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Flexibility in task switching by monolinguals and bilinguals*

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Many bilinguals routinely switch between their languages, yet mixed evidence exists about the transfer of language switching skills to broader domains that require attentional control such as task switching. Monolingual and bilingual young adults performed a nonverbal task-switching paradigm in which they viewed colored pictures of animals and indicated either the animal or its color in response to a cue. Monolinguals and bilinguals performed similarly when switching between tasks (local switch cost) in a mixed-task block, but bilinguals demonstrated a smaller mixing effect (global switch cost) than monolinguals, indicating better ability to reconfigure stimulus–response associations. These results suggest that regular practice using multiple languages confers a broader executive function advantage shown as improved flexibility in task switching.

Keywords: task switching, bilingualism, executive function

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Bilinguals who regularly switch between languages, so that a contextually appropriate language can be selected, receive frequent practice in modulating the relative activation of language sets within working memory. Structurally similar forms of training using task switching and dual-task paradigms are known to produce general improvements in executive control tasks (Bherer, Keramer, Peterson, Colcombe, Erickson & Becic, 2005; Karbach & Kray, 2009; Minear & Shah, 2008), leading to the possibility that language switching practice could also produce executive control benefits. Indeed, bilingualism benefits in executive control task performance have been found in both children (review in Barac, Bialystok, Castro & Sanchez, 2014; meta-analysis in Adesope, Lavin, Thompson & Ungerleider, 2010) and adults (Bialystok, Craik & Luk, 2008; Bialystok, Craik & Ryan, 2006; Colzato, Bajo, Van den Wildenberg, Paolieri, Nieuwenhuis, La Heij & Hommel, 2008; Costa, Hernández & Sebastián-Gallés, 2008; review in Bialystok, Craik, Green & Gollan, 2009). Recently, researchers have begun investigating the potential benefits of bilingualism on task switching. The goal of the present work is to replicate the task switching effects seen in children by Barac and Bialystok (2012) using a young adult population and to clarify conflicting results previously reported for this population.

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Task switching requires the ability to allocate attention to a single task in the context of two potential options, so that a correct task-specific response can be made. This ability to switch attention between two tasks is considered to be an aspect of executive control (DiGirolamo, Kramer, Barad, Cepeda, Weissman, Milham, Wszalek, Cohen, Banich, Webb, Beloposky & McAuley, 2001; Kramer, Hahn & Gopher, 1999; Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000; Sohn & Anderson, 2001; Sylvester, Wager, Lacey, Hernandez, Bichols, Smith & Jonides, 2003). Task switching facility is normally assessed by asking participants to perform two interspersed tasks in order to calculate the cost associated with switching between them (Allport, Styles & Hsieh, 1994; Rogers & Monsell, 1995).

Two forms of cost are generally examined: global switch cost (GSC; a.k.a. mixing cost) is associated with resolution of task-set interference arising from ambiguous stimuli (Mayr, 2001; Rubin & Meiran, 2005), and local switch cost (LSC; a.k.a. switching cost) is associated with reconfiguration of action sets (Rogers & Monsell, 1995). GSC is typically assessed by subtracting performance on task blocks in which only a single task appears from performance on non-switch trials in blocks where the other task alternates, either predictably or randomly. LSC is typically calculated by subtracting performance on non-switch trials from switch trial performance, with all trials coming from blocks in which participants expect task switches to occur.

GSC and LSC involve different executive control processes that activate separate neural regions, demonstrated through a double dissociation (Braver, Reynolds & Donaldson, 2003; Goffaux, Phillips, Sinai &

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Pushkar, 2008; Wylie, Murray, Javitt & Foxe, 2009), and thus should be differentially responsive to bilingualism effects. In particular, the brain regions associated with GSC are believed to be involved in sustained attention, planning, goal processing, and active maintenance; there is also greater working memory demand associated with switch than non-switch blocks as well as a need to maintain attention on the cue throughout switch blocks (Braver et al., 2003). In contrast, some functional Magnetic Resonance Imaging (fMRI) evidence suggests that LSC is associated with general response preparation, regardless of whether a task change occurs (Braver et al., 2003), in line with evidence that cue switching costs account for a substantial proportion of LSC (Arrington & Logan, 2004). GSC typically changes dramatically in magnitude across the lifespan, while LSC typically shows little age-related change (Cepeda, Kramer & Gonzalez de Sather, 2001; Reimers & Maylor, 2005) providing additional evidence that different mechanisms may be involved in each component.

In an fMRI study, Garbin, Sanjuan, Forn, Bustamante, Rodriquez-Pugada, Belloch, Hernandez and Ávila (2010) found a behavioral LSC bilingual advantage in young adults. Gold, Kim, Johnson, Kryscio and Smith (2013) used fMRI to examine GSC effects in younger and older adult bilinguals and monolinguals. Their results showed that bilingualism reduced the magnitude of the neural GSC effect in older adults, suggesting that a more efficient neural system underlies the GSC bilingualism benefit, at least in older adults. Gold et al. failed to find behavioral GSC benefits in young adults.

What does existing evidence say about GSC bilingualism advantages in young adults? Prior and MacWhinney (2010) conducted one of the few studies examining effects of bilingualism on task switching in young adults and found reduced LSC, but not reduced GSC, in bilinguals. A similar study by Prior and Gollan (2011) replicated these results in Spanish–English bilinguals. In contrast, Mandarin–English bilinguals were equivalent to monolinguals in both LSC and GSC. Hernández, Martin, Barceló and Costa (2013, Experiment 3), using the same paradigm, failed to find GSC or LSC effects, replicating Prior and Gollan's Mandarin–English results in a sample of Catalan–Spanish bilinguals. Paap and Greenberg (2013) used a nearly-identical paradigm and failed to find GSC or LSC benefits. Thus, one study found a LSC bilingualism benefit, two studies found no LSC benefit, and one study found mixed results depending on the languages spoken by bilinguals. All four studies failed to find GSC bilingualism benefits in young adults.

Our position is that GSC benefits should be found in cases where interference between stimulus–response mappings must be resolved and active updating must take place, which was not the case for the four studies using variants of Prior and MacWhinney's (2010) paradigm. For the present study, we have chosen a paradigm that requires stimulus–response remapping on 100% of trials (i.e. all trials are response incompatible in that each stimulus is associated with a different response depending on the task). This feature contrasts with Gold et al. (2013) and Garbin et al. (2010), who used 50% response compatible and 50% response incompatible trials. One possibility for Gold et al.'s finding of a GSC benefit in older but not younger adults is that older adults might have been more sensitive to remapping, showing behavioral effects even with just 50% incompatible trials. In contrast, young adults might require 100% response incompatible trials to show a bilingualism effect. Indeed, several studies have shown that tasks that lead to equivalent performance in monolingual and bilingual younger adults reveal a bilingual advantage in older adults (e.g. Bialystok et al., 2008; Bialystok, Poarch, Luo & Craik, 2014). By maximizing the number of trials in which remapping must occur, we should increase power to detect an effect in young adults. Our design also differs from the four behavioral studies described above that use 100% response compatible trials (Hernández et al., 2013, Exp. 3; Paap & Greenberg, 2013; Prior & Gollan, 2011; Prior & MacWhinney, 2010), as our paradigm requires remapping of stimulus–response associations whereas active remapping was not required in these previous studies. Instead, in the previous behavioral studies stimulus–response mappings were held constant, and each combination of task and stimulus was associated with a unique response button. The correct button must be determined, but remapping of the motor program is not required.

We used a computerized task-switching paradigm (Barac & Bialystok, 2012; Cepeda, Cepeda & Kramer, 2000) in which there were switch and non-switch blocks, and participants switched non-predictably between two equally probable tasks, namely, shape and color. This paradigm has resulted in GSC but not LSC bilingualism benefits in children (Barac & Bialystok, 2012). Given that GSC effects can be present in older but not younger adults (Gold et al., 2013), and given that no study to date has demonstrated GSC effects in young adults, the potential for locating a GSC bilingualism benefit in young adults seems questionable. Nonetheless, our view is that the primary effect of bilingualism is on executive control, processes more involved in GSC than LSC. Therefore, we hypothesized that bilinguals would have a smaller GSC than monolinguals in a paradigm that used 100% response incompatible trials and thus maximized the involvement of executive control.

Method

Participants

Sixty-eight young adults (44 female; $M = 19.1$ years old; 37 monolinguals) participated in exchange for course credit, and were recruited through a university participant pool for introductory psychology students. Bilinguals spoke a variety of languages in combination with English, including: Farsi, French, Arabic, Vietnamese, Hindi, Tagalog, Punjabi, Russian, Mandarin, Bosnian, Armenian, Urdu, Hebrew, Portuguese, Spanish, Cantonese, Yoruba, Greek, and Gujarati. Thirteen of the bilinguals reported English as their first language. The Language Background Questionnaire (LBQ; Luk & Bialystok, 2013) showed that on a daily basis bilingual participants used English 48% of the time at home and in social settings. Monolinguals completed the questionnaire to establish that they did not have sustained experience with a second language. Nineteen of the bilingual participants were immigrants.

Tasks and materials

The LBQ was administered to assess how well and how frequently participants spoke English and their other language as well as how they learned each language (at home, at school, both, or by other means). Participants established how much they used each language in different environments (at home, at school, at work, with friends, with family, and overall).

The Kaufman Brief Intelligence Test, Second Edition (K-BIT-2; Kaufman & Kaufman, 2004) Matrices subtest was administered using standard testing procedures. This test is a measure of non-verbal intelligence. To measure receptive vocabulary, the Peabody Picture Vocabulary Test, Third Edition (PPVT-III; Dunn & Dunn, 1997) was administered using standard testing procedures.

A box completion task (Salthouse, 1996) was used to assess processing speed. This task consisted of a sheet of paper containing an array of 35 three-sided squares. The task was to complete the fourth side of each square as fast as possible. Total completion time was measured. An offset reaction time (RT) task (Blackwell, Cepeda & Munakata, 2009) measured latency to remove a finger from the touch screen in response to a stimulus that appeared, and a choice RT task (1D card sort; Blackwell et al., 2009) measured latency to press the touch screen in response to visual circles or stripes that appeared, as well as the latency when an auditory cue prompted the subject to press circles or stripes.

In the task-switching paradigm, participants classified stimuli by color (red or blue) or shape (cow or horse). The task began with two counterbalanced non-switch blocks, one for shape and one for color. Each non-switch block included 22 trials (44 non-switch block trials in total). For the switch blocks, we fixed the number of switch trials and allowed the number of non-switch trials to vary. On each trial, there was a 50% probability of a task change, such that about 50% of the time the task changed on the trial immediately after a task change, on about 25%

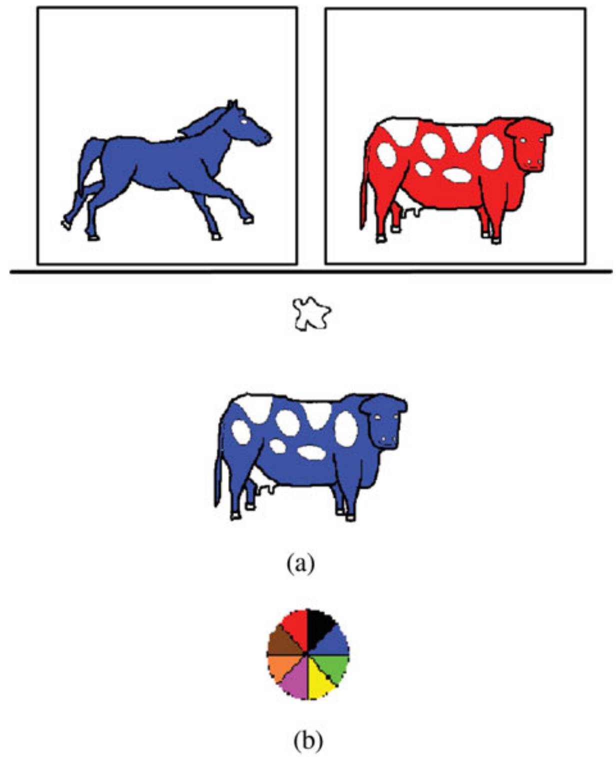

Figure 1. (Colour online) (a) Example trial, with to-be-categorized stimulus on the bottom and response incompatible targets on the top. Red and blue cows and horses were presented. A squiggly outline was used as the shape task cue. (b) A color wheel was used as the color task cue.

of trials the task changed two trials after a task change, and so on. This procedure resulted in approximately the same number of switch and non-switch trials for each subject. We placed no constraints on task changes, which were fully random. During the switch phase, participants completed a practice switch block that contained 22 task switch trials and approximately 22 non-switch trials. After this practice, there were two experimental switch blocks that contained exactly 25 trials in which the task changed along with approximately 25 non-switch trials (about 50 switch trials and 50 non-switch in switch block trials total). Trials in which the task repeated during the switch block were averaged to obtain a non-switch in switch block score, and switch trials were averaged to obtain a switch score. No feedback was provided on task performance.

Two response set stimuli were shown at the top of the screen, and a target stimulus with a task cue (color wheel or black squiggly outline) appeared below, as shown in Figure 1. Blue and horse were always associated with the left index finger, and red and cow were always associated with the right index finger. Stimuli and targets and the task cue appeared on the screen simultaneously and remained

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Table 1. *Age, processing speed, non-verbal intelligence, and receptive vocabulary data (SD) by language status.*

	Monolinguals n = 37	Bilinguals n = 31
Age (years)	19.1 (1.7)	19.2 (1.8)
Box Completion (s to complete 35 items)	24.1 (8.1)	22.5 (8.4)
Offset RT (ms)	352 (35)	366 (55)
Choice RT 1D Card Sort (ms)	908 (183)	931 (365)
Choice RT Task Switching (ms)	718 (212)	730 (153)
K-BIT-2 Matrices (standard score)	91.4 (13.8)	95.1 (14.4)
PPVT-III (standard score)	105.8 (11.7)	100.9 (13.8)

on the screen until participants made a response, followed by a 1000 ms inter-trial interval. All trials were response incompatible.

Procedure

Participants were tested in a university lab room. Tasks were presented in the order LBQ, task switching, PPVT-III, offset RT, K-BIT-2 Matrices, box completion, choice RT 1D card sort, and choice RT task switching.

Results

Background data are reported in Table 1. There were no language status main effects on age, box completion, offset RT, choice RT 1D card sort (average of auditory and visual trials), choice RT task switching (average of non-switch only block trials from task switching paradigm), K-BIT-2 Matrices standard score, or PPVT-III standard score, all *t*s <1.6.

GSC was analyzed using median RTs for non-switch trials in switch blocks vs. non-switch block trials (block type, GSC analysis; within-subjects), and LSC was analyzed using median RTs for switch and non-switch trials within switch blocks (switch status, LSC analysis; within-subjects). Only correct response trials preceded by a correct response trial were included in analyses. Two participants (both monolingual) were removed because of error rates in a cell greater than 25%. No other error rate or RT outliers were detected based on normality tests and observation of histograms and box plots.

Error rates (Table 2) were low for switch and non-switch trials in switch blocks ($M = 5.3\%$ and 2.7% errors respectively), and for non-switch block trials ($M = 1.4\%$), and did not differ by language status; all *t*s < 1. Thus, no other error rate analyses were run. RT data are presented in Table 2. For median RTs, 2 × 2 (block type by language status) ANOVA examined GSC effects by comparing non-switch trials in the single task and switch blocks. There was a main effect of block type, with longer RTs for non-switch trials in the switch block, $F(1,64) = 228.4$, $p < .001$, $\eta^2_p = .78$, no main effect of language status, $F < 1$, and an interaction between block type and language status, $F(1,64) = 4.9$, $p = .03$, $\eta^2_p = .07$, in which the difference between RT in switch and non-switch blocks was smaller for bilinguals, consistent with smaller GSC. We ran *t*-tests to determine if the bilingualism effect was localized to either type of non-switch trial, and failed to find a bilingualism effect for non-switch block trials, $t(64) = 1.1$, $p = .261$, or non-switch trials in switch blocks, $t(64) = 0.9$, $p = .381$. Thus, the interaction is not due solely to slower RTs for bilinguals on non-switch block trials; nor is it due solely to faster performance of bilinguals on non-switch trials in switch blocks. A second 2 × 2 (switch status by language status) ANOVA examined

Table 2. *Error rate and RT data (SD) for switch trial type and switch cost by language status.*

	NN	SS	NS	GSC	LSC
% Errors					
Monolingual	1.5 (2.6)	5.7 (4.8)	2.7 (2.3)	–	–
Bilingual	1.4 (2.5)	4.7 (4.0)	2.7 (2.0)	–	–
Median RT (ms)					
Monolingual	688 (150)	1087 (233)	1025 (225)	337 (155)	61 (72)
Bilingual	730 (153)	1042 (178)	981 (173)	251 (161)	61 (64)
Mean RT (ms)					
Monolingual	792 (225)	1250 (310)	1191 (302)	399 (224)	59 (80)
Bilingual	829 (245)	1169 (244)	1112 (226)	282 (215)	58 (84)

NN = non-switch trial in non-switch block; SS = switch trial; NS = non-switch trial in switch block
Global switch cost (GSC) is the comparison of NN to NS. Local switch cost (LSC) is the comparison of SS to NS.

LSC effects, for median RTs in the switch blocks. There was a main effect of switch status, with longer RTs for switch trials, $F(1,64) = 53.2$, $p < .001$, $\eta^2_p = .45$. Neither the language status main effect nor the interaction reached significance, Fs < 1. Analysis using mean RTs resulted in an identical pattern with nearly identical F-values.

Discussion

The purpose of this study was to determine if long-term experience switching between two languages facilitated performance in switching between two tasks when the stimulus–response mapping requirement was maximized by using 100% response incongruent trials. Background measures revealed no significant differences between language groups on processing speed, age, or IQ, demonstrating that the groups were well matched. Consistent with Barac and Bialystok (2012), who used the same paradigm with a child population, our study found that young adult bilinguals displayed a GSC advantage, but no LSC advantage.

While Gold et al. (2013) failed to find GSC benefits in young adults, our results did find benefits, which might be the result of using a larger percentage of response incompatible trials (i.e. 100% vs. 50%). Thus, our results suggest that bilinguals are better able to actively reconfigure stimulus–response associations, a process required during switch blocks but is not needed during non-switch blocks. Unlike Garbin et al. (2010) who used 50% response incompatible trials, but similar to some previous studies using variants of the Prior and MacWhinney (2010) paradigm, we failed to find LSC benefits of bilingualism. We do not have a parsimonious explanation for LSC results across the literature, thus we suggest further investigation using task switching variants that manipulate factors such as response congruency.

Unlike most previous work on bilingualism and task switching (e.g. Prior & MacWhinney, 2010), we used a paradigm that required active stimulus–response remapping on every trial during switch blocks and, in contrast to previous studies, we found GSC benefits in young adult bilinguals. A parsimonious explanation for our results is that bilingualism improves the ability to reconfigure stimulus–response associations. This may be analogous to the concept–language remappings that take place every time a bilingual switches between languages (Orfanidou & Sumner, 2005). LSC, in contrast, is more analogous to topic changes that characterize stretches of discourse, something that both monolinguals and bilinguals engage in equally. Thus, the unique nature of bilingual language use, namely, the availability of two representational systems, may be responsible for an extended benefit in the way bilinguals perform nonverbal tasks that involve switching.

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