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Partially Overlapping Mechanisms of Language and Task Control in Young and Older Bilinguals

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Abstract

The current study tested the hypothesis that bilinguals rely on domain-general mechanisms of executive control to achieve language control by asking if linguistic and nonlinguistic switching tasks exhibit similar patterns of aging-related decline. Thirty young and 30 aging bilinguals completed a cued language-switching task and a cued color-shape switching task. Both tasks demonstrated significant aging effects, but aging-related slowing and the aging-related increase in errors were significantly larger on the color-shape than on the language task. In the language task, aging increased language-switching costs in both response times and errors, and language-mixing costs only in response times. In contrast, the color-shape task exhibited an aging-related increase in costs only in mixing errors. Additionally, a subset of the older bilinguals could not do the color-shape task, but were able to do the language task, and exhibited significantly larger language-switching costs than matched controls. These differences, and some subtle similarities, in aging effects observed across tasks imply that mechanisms of nonlinguistic task and language control are only partly shared and demonstrate relatively preserved language control in aging. More broadly, these data suggest that age deficits in switching and mixing costs may depend on task expertise, with mixing deficits emerging for less-practiced tasks and switching deficits for highly practiced, possibly “expert” tasks (i.e., language).

Keywords

aging; bilingualism; language switching; task switching; executive control

A remarkable feature of bilingualism is the ability to fluently switch between languages when conversing in natural contexts. From an observer’s perspective bilinguals do this without difficulty. Exactly how bilinguals manage to select the right language at the right time, while avoiding interference from the nontarget language, has been a much-debated

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topic in the current literature on bilingualism. However, there is an emerging consensus that bilingual language control is achieved at least in part by reliance on domain-general mechanisms of executive control (Abutalebi & Green, 2007; Gollan & Ferreira, 2009; for review, Bialystok, Craik, Green, & Gollan, 2009; Hernandez, 2009). The goal of the present study was to test this hypothesis by comparing age-related changes in linguistic and nonlinguistic switching. A secondary goal was to reveal mechanisms fundamental to bilingual language control and to better characterize age-related changes therein.

Aging bilinguals offer an opportunity to test the role of domain-general control in bilingual language control because the ability to shift between tasks has been shown to decline with increased age (for review see Mayr & Liebscher, 2001). Although bilingualism may protect against some aspects of age-related decline in executive control ability, comparisons of young to older bilinguals reveal substantial age-related decline in nonlinguistic executive control even for bilinguals (e.g., in the Simon task; Bialystok, Craik, Klein, & Viswanathan, 2004). Thus, unless bilinguals are equipped with specialized mechanisms for language control that are sheltered from age-related decline in domain-general executive control, bilinguals should exhibit parallel age-related changes in linguistic and nonlinguistic switching.

Gollan, Sandoval, and Salmon (2011) examined the association between linguistic and nonlinguistic control in aging bilinguals with a flanker task and verbal fluency tests. Against the hypothesis of shared control mechanisms for linguistic and nonlinguistic tasks, the rate of cross-language intrusion errors was very low (1% on average and only 3% at most), even in aging bilinguals with deficits in executive control. More specifically, aging bilinguals who made more than 50% errors on incongruent trials of the flanker task (and one who could not do the task at all), exhibited little to no difficulty achieving language control. This relative preservation of language control in the face of obvious difficulty with executive control implies the presence of powerful domain-specific mechanisms of language control that are largely independent of general executive control mechanisms. However, this same study also provided evidence that supports the notion of at least partially overlapping control mechanisms for language and non-linguistic control; that is, (a) cross-language intrusion errors increased with aging, and (b) older bilinguals exhibited a highly robust correlation between errors on the flanker task and cross-language intrusion errors in the verbal fluency task.

Other support for the notion that domain-general control mechanisms are used to achieve bilingual language control comes from a growing literature documenting bilingual advantages on nonlinguistic tasks of executive function. For example, bilinguals were faster to resolve response conflict in the Simon Task (Bialystok et al., 2004) and in the Attentional Network Task (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008) and exhibited smaller Stroop interference effects (e.g., Bialystok, Craik, & Luk, 2008), when compared with matched monolinguals. Another recent study provided evidence of an explicit connection between language switching and nonlinguistic task switching. Prior and Gollan (2011) tested participants on a language-switching task in which they switched between naming numbers 1–9 in their first language (L1) and second language (L2) and a nonlinguistic task in which they switched between making color and shape judgments (a task that previously revealed more efficient switching in bilinguals than in monolinguals; Prior & MacWhinney, 2010). In addition to monolinguals, two types of bilinguals were tested: Spanish-English bilinguals who reported switching languages often in daily life and Mandarin-English bilinguals who reported switching languages significantly less often than the Spanish-English group. The bilingual advantage for task-switching was replicated only in the Spanish-English group, and Spanish-English bilinguals also exhibited smaller language-switching costs than Mandarin-English bilinguals. Both results illustrate an explicit connection between bilingual language use and general switching ability (hence the title of the paper “Good Language Switchers are Good Task Switchers”) and imply that the ability to flexibly shift mental sets is enhanced by a bilingual’s lifelong experience in switching between languages.

Another way to investigate the hypothesis that executive control abilities underlie language control is through direct comparisons of aging effects across nonlinguistic and linguistic switching paradigms. An important distinction for understanding previously reported aging effects on task shifting is between switching and mixing costs. In single-task blocks participants perform just one task. In mixed-task blocks participants are cued to switch between tasks on some proportion of trials. Within these paradigms there are three types of trials: switch trials in mixed-task blocks, non-switch trials in mixed-task blocks (stay trials), and responses in single-task blocks. Contrasting the three types of trials, two types of costs can be considered. *Switching* costs reflect the increase in response times (RTs) on switch versus nonswitch trials within the mixed-task block. *Mixing* costs reflect a different increase in RTs that can be seen when comparing nonswitch trials in the mixed-task block to responses in a single-task block (which are necessarily nonswitch trials because in single-task blocks individuals perform just one task). The costs associated with mixing have been proposed to reflect global sustained control mechanisms that are needed on nonswitch trials in a mixed block to maintain two competing task goals available for response, monitor task cues, and keep track of which task must be completed (Braver, Reynolds, & Donaldson, 2003; Koch, Prinz, & Allport, 2005; Rubin & Meiran, 2005). In contrast, switching costs have been described as reflecting transient control mechanisms that are needed to select the correct task on any given trial (Braver et al., 2003; Mayr & Kliegl, 2000, 2003).

Recent reviews of aging effects on task shifting reveal robust deficits in mixing but relatively intact task-switching abilities in older age (Kray & Lindenberger, 2000; Mayr & Liebscher, 2001; Reimers & Maylor, 2005; Verhaeghen & Cerella, 2002; for meta-analysis see Wasylyshyn, Verhaeghen, & Sliwinski, 2011). Such findings suggest that age deficits may be circumscribed to the maintenance of two task sets, possibly reflecting working memory deficits and implying preserved processes of selective attention associated with local switching costs (Wasylyshyn et al., 2011). However, some individual studies have also identified age deficits in task switching. For example, Meiran, Gotler, and Perlman (2001) found an age-related increase in both mixing and switching costs in a cued-switching task requiring monolinguals to switch between indicating if a stimulus was in the left/right or up/down position of a grid. In addition, Kray, Li, and Lindenberger (2002) found a greater age-related deficit in switching than mixing under conditions of greater task uncertainty (using four tasks instead of just two). A different study by the same investigators found the opposite pattern (a larger age-deficit in mixing than in switching) in a paradigm using predictable task sequences (instead of task cues; Kray & Lindenberger, 2000). Kray et al. (2002) suggested that task cues reduce task uncertainty and reduce age-related differences associated with mixing costs. Thus, the presence or absence of aging deficits and the nature of the deficit can vary substantially with small changes in methodology that influence which underlying cognitive processes are involved.

In contrast to the breadth of literature on aging effects in task switching and mixing, relatively little is known about aging effects on language switching. Hernandez and Kohnert (1999) compared a group of older Spanish-English bilinguals to college-aged bilinguals in a picture-naming task with cued language switching. Older bilinguals made more errors and were slower to respond particularly in the mixed-language blocks. Particularly robust in this study was an age-related increase in failures to switch when cued to do so. In contrast, there were little to no differences between young and older bilinguals in RTs and errors in the blocked conditions in which pictures were named in one or the other language (though there was a trend in the direction of age-related slowing; $p < .06$). One limitation of this study is that the mixing and switching costs were not differentiated (stay and switch trials were not considered separately in analyses of responses in the mixed-language blocks).

One additional study investigated aging effects on language switching. Gollan and Ferreira (2009) distinguished between switching and mixing costs in a voluntary language-switching paradigm with young and older Spanish-English bilinguals. In this study, bilinguals were given the option to switch between languages or not on each trial using "whichever language comes to mind" in the mixed blocks. With these task demands there was no age-related increase in the magnitude of voluntary language mixing costs, but there was a small but significant age-related increase in voluntary switching costs. The age-related increase in voluntary language switching but not mixing costs again differs from the more typical result in the monolingual task-switching literature (which, as reviewed above, more often exhibits age-related increases in mixing rather than switching costs). This raises the question of whether age-related deficits might be found for cued language-mixing, or if something specific to language makes switching more vulnerable than mixing in older age whether cued or voluntary.

In the current study we compared aging effects on cued nonlinguistic and linguistic mixing and switching. Similarities in age deficits across tasks would support the notion of domain-general control mechanisms that subserve language control. Conversely, dissociations in aging effects across tasks would imply limitations on the extent to which language control relies on a general executive system and might reveal unique mechanisms underlying bilingual language control. For this purpose, we examined aging effects on a nonlinguistic switching task that previously revealed a bilingual switching advantage (Prior & MacWhinney, 2010) and an explicit relationship with language switching (Prior & Gollan, 2011).

To date, no study has contrasted aging effects on cued language switching with mixing. Based on results reported for aging effects on voluntary language switching (Gollan & Ferreira, 2009) and high error rates on switch trials for aging bilinguals in a study of cued-language switching (Hernandez & Kohnert, 1999), we predicted a significant age-related increase in cued language-switching costs. With respect to mixing costs, Gollan and Ferreira (2009) observed no aging deficit in voluntary language mixing and concluded that age-related mixing deficits reflect processing mechanisms associated with cue-driven language selection (for related discussion see Mayr & Liebscher, 2001). If so, an age-related increase in cued-language mixing costs should be observed. An alternative possibility is that aging bilinguals may be less vulnerable to mixing deficits in general or more specifically that aging does not affect language mixing, in which case no mixing deficit would be observed even in a cued paradigm.

For the color-shape task, aging bilinguals might show robust switching deficits, as aging bilinguals exhibited in language-switching. This would suggest that switching rather than mixing is vulnerable in aging for bilinguals and would support the notion of shared mechanisms of nonlinguistic and linguistic control. Alternatively, aging bilinguals might show more robust mixing deficits in the nonlinguistic task, as has previously been reported in the aging literature on task switching in monolinguals. This would suggest that age-related switching deficits are specific to bilingual language control and would imply some degree of independence for mechanisms of nonlinguistic and linguistic control.

Method

Participants

Thirty young bilinguals (22 women) were recruited from the University of California, San Diego (UCSD) and participated in the study for course credit. Thirty older bilinguals (21 women) were recruited from a cohort of healthy control participants at the UCSD Alzheimer's Disease Research Center (ADRC) and from the San Diego community. Eighteen older bilinguals were diagnosed as cognitively intact by two senior staff neurologists using criteria developed by the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's disease and Related Disorders Association (ADRDA; McKhann et al., 1984), and diagnosis was based on medical, neurological, and neuropsychological evaluations and a number of laboratory tests (to rule out dementia). Twelve additional aging bilinguals were recruited from the San Diego area and were classified as cognitively intact based on high levels of reported independent functioning in daily life and Dementia Rating Scale scores (Mattis, 1988).

Bilinguals' responses in each language in the language-switching task were assigned as dominant or nondominant based on their ability to name pictures in English and in Spanish on the Multilingual Naming Test (MINT; Gollan, Weissberger, Runnqvist, Montoya, & Cera, 2011). The MINT includes 68 black-and-white line drawings that are presented in order of estimated increasing difficulty. Bilinguals who named more pictures correctly in Spanish than in English on the MINT were classified as Spanish-dominant (seven older adults and seven young adults), and those who named more pictures correctly in English than in Spanish were classified as English-dominant (15 older adults and 23 young adults; these numbers of older bilinguals sum to the 22 older bilinguals included in the primary analyses below). No bilingual person had identical naming scores in English and Spanish.

Matching

Participant characteristics and statistics for the difference between young and older bilinguals are presented in Table 1. Young and older bilinguals were matched for education level and bilingual language proficiency, as measured by the MINT in both Spanish and English. In addition, young and older bilinguals did not differ in the extent of language dominance (dominance was determined by subtracting Spanish from English MINT index scores).

Materials and Procedure

Participants signed consent forms and completed a Language History Questionnaire at the start of the testing session. Older bilinguals not recruited through the ADRC were tested on the Dementia Rating Scale (Mattis, 1988) and the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975) in their self-reported dominant language. For ADRC participants, test scores were obtained from their most recent annual testing at the ADRC.

Participants were tested with the MINT in both English and Spanish, with language of testing in counterbalanced order (first or second) between participants. After administration of the MINT, the color-shape and language-switching paradigms were administered in counterbalanced order. The language and color-shape tasks were the same as those used by Prior and Gollan (2011) with two modifications. First, we reduced the number of trials to 20 trials per block (after reanalysis of those data which revealed substantial power even with the reduced number of trials). Second, the button mappings for the color-shape task appeared directly on the computer screen (instead of as an overlay on the button box). An example of the display in the two tasks is shown in Figure 1. Following Rubin and Meiran (2005) we used a sandwich design such that participants completed two single-task blocks and four mixed-task blocks, followed by two more single-task blocks for each trial type in each task (e.g., color-shape and language). Within each task the order of English versus Spanish and color versus shape was counterbalanced for the single-task blocks. In the color-shape task, participants were cued to judge color with a rainbow patch and shape with a series of black shapes and were instructed to respond with a different button press for each color (red, green) and shape (triangle, circle). In the language task, participants named numbers in English or Spanish based on a cue (American flag for English, and Mexican flag for Spanish). Each trial was preceded by a fixation point that lasted for 500 ms. The fixation point was replaced by a cue that appeared on the screen throughout the remainder of the trial, after which the stimuli appeared alongside the cue. After a delay of 750 ms, another fixation point appeared for 1750 ms, after which it was replaced by the stimulus. The cue and stimuli (and in the color-shape task also the button mappings legend) remained on the screen until the subject responded or 2000 ms passed. At the end of each 20-trial block, a fixation point appeared on the screen for a prolonged period (5 s). Preceding each run, the subject was presented with brief instructions prompting them to “Press any button to begin.”

Participants first completed practice trials with feedback (12 single and 16 mixed responses in each task). After pilot testing, an “easy practice” block was created to accommodate older bilinguals who could not complete the practice trials accurately. The easy version did not impose a response deadline (i.e., did not shift the target stimulus until the participant responded) and also provided feedback. Participants who were unable to complete the regular practice trials with 80% accuracy were tested on the easy practice trials and then retested on the regular practice block again. Participants who could not complete the regular practice trials with 80% accuracy or better after three attempts were excluded from analysis (see below).

In the language-switching task, all young and older bilinguals completed practice trials accurately and proceeded immediately to the experimental task (and there was no need to create an easy version of practice trials for the language task). In the color-shape task, all young bilinguals completed one run through regular practice trials; task-switching proved to be more difficult for older adults who averaged 1.25 (range 1–3 runs) on regular practice trials and 0.5 (range 0–2 runs) on the easy version.

Results

Eight (5 women) of the 30 older adult bilinguals were excluded from analyses. Five (16.7%) of these were excluded because they were unable to do the color-shape task despite repeated attempts at the practice trials. Of interest, all five of these bilinguals were able to complete the language-switching task, and the language-switching data for these five participants are reported in a separate analysis below. Another older bilingual was unable to complete the color-shape task due to arthritis and associated difficulty with button presses, and two more were excluded from analysis because of low education level (6 and 9 years) and resulting lack of education-matched young bilingual controls at UCSD. All young bilinguals were able to complete both tasks.

RTs for incorrect responses were excluded from analyses. Outlier RTs were trimmed for individual participants by calculating a mean RT across all trials and excluding any response deviating by more than 3 standard deviations of the mean. This procedure eliminated 1.9% of the language task data for both older and young bilinguals. In addition, 2.1% of the color-shape task data were eliminated for young bilinguals, and 1.5% of the color-shape task data were eliminated for older bilinguals.

For both language and color-shape tasks, we report separate analyses of mixing costs that contrast nonswitch (stay) trials within mixed-task blocks with nonswitch (single) trials in single-task blocks, and switching costs that contrast stay (nonswitch) with switch trials in mixed-task blocks. Direct comparisons of the two tasks (again separated by switching and mixing effects) are reported after analyses separated by task.

Language Task

To determine whether older bilinguals have a harder time with language mixing and switching, we conducted 2 × 2 ANOVAs with age as a between-subject variable (young, older), and trial type (single vs. stay for the mixing analyses and stay vs. switch for the switching analyses) as within-subject variables. Initially we also conducted 2 × 2 × 2 ANOVAs adding language dominance (dominant, nondominant) as another repeated-measures factor. However, with one exception,[1] none of the two- or three-way interactions with language-dominance were significant; therefore, for ease of exposition, we excluded the dominance factor in reporting our results, although Table 2 shows the results separated by language dominance.

Language mixing—Older bilinguals responded more slowly than young bilinguals, $F(1, 50) = 11.14$, $MSE = 19{,}895$, $\eta_p^2 = .18$, $p < .01$, and participants responded more quickly in the single-task blocks than on stay trials in the mixed block, $F(1, 50) = 70.19$, $MSE = 2{,}318$, $\eta_p^2 = .58$, $p < .01$. Of interest, older bilinguals exhibited significantly larger cued language mixing costs than younger bilinguals, although this interaction between age group and mixing costs was not especially robust, and just reached significance, $F(1, 50) = 3.89$, $MSE = 2{,}318$, $\eta_p^2 = .07$, $p = .05$.

Error rates in the single-task block and on stay trials in the mixed language blocks were very low in both young and older bilinguals. Older bilinguals did not make more errors than young bilinguals ($F < 1$), participants made fewer errors in the single-language blocks than on stay trials in the mixed block, $F(1, 50) = 7.46$, $MSE = .0002$, $\eta_p^2 = .13$, $p = .01$, and unlike the RTs analysis, there was no indication of a mixing cost increase for older relative to younger bilinguals, $F(1, 50) = 2.16$, $MSE = .0002$, $\eta_p^2 = .04$, $p = .15$.

Language switching—Older bilinguals responded more slowly than young bilinguals, $F(1, 50) = 11.87$, $MSE = 34{,}121$, $\eta_p^2 = .19$, $p < .01$, and participants responded more slowly on switch than on stay trials, $F(1, 50) = 113.31$, $MSE = 975$, $\eta_p^2 = .69$, $p < .01$. Of interest, older bilinguals exhibited significantly larger cued language-switching costs than young bilinguals, a significant interaction between age-group and trial type, $F(1, 50) = 5.12$, $MSE = 975$, $\eta_p^2 = .09$, $p = .03$.

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[1] In mixed-language block (switch cost analyses), young bilinguals responded more slowly in their dominant language than in their nondominant language, whereas older bilinguals always responded more quickly in the dominant than in the nondominant language (see Table 2). This interaction between age and language dominance in the mixed-language block was significant, $F(1, 50) = 3.95$, $MSE = 1{,}727$, $\eta_p^2 = .073$, $p = .05$. Reversed language dominance in young bilinguals in mixed language blocks may reflect inhibition of the dominant language (Gollan & Ferreira, 2009), and thus this interaction between dominance and age could be taken as evidence of an inhibitory control deficit in older bilinguals (e.g., Hasher & Zacks, 1988). Also consistent with this interpretation, the age-related mixing deficit (mix cost analyses) was restricted to nondominant language responses, $F(1, 50) = 6.97$, $p < .01$, $MSE = 2{,}160$, $\eta_p^2 = .122$, and was not significant in the dominant language ($p = .26$). This was because young, $F(1, 29) = 3.72$, $MSE = 3{,}928$, $\eta_p^2 = .11$, $p = .06$, but not older bilinguals ($p = .94$), tended to exhibit greater mix costs in the dominant than the nondominant language (a mix-cost asymmetry). These data imply that young but not older bilinguals may inhibit the dominant language as a means for mixing languages more efficiently.

Error analyses parallel the RT findings. Older bilinguals made more errors than young bilinguals, $F(1, 50) = 6.83$, $MSE = .004$, $\eta_p^2 = .12$, $p = .01$, and participants made more errors on switch than on stay trials, $F(1, 50) = 36.414$, $p < .001$, $MSE = .003$, $\eta_p^2 = .42$. The age-related increase in error rates was especially striking on switch trials, a significant interaction between age and switch costs, $F(1, 50) = 6.18$, $MSE = .003$, $\eta_p^2 = .11$, $p = .02$.

Language-task adjustment for baseline speed—

A question of interest, given that older bilinguals named numbers more slowly than young bilinguals, was whether the age-related increase in costs would be significant after adjusting for age-related slowing. For this analysis, we calculated proportional mixing and switching costs by dividing mix costs by single-block trial RTs and switch costs by stay trial RTs, respectively, and then submitted the means to a 2 × 2 ANOVA with age as a between-subject variable (young, older), and cost type (percent mix cost, percent switch cost) as within-subject variables. This analysis revealed a significant main effect of age; thus the age-related increase in costs (collapsed across switching and mixing) survived an adjustment for baseline speed, $F(1, 50) = 4.23$, $MSE = .007$, $\eta_p^2 = .08$, $p = .045$.

Language–task comparison of age effects on switching and mixing—

The analyses to this point revealed age-related increases in both language-switching and -mixing costs. Unlike previous studies of aging effects on nonlinguistic task switching (in which age deficits in mixing were more robust than age deficits in switching), in the above results, the effect size for the age-deficit in language switching ($\eta_p^2 = .09$) was larger than for language mixing ($\eta_p^2 = .07$), and switching but not mixing also revealed an age related increase in the errors analysis. To directly compare age deficits in language switching and mixing, we calculated switch and mix costs for each participant and submitted these values to 2 × 2 ANOVAs with age (young, old) as a nonrepeated factor and cost type (switch, mix) as a repeated factor. In the analysis of RTs, there was no indication that aging differentially affected switch and mix costs (the interaction between age and cost type did not approach significance, $F < 1$). However, the analysis of errors produced a trend toward stronger aging effects on language switching than on language mixing, $F(1, 50) = 3.29$, $MSE = .002$, $\eta_p^2 = .06$, $p = .08$.

Summary of language-task results—

Aging bilinguals exhibited significantly larger switching and mixing costs in RTs, and the age-related switch cost deficit was also highly robust in error rates. The age-related increase in costs survived an adjustment for baseline speed differences across age groups, and aging deficits in language control were not stronger for mixing than for switching. These results distinguish aging effects on language control from previously observed aging effects on nonlinguistic task control in which aging seemed to affect mixing more than switching (e.g., Wasylyshyn et al., 2011). Instead, if anything, age deficits on language control exhibited some trends in the opposite direction (more robust switching than mixing deficits, as previously reported for voluntary language switching in Gollan & Ferreira, 2009). The analyses in the next section will be informative as to whether mechanisms specific to language control or to bilingualism in general are critical in producing this difference.

Color-Shape Task

To determine whether aging bilinguals have more difficulty with nonlinguistic task control, we conducted a 2 × 2 ANOVA with age as a between-subject variable (young, older), and trial type (single vs. stay for the mixing analyses and stay vs. switch for the switching analyses) as within-subject variables. Initially we also conducted 2 × 2 × 2 ANOVAs adding decision type(color, shape) as another repeated-measures factor. However, with one exception,[2] none of the two- or three-way interactions with decision type were significant; therefore, for ease of exposition, we excluded decision type as a factor in reporting our results, although Table 3 shows the results separated by decision type.

Color-shape mixing—Older bilinguals responded more slowly than young bilinguals, $F(1, 50) = 51.89$, $MSE = 30{,}649$, $\eta_p^2 = .51$, $p < .01$, and participants responded more quickly in the single-task blocks than on stay trials in the mixed block, $F(1, 50) = 35.87$, $MSE = 3{,}561$, $\eta_p^2 = .42$, $p < .01$. Unlike the language-mixing results that exhibited a significant age-related increase in mixing costs, in the color-shape task, there was no age-related increase in mixing costs, $F(1, 50) = 1.04$, $MSE = 3{,}561$, $\eta_p^2 = .02$, $p = .31$.

Although the RTs did not exhibit an age-related increase in mixing costs, a robust age-related mixing deficit appeared in the error rates. Older bilinguals made more errors than young adult bilinguals, $F(1, 50) = 9.26$, $MSE = .005$, $\eta_p^2 = .16$, $p < .01$, and participants made more errors on stay trials in the mixed-block than in the single-task blocks, $F(1, 50) = 34.89$, $MSE = .001$, $\eta_p^2 = .41$, $p < .01$. In addition, there was a significant interaction between trial type and age group, such that older bilinguals made significantly more errors than young bilinguals, particularly on stay trials in the mixed block, $F(1, 50) = 8.76$, $MSE = .001$, $\eta_p^2 = .15$, $p = .01$.

Color-shape switching—Older bilinguals responded more slowly than young bilinguals, $F(1, 50) = 39.63$, $MSE = 47{,}952$, $\eta_p^2 = .44$, $p < .01$, and participants responded more slowly on switch than on stay trials, $F(1, 50) = 48.48$, $MSE = 1{,}813$, $\eta_p^2 = .49$, $p < .01$. Unlike the language-switching results, there was no indication of an age-related increase in switch costs; the interaction between age and trial type was not significant, $F(1, 50) = 1.76$, $MSE = 1{,}813$, $\eta_p^2 = .03$, $p = .19$.

Error analyses parallel the RT findings. Older bilinguals made more errors than young bilinguals, $F(1, 50) = 12.88$, $MSE = .01$, $\eta_p^2 = .21$, $p < .01$, and participants made more errors on switch than on stay trials, $F(1, 50) = 17.93$, $MSE = .002$, $\eta_p^2 = .26$, $p < .01$, but the interaction between age and trial type was not significant, $F(1, 50) = 2.03$, $MSE = .002$, $\eta_p^2 = .04$, $p = .16$.

Summary of color-shape task results—The pattern of aging deficits in the color-shape task was quite different from that seen in the language task. Although older bilinguals

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[2] In the analysis of mixing costs, older bilinguals were slower to make shape than color judgments, $F(1, 21) = 6.91$, $MSE = 3{,}824$, $\eta_p^2 = .25$, $p = .02$, whereas young bilinguals made shape and color judgments equally quickly ($p = .19$), a marginally significant interaction between decision type and age, $F(1, 50) = 3.60$, $MSE = 2{,}360$, $\eta_p^2 = .10$, $p = .06$). Greater difficulty with shape than with color decisions is sometimes also found in children (see Chevalier, Blaye, Dufau, & Lucenet, 2010; Ellefson, Shapiro, & Chater, 2006). The aging-related preference for color over shape could suggest a form of regressed functioning associated with older age. In the mixed-task block (switch cost analysis), young bilinguals exhibited significantly larger switch costs in making color than shape decisions, $F(1,29) = 8.56$, $MSE = 1{,}051$, $\eta_p^2 = .23$, $p = .01$, whereas older bilinguals exhibited similarly sized switch-costs for color as for shape decisions ($p = .39$). This finding might seem parallel to the above reported finding (see footnote 1) in which only young bilinguals showed a tendency towards a language mixing-cost asymmetry; however, it is not clear how to interpret the asymmetry of switch costs in young bilinguals with the color-shape task, given that they did not exhibit any task dominance effects (i.e., young bilinguals responded equally quickly in making color versus shape decisions).

responded more slowly than young bilinguals in both tasks, only the language task exhibited robust age-related increases in switching and mixing costs in RTs and a robust age-related increase in switching costs in the error rates. Conversely, in the color-shape task, there was no age-related increase in costs in RTs, and only mixing errors exhibited an age-related increase in costs. In addition, aging deficits seemed to be more pronounced for the color-shape task compared to the language control task, suggesting a relative preservation of language compared to nonlinguistic tasks in aging. For example, in the color-shape task, age-related slowing was significant across all three trial types (single, stay, and switch), whereas in the language task, slowing was restricted mostly to switch trials. To test if the apparently greater aging effect on the color-shape than the language task was significant, we compared the two tasks directly in two additional analyses.

Task Comparison: Color-Shape Versus Language

To compare aging effects across tasks we conducted 2 × 2 × 2 ANOVAs, with task (language, color-shape) and trial type (single vs. stay for the mixing analyses, and stay vs. switch for the switching analyses) as within-subject factors and age (young, older) as a between-subject factor. The contrast between tasks is illustrated in Figure 2.

The primary goal in these analyses was to answer two questions: (a) Is age-related slowing and the age-related increase in errors larger in one task than in the other (i.e., to look for interactions between age and task), and (b) is the age-related increase in switching and mixing costs significantly larger in one task than in the other (i.e., three-way interactions between age, task, and trial-type). To emphasize the main points, in this section we forgo the convention of reporting main effects, then two-way interactions (which were largely redundant with results already reported above), and then three-way interactions, and instead focus specifically on interactions between age and task.

Cross-task mixing effects—Of interest, age-related slowing was substantially greater in the color-shape task than in the language task, a highly robust crossover interaction between age group and task, $F(1, 50) = 28.19$, $MSE = 11{,}074$, $\eta_p^2 = .36$, $p < .01$. More specifically, aging caused a complete *task dominance reversal* such that older bilinguals named numbers more quickly than they made color-shape judgments ($p = .01$), whereas young bilinguals exhibited the opposite pattern (i.e., made color-shape judgments more quickly than they named numbers; $p < .01$). Turning to mixing costs, the three-way interaction between age, task-type, and mixing cost (trial type) was not significant ($F < 1$). Thus although the language task exhibited an age-related increase in mixing costs in the analyses above and the color-shape task did not, this difference between tasks did not approach statistical significance.

As for RTs, the age-effect on error rate was larger in the color-shape than in the language task, $F(1, 50) = 7.48$, $MSE = .002$, $\eta_p^2 = .13$, $p = .01$, although in this case it was not a cross-over interaction (both young and older bilinguals made more errors on color than on shape decisions). Of interest, the age-related deficit in mixing errors on the color-shape task was significantly larger than aging effects on mixing errors in the language task (which, as reported above, did not exhibit an age-deficit in mixing errors), a significant three-way interaction between age, task-type, and mixing cost, $F(1, 50) = 4.05$, $MSE = .001$, $\eta_p^2 = .08$, $p = .050$.

Cross-task switching effects—As just reported for the cross-task mixing costs comparison, there was again a significant task-dominance reversal in the analysis of switching costs; age-related slowing was significantly larger for the color-shape task than it was in the language task, $F(1, 50) = 28.19$, $MSE = 11{,}074$, $\eta_p^2 = .36$, $p < .01$. The three-way interaction did not approach significance ($F < 1$).

As for RTs, the age-effect on error rates was larger in the color-shape than in the language task, $F(1, 50) = 4.61$, $MSE = .004$, $\eta_p^2 = .08$, $p = .04$. Whereas young adults showed relatively equal error rates between tasks, older adults produced more errors in the color-shape task than in the language-switching task. The three-way interaction was not significant ($F < 1$).

Summary of task comparison—First, in both the mixing and the switching comparisons, and in both RTs and errors analyses, the color-shape task exhibited significantly larger aging effects than the language task. In the analysis of RTs, this was expressed in the form of a full task-dominance reversal across the aging contrast (i.e., with older bilinguals responding more quickly in the language task than in color-shape and young bilinguals responding more quickly in color-shape than in the language task). Second, comparing aging effects on switching and mixing costs across tasks, these were significantly larger in the color-shape than in language task only in the analysis of task-mixing effects on error rates.

Association Between Tasks via Inability to Do the Color-Shape Task in Some Older Bilinguals

The results reported thus far reveal many differences between the color-shape and language tasks. Above we reported that five aging bilinguals were unable to accurately complete the color-shape task despite multiple attempts at practice trials. However, these same five aging bilinguals were all able to complete the language task. This dissociation seems to confirm the hypothesis of separate control mechanisms for linguistic and nonlinguistic switching. In this final analysis, we probed for possible parallels in aging effects across tasks by considering if the five bilinguals who were unable to complete the color-shape task exhibited any evidence of a control deficit in their performance on the language task. To this end, we matched these five older bilinguals to 10 older bilinguals who were able to complete both tasks on age, education, and English and Spanish naming scores. To achieve this matching we included two older bilinguals who were excluded from the original analysis because of low education levels. Participant characteristics for bilinguals included in these comparisons are shown in Table 4.

On the hypothesis of partially shared control mechanisms for language and nonlinguistic tasks, we predicted that the older bilinguals who could not complete the color-shape task would exhibit relatively impaired language control, when compared to age- and education matched older bilinguals who were able to complete both tasks. The data for these analyses are shown in Figure 3 (because of the small number of participants in these analyses, we plotted the distribution of data points for each group in each condition; statistical comparisons are to be interpreted with caution).

In the analysis of language mixing effects, there were no significant main effects or interactions ($p \geq .16$). Aging bilinguals who could not do the color-shape task did not respond more slowly on single and stay trials and did not exhibit larger mixing costs, relative to matched controls. However, in the analysis of language-switching costs, there was a marginally significant main effect of group such that older bilinguals who could not do the color-shape task responded more slowly than matched controls in the mixed-language block, $F(1, 13) = 3.35$, $MSE = 106{,}876$, $\eta_p^2 = .20$, $p = .09$. Of greatest interest, older bilinguals who could not do the color-shape task exhibited significantly larger language-switching costs than matched bilinguals who were able to do both tasks, a significant trial type by group interaction, $F(1, 13) = 10.38$, $MSE = 2{,}812$, $\eta_p^2 = .44$, $p = .01$. It is important that the larger language switch costs for bilinguals who could not do the color-shape task were not the result of a speed–accuracy trade-off; there was no age by condition interaction in the error analyses of language-mixing ($p = .46$) and language-switching ($p = .90$).

The appearance of larger language-switching costs in aging bilinguals who could not do the color-shape task reveals an explicit connection between linguistic and nonlinguistic control and implies shared mechanisms underlying these processes.

General Discussion

The present study was designed to investigate the hypothesis of a domain-general control mechanism for language selection and non-linguistic task shifting by directly comparing aging effects on the two. Previous studies appeared to reveal a dissociation between aging effects across tasks with aging affecting mixing more than switching in studies of monolinguals performing nonlinguistic tasks (e.g., Mayr & Liebscher, 2001; for review see Wasylyshyn et al., 2011) and aging affecting language switching but not mixing in a voluntary language-switching paradigm (Gollan & Ferreira, 2009). However, left unanswered was the question of whether aging affects cued language mixing or not. The current data largely confirm the apparent dissociation between linguistic and nonlinguistic control; revealing an age-related increase in both language-mixing and language-switching costs and confirming that these aging effects were in some ways more robust for switching than for mixing. In contrast, in nonlinguistic task control, the same aging bilinguals exhibited a significant mixing deficit (in error rates) and no switching deficit, a result more typical of the aging literature on task switching. Summarizing the key findings, several differences and some more limited similarities were found in the comparison of aging effects on linguistic and nonlinguistic tasks.

Summary of Results

1. In the language task (see Table 2), there was an aging-related increase in mixing and switching costs in RTs, with switching more affected than mixing in errors. Older bilinguals showed significantly larger mixing and switching costs than young bilinguals, and this increase in costs survived an adjustment for older bilinguals' overall slower baseline response speed. Aging affected switching and mixing to the same extent in the analysis of RTs, but only the switching deficit was also robust in errors (i.e., older bilinguals failed to switch languages when cued to do so much more often than young bilinguals).
2. In the color-shape task (see Table 3), there was an aging-related increase in mixing cost errors only. In contrast with the language task, in the color-shape task, there was no age-related increase in switching and mixing costs in RTs. Instead, older bilinguals responded much more slowly than young bilinguals on all trial types and exhibited significantly larger mixing costs than young bilinguals in the error analyses.
3. There was larger aging-related slowing, a larger aging-related increase in errors, and a larger aging-related increase in mixing cost errors in color-shape than in language task. Although older bilinguals responded more slowly, and made more errors, than young bilinguals in both tasks, both of these main effects of aging were significantly larger in the color-shape than in the language task. In the analysis of RTs, this was expressed as a significant task-dominance reversal across the aging contrast; although the color-shape task was easier than the language-task for young bilinguals, the language task was easier than the color-shape task for older

bilinguals (see Figure 2).[3] The aging-related increase in mixing costs in errors was significantly larger in the color-shape task than in the language task (which exhibited an aging-related increase in mixing costs only in RTs).

4. The inability to do the color-shape task was associated with larger language-switching costs. Five older bilinguals who were unable to do the color-shape task were all able to do the language-switching task, but also exhibited significantly larger language-switching costs than matched older bilinguals who were able to do both tasks.

Theoretical Implications of Differences in Aging Effects Across Tasks

This summary of key findings reveals more differences than similarities in the aging effects observed across tasks. Furthermore, these differences were found even though the cross-task comparison was within subjects; that is, although the same young and older bilinguals completed both tasks, very different aging effects were found in each. Perhaps the most striking difference was that aging effects overall were greater on the color-shape than on the language task. This result was particularly apparent in the RTs, which exhibited task-dominance reversal across age groups (see Figure 2). This result, along with the finding that older bilinguals who could not do the color-shape task had no problem doing the language-switching task, suggests domain-specific control mechanisms and relatively spared language control in older age.

An important consideration, when interpreting the finding of greater aging effects on the color-shape than on the language task (here referring to main effects of slowing and increase in errors), is that it is not likely that this result was a simple function of task difficulty. In fact, it could be argued that the color-shape task was the “objectively easier” task if young bilinguals provide the means for judging task difficulty, given that young bilinguals responded more quickly in the color-shape task than in the language-task (see Figure 2). A priori it might have seemed that the language task should be objectively more difficult for all participants. Specifically, although the color-shape task had only two possible response options in the single-task and four possible responses in mixed-task blocks, the language task had nine possible responses in single-task blocks and 18 possible responses (1–9 in English or 1–9 in Spanish) in mixed-task blocks. Thus, it could be argued that the larger response set makes the language task objectively more difficult than the color-shape task.

A further difference across tasks was that although both tasks exhibited aging-related increases in costs, these varied across tasks in a manner that largely confirms a contrast that seemed apparent when reviewing the existing literatures on linguistic and nonlinguistic switching. In particular, in the language task, aging was associated with a highly robust increase in cued switching costs (in both errors and RTs), whereas mixing was more affected in the color-shape task. The vulnerability of switching rather than mixing in aging bilingual language control was further confirmed in an analysis that showed greater language-switching (but not mixing) costs in five older bilinguals who were unable to do the color-shape task. Taken together these findings point to a dissociation in control mechanisms across domains, with a vulnerability in language *switching* to the effects of aging and a vulnerability in nonlinguistic task *mixing* to the effects of aging (recent research on young bilinguals reveals similar dissociations between task and language control; Calabria, Hernández, Branzi, & Costa, 2011).

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[3] Note that in Prior & Gollan (2011), button mappings were displayed on the button box instead of on the computer screen, and in those conditions young bilinguals recruited from the same population responded more slowly in the color-shape than in the language task. Thus, this small change in method seems to have had a profound effect on overall RTs for the color-shape task (speeding responses for young bilinguals).

A further difference between tasks that deserves some comment is that only language switching exhibited significant age-related increases in switching and mixing costs in response times. It is important not to take the absence of an age-related increase in costs in RTs in the color-shape task as evidence of spared nonlinguistic task control in aging bilinguals. First, the error data revealed a significant age-related increase in mixing costs (ruling out the notion of fully intact nonlinguistic control). In addition, there may be trade-offs between aging effects on overall speed versus on costs; mixing and switching costs have been reduced in experimental settings by varying the timing of the cue display, which allows for increased preparation time (e.g., Meiran, 1996; Rogers & Monsell, 1995). In the color-shape task, older bilinguals may have slowed their rate of response execution to a point that was closer to the ceiling of possible costs associated with switching and mixing. The presence of slowing across all trial types in the color-shape task could reflect the joint consequences of increased difficulty with the tasks, reduced resources available for control processing in the context of a more difficult task, and decline in control processes.

In recent studies, slowed responses without an increase in switching costs have sometimes been interpreted as a relative advantage in task control. For example, one study reported that Spanish-English bilinguals with lower Socioeconomic Status (measured by parents' education level), responded more slowly overall than monolinguals but exhibited equivalent switch costs relative to monolinguals (Prior & Gollan, 2011). Similarly, in another study kindergarten-aged Spanish-English bilinguals performed equally well as their monolingual peers, and after controlling for verbal scores and parent education/income level, the bilinguals performed significantly better on tasks that require managing conflicting attentional demands such as the Attentional Network Task (Carlson & Meltzoff, 2008). In both studies, it was suggested that bilingualism offsets the effects of Socioeconomic Status. In the current study if we adjust for baseline response speed in the color-shape task, older bilinguals exhibited 9% (SD = .2%) switch costs and 10% (SD = .3%) mixing costs, and young bilinguals exhibited 8% (SD = 2%) switch costs, and 11% (SD = 2%) mixing costs, yielding nonsignificant aging effects on proportionally adjusted switching and mixing costs, p = .53 and p = .54, respectively. Thus, the lack of an age-related increase in switch and mix costs despite slower RTs in the color-shape task should certainly not be interpreted as an age-related advantage over young bilinguals in task control.

Although we observed differences between aging effects on the two tasks, the extent to which such differences challenge the hypothesis of shared-control mechanisms for linguistic and non-linguistic task control is inherently limited in some ways. Differences between tasks could arise for a variety of reasons that have little to do with control mechanisms and instead reflect other processes that are necessarily different across the two tasks. One noteworthy difference was the requirement to respond with button presses in the color-shape but not the language task. In previous studies, age-related slowing was always observed, but robust age deficits in costs were found only with overlapping mappings (e.g., Mayr, 2001). In the current study button mappings did not overlap in the color-shape task (i.e., each of the four possible responses was associated with one of four different buttons on the response box), but in the language-task, responses for both languages were produced by the same (overlapping) mouth. This could have introduced some apparent differences between tasks. Importantly, there was no requirement to memorize the button mappings (which were displayed at the bottom of the screen on every trial; see Figure 1). Additionally, the sandwich design allowed participants substantial practice with the button mappings for each task prior to the mixed-task block. Below we consider the possible effects of button responses in the color-shape but not the language task in greater detail.

Vulnerability of Language Switching in Aging: Language as an Expert Task

The current data add to an emerging body of evidence documenting reduced language control in aging bilinguals and pinpointing language switching as being particularly vulnerable to aging effects. The age-related decline in language switching was expressed both as an increase in switch costs in RTs and also as a failure to switch languages when cued to do so (for similar findings see Hernandez & Kohnert, 1999). The current study added a finding of a significant age-related increase in language-mixing costs (in RTs but not in errors), and this result contrasts with previous findings of intact language mixing for aging bilinguals in a voluntary switching paradigm (Gollan & Ferreira, 2009) and establishes an association between language-mixing deficits and being forced to select a language in response to a cue. As noted above, the presence of a robust switching deficit in aging language control seems to be different from aging effects observed in previous studies of task switching in monolinguals in which mixing deficits were often more robust than switching deficits in older age (for most recent review see Wasylyshyn et al., 2011). Some studies of aging monolinguals also revealed robust age-related increases in cued task-switching costs (e.g., Kray et al., 2002). Further investigation of the conditions that change the expression of age-related deficits in executive control (which sometimes appear as increased switching costs and other times as increased mixing costs) with changes in the experimental tasks are likely to reveal the mechanisms underlying both task and language control.

These considerations reveal the importance of interpreting costs and measures of executive control in the context of overall performance. Caution should be used when interpreting results with adjustments for baseline response speed, and presentation of results exclusively in the form of difference scores (costs) should be avoided as this practice can obscure important differences. Though the difference in the magnitude of age-related slowing across tasks is not expected on the assumption of shared mechanisms of control for linguistic and nonlinguistic task switching, strictly speaking we cannot rule out the possibility that the requirement of button responses (e.g., rather than spoken responses) or some specific difficulty with shape judgments in aging caused the larger aging effects.

To investigate if requirement to respond with button responses in the color-shape task but not in the language task may have spuriously caused differences between aging effects across the two tasks, we retested 12 of the older bilinguals (approximately 9 months after their initial participation; range 2 to 17 months) on a voice version of the color-shape task. In the voice version, participants were instructed to simply say the color or shape names (in whichever language they preferred). In the same testing session, participants also repeated the original tasks (i.e., the language task and color-shape with button press responses using the same button mappings as on the first testing session). The two color-shape versions were counterbalanced and either administered before or after the language task.

The data from this follow-up study are shown in Figure 4. Most notably, in the mixed-task block, response times on the second administration of the color-shape button-press task (single $M = 752$; stay $M = 788$; switch $M = 857$) were significantly slower than responses in the voice version of the color-shape task (single $M = 698$; stay $M = 731$; switch $M = 789$; $p \leq .03$), but switch and mix costs were not different across the two versions of the task (both Fs < 1). Thus, overall speed and the requirement to respond with button presses do *not* appear to determine the size of switch and mix costs. Also of interest, in both tasks, mixing costs, but not switching costs, were significantly smaller on the second testing session than on the first testing session. For the 12 older bilinguals who were tested a second time, language-mixing costs were 87 ms in the first testing session (single $M = 691$; stay $M = 788$; switch $M = 841$), and only 39 ms in the second testing session (single $M = 669$; stay $M = 708$; switch $M = 776$), a significant interaction between testing session and mixing-cost size,

$F(1, 11) = 7.09$, $\eta_p^2=.39$, $p = .02$. Similarly, in the color-shape task (button-press version), mixing-costs were 84 ms in the first testing session (single $M = 752$; stay $M = 836$; switch $M = 906$) and only 39 ms in the second testing session (see previous paragraph for means), a marginally significant interaction between testing session and mixing-cost size, $F(1, 11) = 3.66$, $\eta_p^2=.249$, $p = .08$. In contrast, switch costs did not change in size across testing sessions (both Fs < 1: 63 and 68 ms, respectively, for first and second testing sessions in the language task, and 70 and 69, ms, respectively, for first and second testing sessions in the color-shape task). These data seem to imply that mixing costs decrease with increasing experience with a task. This in turn might explain why age-related deficits in language control tend to appear in switching (a highly practiced task), whereas age-related deficits in nonlinguistic (and relatively less practiced) tasks tend to appear in mixing. These data increase confidence in our conclusion that aging differentially affects language and task control and that the differences we observed in aging effects across the two tasks were not an artifact of methodological differences in how we implemented the two tasks.

The differences we observed between tasks imply that there is not complete overlap between mechanisms of task and language control. A question of interest is whether or not anything else in the aging effects we observed can pinpoint the nature of sharing between nonlinguistic and linguistic control mechanisms.

Theoretical Implications of Similarities Between Aging Effects Across Tasks

Despite the striking differences in aging effects across tasks, we also observed some similarities between tasks that provide some clues as to the nature of shared control mechanisms that decline in concert as bilinguals age. One obvious place to look for similarities between language and task switching would be to look for evidence of reduced inhibitory control in aging bilinguals in both tasks. Inhibition has been proposed to play an important role in efficient task (Anderson, Reinholz, Kuhl, & Mayr, 2011; Mayr, Diedrichsen, Ivry, & Keele, 2006; see also Mayr & Keele, 2000) and language control (Green, 1998; Meuter & Allport, 1999; Philipp & Koch, 2009; but see Finkbeiner, Almeida, Janssen, & Caramazza, 2006), both of which may be achieved in part by inhibiting dominant responses as a means for allowing nondominant responses to be selected when cued. According to the Inhibitory Deficit Hypothesis (Hasher & Zacks, 1988), aging results in a reduction in inhibitory control mechanisms across all cognitive systems. Numerous studies have supported this hypothesis across domains such as language comprehension, episodic memory, and speech production (e.g., Connelly, Hasher, & Zacks, 1991; Hartman & Hasher, 1991; May, Zacks, Hasher, & Multhaup, 1999; but see, e.g., Burke, 1997; Graham & Burke, 2011; Mayr, 2001). If inhibitory control is impaired in older age, then older bilinguals would be less able to use inhibition for both task and language selection. In bilinguals, inhibition might be useful in tasks that require language mixing, to equalize the relative accessibility of the two languages that need to be produced (Gollan & Ferreira, 2009). Early studies of language switching revealed significant switch-cost asymmetries (with larger switch costs for the dominant language; Meuter & Allport, 1999), and this was taken as evidence for role of inhibition in bilingual language production (Green, 1998; Kroll, Bobb, Misra, & Guo, 2008). The young and older adult bilinguals in the current study were matched for bilingual language proficiency (using scores on a picture naming test) and thus were equally balanced in their knowledge of English and Spanish (see Table 1). Moreover, the possible relevance of inhibition for the present tasks does not seem as important (but see footnotes 1 and 2), given that language dominance and task dominance effects were not particularly strong in the current paradigms (e.g., bilinguals named numbers equally quickly in their two languages, and only older, but not younger, bilinguals were slower to make shape than color judgments).

One result in the present study simultaneously provides evidence for shared mechanisms of control for linguistic and nonlinguistic switching (i.e., domain-general control), but also demonstrates the relative preservation of language control in aging (i.e., domain-specific control): the finding that older bilinguals who could not do the color-shape task both (a) exhibited larger language-switching costs than matched aging bilinguals who were able to do the color-shape task and (b) were still able to do the language-switching task (see Figure 3; these findings are to be interpreted with caution given the small number of participants who were included in this comparison). The finding of a significant switching deficit for these participants demonstrates an explicit link between ability to perform the color-shape task and the magnitude of switch costs in the language task and points to a basic connection between linguistic and nonlinguistic switching. At the same time, the fact that these bilinguals were able to do the language-switching task with no more practice than young bilinguals, but could not perform the color-shape task despite multiple opportunities at slower paced practice trials reveals some fundamental differences between aging effects on the two tasks and suggests relatively sheltered and preserved language abilities in older age.

Conclusions

Direct comparisons of aging effects on linguistic and nonlinguistic switching and mixing reveal some striking differences between tasks and relative preservation of bilingual language processing in aging. Although the differences far outnumbered the similarities in aging effects observed across tasks, it is important to consider that many possible factors could produce differences between tasks and that it is difficult to pinpoint the differences specifically to control processes. Moreover, despite the many differences between tasks, some subtle but interesting parallels were also found, and these support the hypothesis that language selection is at least partially dependent on a general control system. Having found many differences but also some similarities in aging effects across the two tasks, the most likely conclusion to be drawn is that language control mechanisms overlap only partially with nonlinguistic control mechanisms. Similar conclusions were recently drawn in a study of aging effects on cross-language intrusion errors and correlations with a nonlinguistic flanker task (Gollan, Sandoval, & Salmon, 2011). However, to what extent the differences observed in the current study reflect specifics of the tasks that are necessarily different across domains, versus differences in underlying control mechanisms remains to be further explored.

A more general possible implication of the current data is that the nature of control processes may change or domain-specificity in control mechanisms may develop with task expertise (whether linguistic or nonlinguistic). On this view, language control may be distinct from nonlinguistic control precisely because language is a highly practiced (possibly “expert” system), rather than reflecting functionally independent specialized mechanisms of language control per se. Further investigation would be needed to explore the notion of language as an expert task; however, given that people use language constantly throughout every day of their lives, language might reasonably fit some proposed requirements for achieving expert ability on a task (e.g., Ericsonn & Lehmann, 1996). By exploring the possibility of at least some domain specificity in language control, research on bilingualism will contribute to longer standing debates concerning the extent to which cognitive control is domain-general versus domain-specific across other tasks as well (e.g., for reviews see Egner, 2008; Monsell & Driver, 2000).

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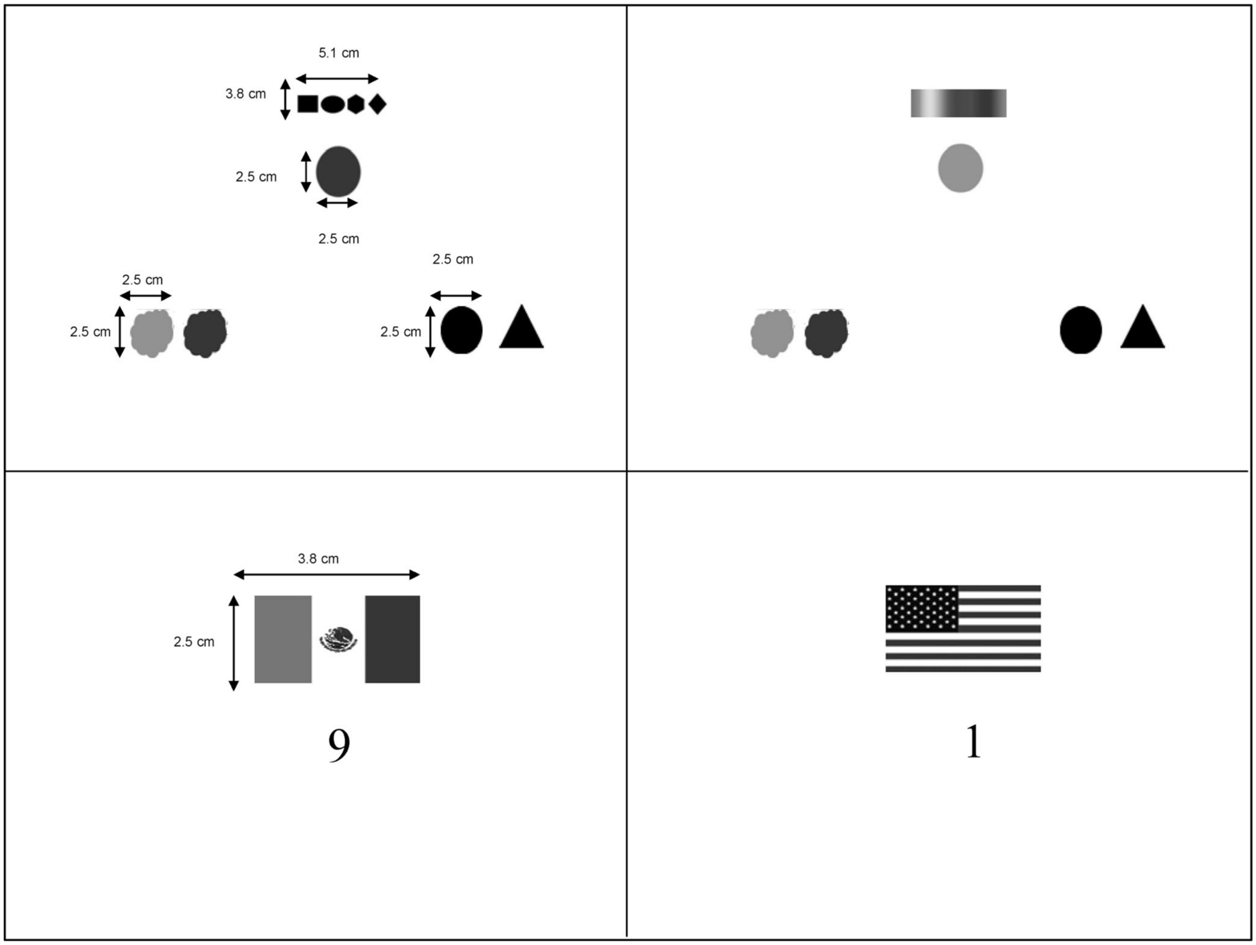

Figure 1.
Computer screen display for the color-shape task (top panel) and language-switching task (bottom panel). Top left and bottom left panels indicate the size of each feature. Images appeared in color during actual task.

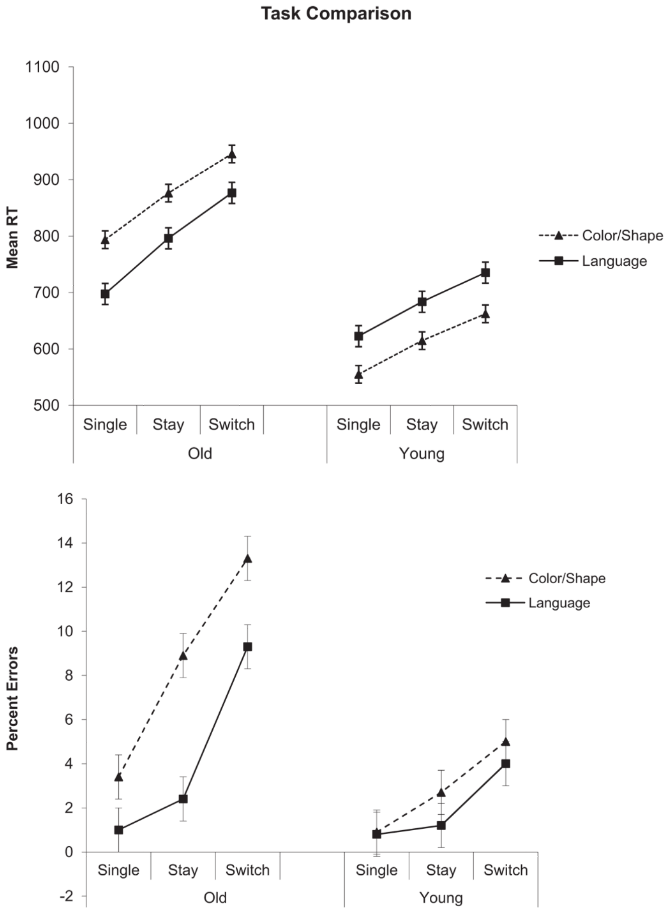

Figure 2.

Mean RTs (ms) and proportion of errors for single, stay, and switch trials in the cross-task comparison (collapsed across dominance within each task).

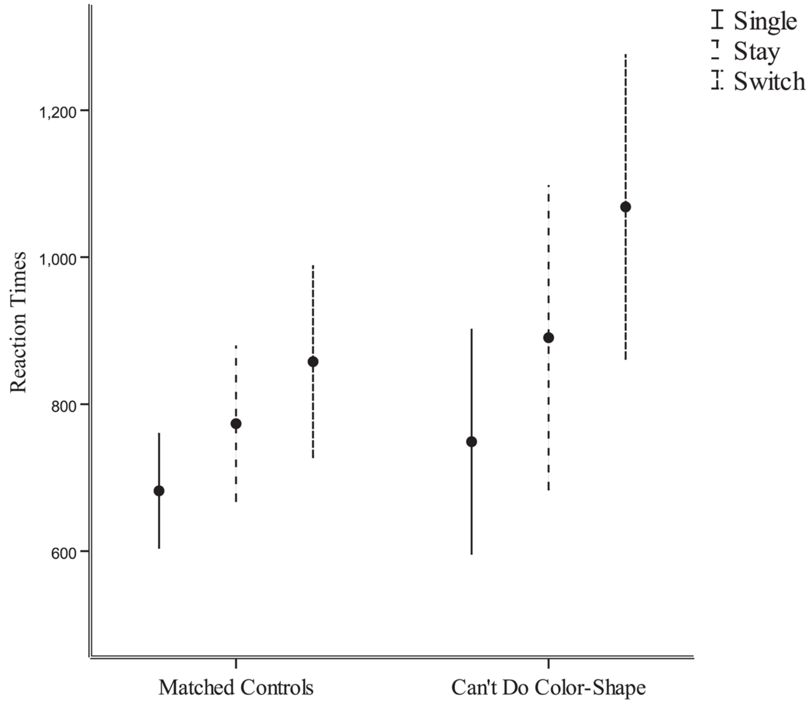

Figure 3.
Distribution of reaction times (ms) for naming numbers in the language task for older bilinguals who could not complete the color-shape task and matched controls.

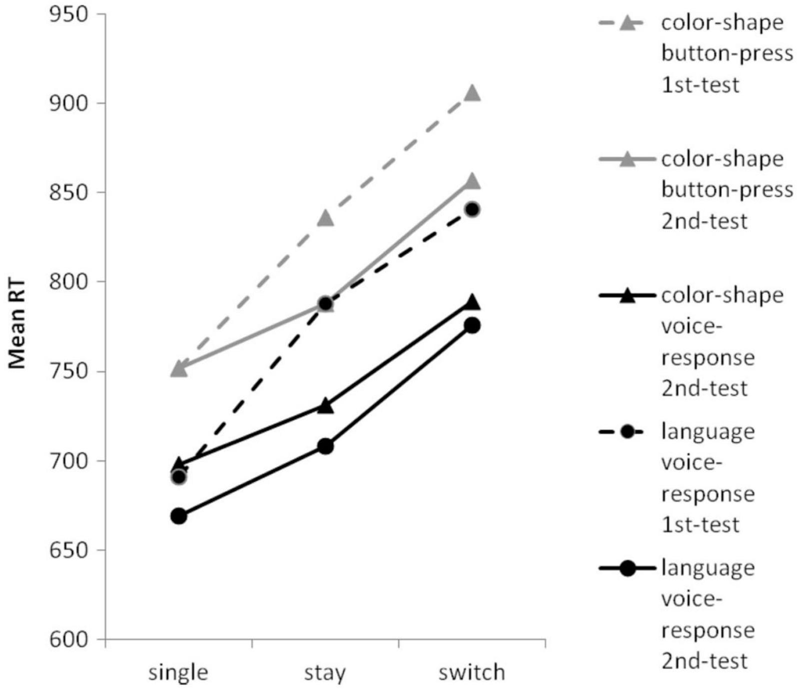

Figure 4.

Mean RTs (ms) for single, stay, and switch trials for 12 bilinguals tested in a first testing session on the color-shape task with button-press responses and the language-task with voice responses and for repeated testing on both tasks in a second testing session as well as a voice-response version of the color-shape task.

Table 1

Participant Characteristics for Young and Older Bilinguals Who Were Able to Complete Both Linguistic and Nonlinguistic Switching Tasks

	Young bilinguals (*n* = 30)		**Older bilinguals (*n* = 22)**	
	M	***SD***	***M***	***SD***
Age	20.7	2.2	75.6**	8.7
% Female	73.3%	N/A	73.0%	N/A
Education	14.1	1.1	14.0	2.2
Age first exposure to English	4.0	3.3	6.6*	5.8
Age first exposure to Spanish	0.4	1.3	2.0	8.0
% Currently using Spanish	24.2	17.4	28.7	26.4
% Grow up using Spanish	45.8	19.3	58.0†	32.9
How often speak to bilinguals currently[a]	2.7	1.3	2.7	1.1
How often speak to bilinguals growing up[a]	3.0	1.5	2.4	1.3
DRS	N/A	N/A	136.8	4.2
MMSE	N/A	N/A	28.3	1.7
MINT English percent correct	88.9	6.8	88.7	11.8
MINT Spanish percent correct	73.9	12.2	76.9	12.6
Self-ratings[b]				
English speak	6.5	0.7	5.9*	1.2
English listen	6.7	0.6	6.1*	1.3
English write	6.5	0.8	5.8*	1.4
English read	6.8	0.6	6.1**	1.0
Spanish speak	6.2	0.9	5.8	1.2
Spanish listen	6.0	1.0	5.4†	1.7
Spanish write	5.3	1.2	5.0	1.8
Spanish read	6.6	0.6	6.0*	1.1

Note. DRS = Dementia Rating Scale; MMSE = Mini Mental State Examination; MINT = Multilingual Naming Test.

[a] The following 7-point scale was used: 1 = *rarely or never*, 2 = *less than 1 hr/day*, 3 = *about 1 hr/day*, 4 = *about 2 hr/day*, 5 = *about 3– 4 hr/day*, 6 = *about 5 hr/day*, and 7 = *6 or more hr/day.*

[b] Self-ratings were based on a 7-point scale: 1 = *almost none*, 2 = *very poor*, 3 = *fair*, 4 = *functional*, 5 = *good*, 6 = *very good*, and 7 = like native speaker.

† Marginally significant *t* test comparing older adults to young adults ($p < .10$).

* Significant *t* test comparing older adults to young adults ($p < .05$).

** Significant *t* test comparing older adults to young adults ($p < .01$).

Table 2

Mean and Standard Deviation by Participant Group and Condition for the Language Task

		Language task RTs							
		Single		**Stay**		**Switch**			
Participant group	**Language**	***M***	***SD***	***M***	***SD***	***M***	***SD***	**Mix cost**	**Switch cost**
Older bilinguals	Dominant	685	86	784	150	874	172	99	90
	Nondominant	710	118	808	152	879	176	98	71
	Difference	25		24		5			
Young bilinguals	Dominant	616	58	688	116	740	115	72	52
	Nondominant	630	76	679	104	731	114	49	52
	Difference	14		−9		−9			

		Language task percent errors							
		Single		Stay		Switch			
Participant group	Language	*M*	*SD*	*M*	*SD*	*M*	*SD*	Mix cost	Switch cost
Older bilinguals	Dominant	1.5	0.1	2.0	0.1	9.0	0.1	0.5	7.1
	Nondominant	0.6	0.0	2.8	0.0	9.5	0.1	2.2	6.7
	Difference	−0.9		0.8		0.5			
Young bilinguals	Dominant	0.6	0.0	1.0	0.0	3.7	0.1	0.4	2.7
	Nondominant	0.9	0.0	1.4	0.0	4.3	0.1	0.4	3.0
	Difference	0.3		0.3		0.6			

Note. RT = reaction time.

Table 3

Mean and Standard Deviation by Participant Group and Condition for the Color-Shape Task

		Nonlinguistic task RTs							
		Single		**Stay**		**Switch**			
Participant group	**Language**	***M***	***SD***	***M***	***SD***	***M***	***SD***	**Mix cost**	**Switch cost**
Older bilinguals	Color	781	118	854	181	937	173	74	82
	Shape	806	124	898	212	955	204	92	57
	Difference	25		44		18			
Young bilinguals	Color	556	90	605	123	670	146	50	65
	Shape	555	93	624	133	654	149	69	30
	Difference	−1		19		−16			

		Nonlinguistic task percent errors							
		Single		Stay		Switch			
Participant group	Language	*M*	*SD*	*M*	*SD*	*M*	*SD*	Mix cost	Switch cost
Older bilinguals	Color	3.4	0.1	6.4	0.1	12.7	0.1	3.0	6.4
	Shape	3.4	0.1	11.5	0.1	13.9	0.1	8.1	2.4
	Difference	0.0		5.1		1.1			
Young bilinguals	Color	1.1	0.0	2.8	0.0	5.8	0.1	1.8	3.0
	Shape	0.8	0.0	2.6	0.1	4.1	0.0	1.9	1.5
	Difference	−0.3		−0.2		−1.7			

Note. RT = reaction time.

Table 4

Participant Characteristics for Older Adults Who Could Not Complete the Color-Shape Task and Matched Controls

	Older bilinguals who could not do color-shape task (n = 5)		**Matched controls (n = 10)[a]**	
Characteristics	***M***	***SD***	***M***	***SD***
Age	80.8	6.4	78.2	6.7
% Female	80.0	N/A	70.0	N/A
Education	10.6	1.9	12.4	3.6
Age first exposure to English	6.5	4.7	12.2	7.1
Age first exposure to Spanish	0	0	0	0
% Currently using Spanish	53.0	19.9	52.0	32.5
% Use of Spanish in childhood	76.0	25.1	83.4	20.7
How often speak to bilinguals currently[b]	3	1.4	2.6	1.0
How often speak to bilinguals in childhood[b]	3.5	0.7	2.3	1.5
DRS	134.5	2.6	136.5	4.0
MMSE	27.6	2.6	28.6	1.7
MINT English percent correct	81.5	8.5	86.5	7.4
MINT Spanish percent correct	80.6	6.0	87.5	7.7
Self-ratings[c]				
English speak	5.4	1.1	5.2	1.2
English listen	5.2	0.4	5.3	1.7
English write	4.2	1.9	4.9	2.0
English read	5.8	0.8	5.7	1.2
Spanish speak	6.1	1.0	6.5	0.8
Spanish listen	5.6	2.1	6.4	1.1
Spanish write	5.6	2.1	6.2	0.9
Spanish read	6.2	0.8	6.5	1.0

Note. DRS = Dementia Rating Scale; MMSE = Mini Mental State Examination; MINT = Multilingual Naming Test.

[a] No significant differences were found between the older adults who could not complete the color-shape task and their matched controls on any of the variables listed (all ps ≥ .10). They differed marginally on Spanish naming scores (p = .10), in which matched controls did slightly better on the Spanish portion of the MINT. They also differed marginally on age of first exposure to English (p = .13), in which the matched controls learned Spanish slightly later in life.

[b] The following 7-point scale was used: 1 = *rarely or never*, 2 = *less than 1 hr/day*, 3 = *about 1 hr/day*, 4 = *about 2 hr/day*, 5 = *about 3–4 hr/day*, 6 = *about 5 hr/day*, and 7 = *6 or more hr/day*.

[c] Self-ratings were based on a 7-point scale: 1 = *almost none*, 2 = *very poor*, 3 = *fair*, 4 = *functional*, 5 = good, 6 = very good, and 7 = like native speaker.