by which dimension to match the stimuli. After the DCCS computer task, participants were accessed for their proficiency in the non-test language using the other form of the PPVT.

Results

The primary dependent measures were accuracy (ACC) and reaction time (RT). Four children and four young adults failed to reach 80% accuracy during the baseline trials, and their data were excluded from the final analysis. Furthermore, 6 senior adults and 1 child achieved zero accuracy during all the switch trials and their data were also excluded. In addition, among the participants in the final sample, the following trials were excluded from the final RT data analyses: (1) the first four trials following each practice or break, (2) trials on which participants erred, (3) trials immediately following an error, and (4) the trials where RTs were shorter than 100 ms or longer than 3 SDs of the median RTs for the corresponding age group and condition. Only 109 participants' RTs were kept (children: N = 36; young adults: N = 40; elderly adults: N = 33). Separate one-way analyses of variance (ANOVAs) on the ACCs and RTs failed to show any significant effects of gender, dominant dimension, or test language, so data were combined across these variables.

Vocabulary

Participants' PPVT scores (see Table 1) reflected their English and Chinese language proficiency. Sample *t* tests showed that both English and Chinese PPVT scores for each age group were significantly greater than 70, indicating that the participants in the current study were indeed proficient bilinguals.

Table 1
Mean (and Standard Deviation) Scores of the Peabody Picture Vocabulary Test by Version.

	Children	Young Adults	Elderly Adults
English Scores	101.06 (19.59)	102.05 (16.31)	86.91 (13.92)
Chinese Scores	83.61 (19.32)	109.18 (13.80)	95.39 (9.48)

Baseline

Performance during the baseline blocks was analyzed using separate 3 (Age: children, young adults and elderly adults) × 4 (Version: SD, NP, PP, and TC) ANOVAs for ACC and RT. For ACC, there was a significant effect of age (F (2, 106) = 23.49, $p < .001$, $\eta_p^2 = .31$). Tukey HSD tests ($p < .05$) showed that children (M = .96, SE = .00) were significantly less accurate than younger (M = .98, SE = .00) and elderly adults (M = .99, SE = .00). There was no significant effect of version (F (3, 318) = 1.23, $p > .05$) or any interaction (F (6, 318)

= .59, $p > .05$). For RT, there was a significant effect of age (F (2, 106) = 68.06, $p < .001$, $\eta_p^2 = .56$). Tukey's HSD tests ($p < .001$) showed that younger adults (M = 612.04, SE = 36.30) were significantly faster than children (M = 1227.09, SE = 38.27) and older adults (M = 921.82, SE = 39.97). There was no significant effect of version (F (3, 318) = 1.70, $p > .05$) or any interaction (F (6, 318) = 1.22, $p > .05$). With the averages of four baseline ACCs and RTs, separate curve fitting indicated that a significant quadratic trend appeared in both the baselines of ACC ($R_{adj}^2 = .25$, F (2, 106) = 19.17, $p < .001$) and RT ($R_{adj}^2 = .06$, F (2, 106) = 4.37, $p < .05$).

Local switch costs

Local switch costs were calculated by comparing the performance on the switch trials during the switch blocks with the performance on the baseline trials during the nonswitch blocks (Meiran, 1996; Rogers & Monsell, 1995). The local switch costs for ACCs (LSC-ACCs) were calculated by subtracting the proportion correct on the switch trials during the switch block from the proportion correct on the baseline trials, then dividing by the proportion correct on the baseline trials. The local switch costs for RTs (LSC-RTs) were calculated by subtracting the median RT on the baseline trials from the median RT on the switch trials during the switch block, then dividing by the median RT on the baseline trials.

To examine the LSC-ACCs, a 3 (Age) × 4 (Version) ANOVA on LSC-ACC was used. Results showed that there was a significant effect of age (F (2, 106) = 18.89, $p < .001$, $\eta_p^2 = .26$), a significant version difference (F (3, 318) = 56.52, $p < .001$, $\eta_p^2 = .35$), and a significant interaction between age and version (F (6, 318) = 8.52, $p < .001$, $\eta_p^2 = .14$). All participants had significantly larger LSC-ACCs in the SD version (M = .28, SE = .02) than in the rest of three versions. In addition, they had significantly larger LSC-ACCs in the PP version (M = .12, SE = .02) than in the NP (M = .05, SE = .01) and TC versions (M = .08, SE = .02). Further analysis showed that age differences only appeared in the SD (F (2, 106) = 34.82, $p < .001$, $\eta_p^2 = .40$), the PP (F (2, 106) = 5.61, $p < .01$, $\eta_p^2 = .10$) and the TC versions (F (2, 106) = 3.98, $p < .05$, $\eta_p^2 = .07$), not in the NP version (F (2, 106) < 1). Tukey HSD tests ($p < .05$) showed that (see Figure 2) in the SD version, the children (M = .48, SE = .21) had significantly larger LSC-ACCs than both the young (M = .21, SE = .17) and elderly adults (M = .15, SE = .15); and in both the PP and TC versions, the children (PP: M = .20, SE. = .25; TC: M = .14, SE = .23) had significantly larger LSC-ACCs than the elderly adults (PP: M = .06, SE. = .11; TC: M = .04, SE = .08). Separate curve fitting indicated that significant quadratic trends only appeared in the LSC-ACCs in the SD ($R_{adj}^2 = .22$, F (2, 106) = 16.25, $p < .001$), and the PP ($R_{adj}^2 = .05$, F (2, 106) = 3.89, $p < .05$) versions.

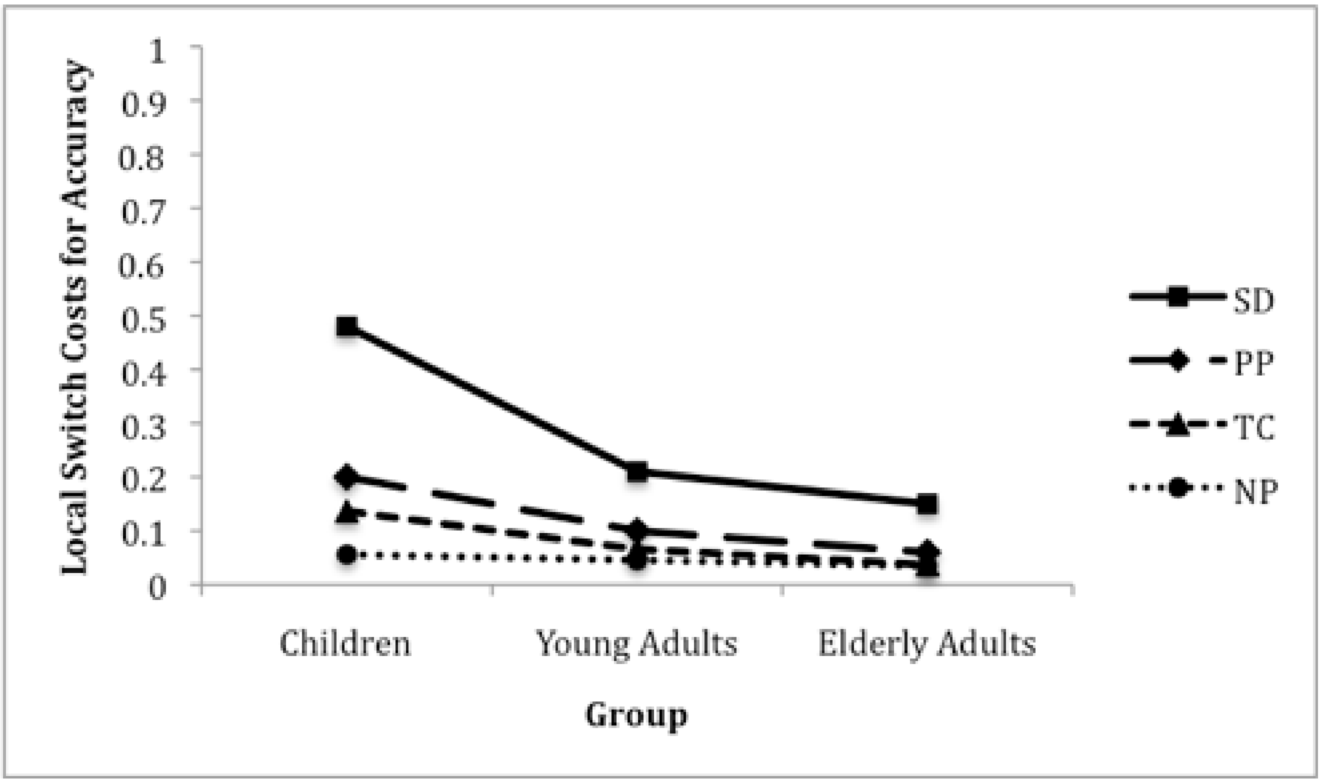

Figure 2: Local switch costs for reaction time across the Standard (SD), the Positive Priming (PP), the Negative Priming (NP), and the Total Change (TC) conditions in children, young adults, and elderly adults.

To examine the LSC-RTs, a 3 (Age) × 4 (Version) ANOVA was used. Results showed (see Figure 2) that there was a significant effect of age (F (2, 106) = 14.40, $p < .001$, $\eta_p^2 = .21$), and Tukey HSD tests ($p < .05$) showed that the LSC-RTs in the young adults (M = 0.52, SE= 0.05) and elderly adults (M = 0.61, SE = 0.06) were significantly smaller than those in the children (M = 0.90, SE = 0.05). In addition, there was a significant version difference (F (3, 318) = 13.12, $p < .001$, $\eta_p^2 = .11$). Further analysis showed that the LSC-RTs in the SD version (M = 0.84, SE = 0.05) were significantly larger than in the NP (M = 0.48, SE = 0.03) and the PP versions (M = 0.64, SE = 0.05) but similar to those in the TC version (M = 0.75, SE = 0.05); the LSC-RTs in the PP version were similar to those in the TC version, but were significantly larger than those in the NP version. The LSC-RTs in the TC version were significantly larger than those in the NP version. Separate curve fitting did not show any significant quadratic trends in the LCS-RTs.

Global Switch Costs

Global switch costs were calculated by comparing the performance on the task repetition trials during the switch blocks with the performance on the baseline trials during the nonswitch blocks (e.g., Meiran et al., 2001). The global switch costs for ACCs (GSC-ACCs) were calculated by subtracting the proportion correct on the repeat trials during the switch block from the proportion correct on the baseline trials and then dividing by the proportion correct on the baseline trials. The global switch costs for RTs (GSC-RTs) were calculated by subtracting the median RT on the baseline trials from the median RT on the repeat trials during the switch block then dividing by the median RT on the baseline trials.

To compare the GSC-ACCs, a 3 (Age) × 4 (Version) ANOVA was used. Results showed that there was only a significant effect of version (F (3, 318) = 3.03, $p < .05$, $\eta_p^2 = .03$). Further analysis showed that although the GSC-ACCs in the TC version (M = .01, SE= .00) was similar to the rest of the versions, the GSC-ACCs in the SD (M = .02, SE = .00) and PP versions (M = .02, SE = .00) were significantly larger than that of the NP version (M = .00, $SE.$ = .00).

To compare the GSC-RTs, a 3 (Age) × 4 (Version) ANOVA was used. Results showed that there was a significant effect of age (F (2, 106) = 3.93, $p < .05$, $\eta_p^2 = .07$), and Tukey HSD tests ($p < .05$) showed that the GSC-RTs in the young adults (M = 0.15, SE = 0.02) were significantly smaller than those in the children (M = 0.23, SE = 0.02) but similar to the elderly adults (M = 0.16, SE = 0.02). In addition, there was also a significant effect of version (F (3, 218) = 14.57, $p < .001$, $\eta_p^2 = .12$) and a significant interaction between age and version (F (6, 318) = 2.28, $p < .04$, $\eta_p^2 = .04$). All participants had significantly larger GSC-RTs in the SD version (M = 0.27, SE = 0.02) than in the other three versions. In addition, they had significantly larger GSC-RTs in the PP version (M = 0.21, SE = 0.03) than in the NP (M = 0.11, SE = 0.02) and the TC versions (M = 0.12, SE = 0.02). Further analysis showed that an age difference appeared only in the SD (F (2, 106) = 3.77, $p < .05$, η_p^2 = .07) and the PP versions (F (2, 106) = 4.90, $p < .01$, $\eta_p^2 = .09$), not in the NP and the TC versions (F (2, 106) < 1). Tukey's HSD tests ($p < .05$) showed that in the SD version, the children (M = 0.36, SE = 0.35) had significantly larger GSC-RTs than the young adults (M = 0.23, SE = 0.11); and in the PP version, the children (M = 0.32, SE = 0.42) had significantly larger GSC-RTs than both the young (M = 0.13, SE = 0.12) and elderly adults (M = 0.16, SE = 0.19).

Discussion

The current study examined the developmental trend of task switching ability in children, young adults, and elderly adults, who are proficient English-Chinese bilinguals. Significant quadratic trends were found in baselines. This is consistent with the findings from monolingual populations: Children are less accurate and much slower than younger adults while elderly adults are slower than younger adults though they may be equally accurate (Salthouse et al., 1998).

After taking baseline ACC and RT into consideration, a significant quadratic function of age was found in the local switch costs of the SD version. Children had significantly larger local switch costs than young adults and elderly adults. These suggest that the ability to switch between tasks flexibly was still developing in the 7 year old bilingual children. Such a pattern is similar to that found among monolinguals (Casey et al., 2004). Nevertheless, young and elderly adults appeared to have similar local switch costs in the SD version, suggesting that bilingualism may slow down the decay of cognitive flexibility in elderly adults (Bialystok et al., 2006).

Similarly, a significant quadratic function of age was found in the local switch costs of the PP version. Children had significantly larger local switch costs than adults, suggesting that they are still developing the ability to suppress the previously activated task sets. This pattern is similar to that found with monolinguals (Davidson et al., 2006). Although there was a tendency of decay, elderly adults appeared to have similar local switch costs in the PP version as young adults. These suggest that bilingualism may slow down the ability to suppress the previously activated task sets in elderly adults (Hasher & Zack, 1988).

However, no quadratic function of age in the local switch costs of the NP version was observed. Elderly adults had similar switch costs to young adults, unlike monolingual elderly adults who have shown difficulty with disinhibition (May et al., 1995). These results suggest that the ability to re-activate the previously suppressed task sets is preserved in bilingual elderly adults. Children had significantly larger local switch costs than adults in terms of RT, suggesting that they are still developing the ability to re-activate the previously suppressed task set. This pattern is similar to that observed for monolinguals (Müller et al., 2006).

In addition, there was no quadratic function of age in the local switch costs of the TC version. Unlike monolingual elderly adults (Craik & Bialystok, 2006), bilingual elderly adults appeared to have similar local switch costs to young adults, suggesting that the ability to maintain and update information still functions well in the 60 years old bilingual adults. However, children had larger local switch costs than the adults. This suggests that the ability to maintain and update information is still developing in the 7 year old bilingual children.

Additionally, children had significantly larger global switch costs than young adults in the SD version and both young adults and elderly adults in the PP version. These indicate that children are still developing the ability to maintain and select appropriate task sets in a continuous switching context. Compared to the PP version, the SD version is still challenging for elderly adults. It seems that even for bilingual elderly adults, when

the task is demanding, flexibility is lost. Such a pattern has been observed in monolingual elderly adults as well (Zelazo, Craik, & Booth, 2004).

These results imply that a bilingual advantage may accumulate through childhood, and be maintained in late adulthood. In particular, bilingualism may slow down the decay of cognitive flexibility in elderly adults. Compared to monolingual young adults, during task switching, elderly adults appear to have similar switch costs during information maintaining and updating, suppressing previous task sets, re-activating previously suppressed task sets, and integrating task sets. These suggest that the accumulated bilingual advantage is domain general, including various higher cognitive functions.

Although bilingual children outperform monolingual children in inhibitory control and task switching (e.g., Bialystok et al., 2006), similar to monolinguals, during early and middle childhood, bilinguals are still developing the abilities to maintain and update information, integrate task sets, suppress previously activated task sets, and disinhibit previously suppressed task sets. In other words, bilingual children may show some advantages in the performance of executive function, but their developmental trajectory of executive function is similar to monolinguals.

In conclusion, bilingual advantage may accumulate through childhood, and be preserved in late adulthood. In particular, bilingualism may slow down the decay of cognitive flexibility in elderly adults.

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