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Cross-Language Intrusion Errors in Aging Bilinguals Reveal the Link Between Executive Control and Language Selection

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Abstract

Bilinguals outperform monolinguals on measures of executive control, but it is not known how bilingualism introduces these advantages. To address this question, we investigated whether language-control failures increase with aging-related declines in executive control. Eighteen younger and 18 older Spanish-English bilinguals completed a verbal-fluency task, in which they produced words in 18 categories (9 in each language), and a flanker task. Performance on both tasks exhibited robust effects of aging, but cross-language and within-language errors on the verbal-fluency task differed in a number of ways. Within-language errors occurred relatively often and decreased with higher levels of education in both younger and older bilinguals. In contrast, cross-language intrusions (e.g., inadvertently saying an English word on a Spanish-language trial) were rarely produced, were not associated with education level, and were strongly associated with flanker-task errors in older but not younger bilinguals. These results imply that executive control plays a role in maintaining language selection, but they also suggest the presence of independent forces that prevent language-selection errors.

Keywords

aging; bilingualism; lexical access; attention; frontal lobe

Every once in a blue moon, bilinguals accidentally slip a word from one language into something they are saying in another language. Such cross-language intrusions differ markedly from intentional code switches, which occur frequently and often involve nouns (e.g., "How about a *cerveza*?" instead of "How about a beer?"). Unintended cross-language intrusions, which often involve closed-class words (e.g., "*Pues* … I don't know" for "Well … I don't know" or "I mean … *ése*!" for "I mean … that one!"), are rare in spontaneous speech (Poulisse, 1999) and in the laboratory. In a previous study, young bilinguals virtually never produced cross-language intrusions—when tested in their dominant-language, only 1 out of 24 bilinguals made such intrusions; even when tested in both languages, less than half of the bilinguals produced cross-language intrusions (Sandoval, Gollan, Ferreira, & Salmon, 2010). The rarity of these intrusions is surprising given theories that characterize language

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production as a basically competitive process (e.g., Levelt, Roelofs, & Meyer, 1999) and given evidence of interference when monolinguals produce synonyms (Jescheniak & Schriefers, 1998; Peterson & Savoy, 1998). Whereas same-language synonyms can be produced interchangeably, words with equivalent meanings in different languages usually cannot be (unless bilinguals who know the same languages are conversing). The fact that bilinguals can speak in one language with little to no intrusion from their other language implies that powerful language-control mechanisms exist—and could even suggest that there are specialized mechanisms of language control (Costa, Miozzo, & Caramazza, 1999).

However, recent evidence suggests that bilinguals use general control mechanisms to achieve language-selective production (Green, 1998); bilinguals outperform monolinguals on cognitive-control measures (Bialystok, Craik, Green, & Gollan, 2009), such as the flanker task (Costa, Hernández, & Sebastián-Gallés, 2008). In the flanker task, participants indicate the direction a center arrow points when it is flanked by arrows pointing in the same direction (congruent trials) or when it is flanked by arrows pointing in the opposite direction (incongruent trials). In the latter case, flanking arrows must be ignored while attention is focused exclusively on the center arrow (Fan, McCandliss, Sommer, Raz, & Posner, 2002). Researchers have speculated that bilinguals' speed advantage on this task may reflect their constant need to monitor which language they speak with whom (Costa, Hernández, Costa-Faidella, & Sebastián-Gallé, 2009).

The proposal that bilingual language control relies on general control mechanisms predicts that cross-language intrusion errors should increase as executive control declines in older age. Brain regions that support executive control (e.g., see Braver, Reynolds, & Donaldson, 2003; Fan, Flombaum, McCandliss, Thomas, & Posner, 2003) and language control (e.g., see Abutalebi et al., 2008; Crinion et al., 2006) are vulnerable in aging (e.g., Raz, 2000). Although aging bilinguals exhibit relatively less decline on some tests of executive control than aging monolinguals do (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004), when such decline occurs in bilinguals, it should be associated with decline in language control.

Surprisingly little is known about whether language control changes with aging. In cued language switching, older bilinguals more often failed to switch languages when cued to do so, and exhibited greater costs in response times, than younger bilinguals did (Hernandez & Kohnert, 1999). However, in voluntary language switching, age effects on switching were small, and language mixing was intact (Gollan & Ferreira, 2009). The finding of intact voluntary language control in older bilinguals could imply specialized mechanisms of language control (Costa & Santesteban, 2004) that remain sheltered from age-related decline. If such mechanisms exclusively control language selection, cross-language intrusion errors might not increase in aging. Alternatively, if language control even just partially relies on executive control, then intrusions should increase as executive control declines in aging. In the study reported here, we tested whether failures of language control were associated with increasing age and with flanker-task performance.

Method

Participants

Eighteen older Spanish-English bilinguals participated in the study. Eleven were recruited from control participants at the Alzheimer's Disease Research Center at the University of California, San Diego (UCSD). Participants were diagnosed as cognitively intact by two neurologists on the basis of medical, neurological, and neuropsychological exams. The other 7 of the 18 older bilinguals were recruited from the San Diego area and were classified as cognitively intact on the basis of reported daily activities, scores on the Dementia Rating

Scale (DRS; Mattis, 1988), and scores on the Mini Mental Status Examination (Folstein, Folstein, & McHugh, 1975).[1]

Forty-seven younger Spanish-English bilingual college students were recruited at UCSD. Eighteen of these younger bilinguals were matched to the older bilinguals for age of acquisition and degree of reported daily use of both languages. On average, the older bilinguals were less educated than the younger bilinguals and rated their language proficiency as lower (see Table 1 for characteristics of both groups of participants).

Materials and procedure

Participants performed a flanker task and a verbal-fluency task (task order was counterbalanced). Stimuli were presented using PsyScope 1.2.5 software (Cohen, MacWhinney, Flatt, & Provost, 1993) on a MacBook Pro laptop with a 15-in. display.

Flanker task—The flanker task we administered was adapted from Fan et al. (2002). Targets were 48 congruent displays (five arrows pointing in the same direction), 48 neutral displays (a single arrow flanked by lines without arrowheads), and 48 incongruent displays (a center arrow flanked by two arrows on each side pointing in the opposite direction). Incongruent displays were evenly divided between left- and right-pointing center arrows. To increase difficulty (and possibly sensitivity to bilingual effects) relative to the original flanker task, we evenly presented stimuli in each trial type on the center, left, or right sides of the screen (creating double incongruence on some trials, for example, when a target consisting of a left-pointing center arrow flanked by right-pointing arrows appeared on the right side of the screen). Trials were preceded by a location cue (a procedure that produced the largest speed advantage when comparing bilinguals to monolinguals in Costa et al., 2008). Trials of each type (congruent, neutral, and incongruent displays each presented on the left, right, and center of the screen) were presented at least once in a random order before any type was repeated.

At the start of each trial, a central fixation point appeared for 800 ms; after 400 ms, the fixation point was accompanied for 100 ms by a location cue. After 800 ms, the target stimulus appeared for 1,700 ms or until a response was made. The intertrial interval was 1,700 ms. Participants pressed a button on the left or right of a button box to indicate the direction in which the center arrow was pointing. Practice blocks began with six neutral trials, followed by six congruent trials, then six incongruent trials, and ended with nine trials with equal numbers of the different trial types presented in a random order.

Verbal-fluency task—The fluency task we administered is used widely in clinical settings, is sensitive to bilingualism (Grogan, Green, Ali, Crinion, & Price, 2009), and may be particularly sensitive to between-language interference (Sandoval et al., 2010). In this task, speakers are given 60 s to produce members of semantic categories (e.g., animals) or letter categories (e.g., words that start with *S*). In our study, semantic categories included musical instruments, adjectives, supermarket items, colors, sports, country names, animals, occupations, nouns, and fruits and vegetables. Semantic categories were counterbalanced across languages between participants. Letter categories were words that start with *F*, *A*, *S*, and *L* in English and words that start with *P*, *M*, *R*, and *D* in Spanish (not counterbalanced

[1]Scores on the DRS ($M = 134.3$, $SD = 4.3$) were somewhat low relative to scores of highly educated, cognitively intact monolingual English speakers. This could have been due to a bilingual disadvantage (Gollan, Montoya, & Werner, 2002), the difference in the translation of the test (Peña, 2007) for the 7 bilinguals who preferred to be tested in Spanish instead of English, or the relatively lower education level for some bilinguals in this cohort (the correlation between education level and DRS scores was highly robust, $r = .763$, $p < .01$). Older bilinguals' scores on the Mini Mental Status Examination were within normal limits ($M = 28.7$, $SD = 1.7$).

because *F*, *A*, and *S* and *P*, *M*, and *R* are matched for difficulty between languages; Artiola, Fortuny, Heaton, & Hermosillo, 1998).

Bilinguals completed nine categories (five semantic, four letter) in English first, followed by nine categories in Spanish. Within each language, categories were administered in a different random order for each bilingual. Testing was done in English first to minimize language switching, given that English is the dominant language in the participants' environments. Instructions in English preceded English trials, and instructions in Spanish preceded Spanish trials.

Results

Flanker task

Table 2 shows response times (RTs), actual errors (incorrect button presses), and time-out errors (trials on which participants failed to respond before 1,700 ms) on the flanker task. RTs under 250 ms were excluded from analysis (eliminating < 1% of correct responses). Screen location did not interact with any of the effects of interest (error rates were lower in the center of the screen and about equally high on either side of the screen for all flanker types); thus, results were collapsed across this variable. One older bilingual could not perform the flanker task on practice trials, despite multiple attempts, and thus did not participate in actual trials.

Among older bilinguals, significant flanker-interference effects (the difference between incongruent and neutral trials) were observed in RTs and time-out errors (both *p*s < .01), and also in actual errors ($p = .03$). Among younger bilinguals, significant flanker-interference effects were observed in RTs and time-out errors (both *p*s < .01), but not in actual errors ($p = .48$).

RTs for correct responses and error rates (collapsing actual errors and time-out errors) were submitted to two analyses of variance (ANOVAs) with flanker type as a repeated factor. Older bilinguals responded more slowly than matched younger bilinguals, $F(1, 33) = 82.34$, $MSE = 61{,}744$, $\eta_p^2 = .71$, $p < .01$, and responses were slower on incongruent than on congruent or neutral trials, $F(1, 33) = 64.03$, $MSE = 7{,}622$, $\eta_p^2 = .66$, $p < .01$; however, age-related slowing was equivalent across trial types ($F < 1$; but time-out errors revealed a significant interaction with age group). Older bilinguals also made significantly more errors than younger bilinguals did, $F(1, 33) = 21.51$, $MSE = 0.067$, $\eta_p^2 = .40$, $p < .01$. In both groups, error rates were highest on incongruent trials, $F(1, 33) = 38.64$, $MSE = 0.003$, $\eta_p^2 = .54$, $p < .01$, but this was particularly so for older bilinguals, $F(1, 33) = 30.91$, $MSE = 0.003$, $\eta_p^2 = .48$, $p < .01$.

Verbal-fluency task

In semantic categories, superordinate exemplars (e.g., bird) were credited only if no subordinate exemplars (e.g., mocking bird) were produced. Within-language errors included perseverations (repetitions), malapropisms (nonwords that sound similar to existing words; e.g., "persinnamon" on a fruits-and-vegetables trial, or "fonoramic" on an *F*-words trial), instruction violations (e.g., morphological variants, such as "sit" and "sat," or proper names, such as "Frances"), and intrusions (e.g., "Hawaii" on a countries trial). Any response in the nontarget language was considered a cross-language intrusion (e.g., "octopus" instead of "pulpo" on an animals trial in Spanish, or "arriba" on an English *A*-words trial).

Table 3 shows raw numbers of responses and the percentage of each response type, thus characterizing errors as a function of total fluency. For example, production of two cross-language intrusions in 200 responses is a 1% intrusion rate (2/200 × 100), whereas two

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intrusions among only 100 responses is a 2% intrusion rate (2/100 × 100). Bilinguals in both groups rarely produced cross-language intrusions (2 older bilinguals produced none, and the rest produced between one and four errors, for a total of 31 intrusions in the entire data set). Thus, in looking for age effects on cross-language intrusions, we collapsed across all 18 categories (five semantic and four letter in both English and Spanish).

Older bilinguals made significantly fewer correct responses and significantly more within-language and cross-language intrusion errors than did younger bilinguals (see Table 3). However, older bilinguals were less educated than younger bilinguals. To address this confound, we conducted an analysis of covariance (ANCOVA) looking at age effects on cross-language intrusion rates, with years of education as a covariate and including all 47 younger and 18 older bilinguals tested. This analysis revealed significant age effects on both raw numbers of cross-language intrusions ($p = .02$) and percentage of cross-language intrusions ($p = .01$), but only marginal effects of education level on these two variables ($p = .07$ and $p = .09$, respectively). In a second analysis, we matched 10 older bilinguals on a subject-by-subject basis with 10 younger bilinguals who produced a similar number of correct responses in English and Spanish (both ps ≥ .73). These fluency-matched subgroups did not differ in self-reported proficiency level in either language (both ps ≥ .27). But older bilinguals produced significantly more raw numbers of cross-language intrusion errors ($p = .01$) and a significantly greater percentage of crosslanguage intrusion errors ($p = .04$) than their fluency-matched young bilingual counterparts. Thus, age effects on crosslanguage intrusion rates were not driven by education level (see also correlations in Tables 4 and 5).

Age effects on other response types also were robust after correcting for the education confound. An ANCOVA with age group as the predictor, education as a covariate, and within-language errors as the dependent variable revealed significant age and education effects on raw numbers of within-language errors and percentage of within-language errors (ps < .01). The age effect on within-language errors was also highly robust when comparing the fluency-matched subgroups ($p < .01$). Finally, in an ANCOVA with age group as the predictor, education as a covariate, and correct responses as the dependent variable, age and education effects on raw numbers of correct responses were not significant (ps ≥.15), but both age and education effects were highly robust on percentage of correct responses (ps < .01).

Age-by-flanker-task analyses

To determine whether the significant age effects on both the flanker task and cross-language intrusions were related, we examined age and flanker-task errors on incongruent trials in a multiple regression. The primary goal of this analysis was to determine whether flanker-task performance was related to language-control failures independently of age effects. The hypothesis that language control relies on nonlinguistic mechanisms of executive control would be most strongly supported if flanker-task performance explained unique variance in predicting the rate of language-control failures. To test this hypothesis, we conducted a multiple regression analysis with age (as a categorical variable coded with 1s and −1s) and flanker-task errors on incongruent trials (as a continuous variable) using data from the 17 older bilinguals who were able to complete the flanker task and from matched younger bilinguals (see Table 1). Consistent with the hypothesized relationship between executive control and language control, the results of this analysis revealed a significant effect of flanker task, $\beta = 0.709$, $p < .01$, but not of age, $\beta = -0.117$, $p = .54$, on cross-language intrusion errors. Thus, when age and flanker-task errors are considered together, only flanker-task errors significantly predict cross-language intrusion errors.

There was also some indication of an interaction between age and flanker-task errors, such that flanker-task errors might predict cross-language intrusion rates in older bilinguals but not in younger bilinguals. To examine this possibility, we created an interaction term by first centering the continuous predictor (flanker-task errors; Aiken & West, 1991) and then multiplying the centered predictor by the codes in the age-contrast predictor. In this analysis, none of the three individual predictors were significant, but their interaction approached significance ($p = .11$). To increase statistical power (Cohen, 1988), we repeated the analysis using data from all 47 younger bilinguals (and 17 older bilinguals, as in the previous analysis). We found a marginally significant main effect of age, $\beta = 0.277$, $p = .05$, and no significant main effect of flanker-task errors, $t < 1$, but a highly robust effect for the interaction between age and flanker-task errors, $\beta = 0.486$, $p < .01$.

Correlations between the flanker and verbal-fluency tasks

To further explore the apparent interaction between flanker-task errors and age as a predictor of failures of language control, we examined the correlations between flanker-task performance and fluency measures separately by age group. Tables 4 and 5 show correlations between verbal-fluency measures and performance on incongruent trials of the flanker task. Confirming the previously noted age effects on cross-language intrusion rates, the correlations show that increased age within the older bilingual group was associated with significantly higher rates of cross-language intrusions. Additionally, confirming the previously noted interaction between age and flanker-task errors in older bilinguals, but not in younger bilinguals, cross-language intrusions were strongly correlated with flanker-task errors. In fact, in older bilinguals, cross-language intrusions seemed to be more strongly predicted by flanker-task errors than by age.

Because age and flanker-task error rates were correlated in older bilinguals, we considered whether each variable explained any unique variance in predicting cross-language intrusions. When entered simultaneously into a linear regression, flanker-task errors were a significant predictor of cross-language intrusion rates in older bilinguals, $\beta = 0.69$, $p = .01$, but age (entered as a continuous predictor) was not, $\beta = 0.06$, $t < 1$. Flanker-task errors were not the strongest predictor of every fluency outcome in older bilinguals; looking at within-language errors, for example, education level was a significant predictor, $\beta = -0.54$, $p = .03$, with more educated bilinguals producing fewer within-language errors (see also Table 4); however, flanker-task errors did not predict within-language errors, $\beta = 0.23$, $p = .33$. These analyses are to be interpreted with caution given the small number of participants; with a larger number of older bilinguals, independent effects of age on cross-language intrusions might emerge. That said, these analyses increase confidence in the relationship between the flanker task and bilingual language control; this relationship seems to be quite strong (and is certainly not driven exclusively by age effects).

In younger bilinguals, neither age nor the flanker-task measures predicted cross-language intrusion rates. However, the older college students naturally had significantly higher education levels than the younger college students, and increased age and university attendance was associated with improvements in within-group fluency performance (e.g., more correct responses and fewer within-language errors). Finally, the lack of a relationship between flanker-task errors and cross-language intrusion errors in younger bilinguals was confirmed when we included data from all 47 younger bilinguals tested (in which flanker-task errors on incongruent trials ranged from 0 to 35%; if anything, this correlation trended in the wrong direction, $r = -.25$, $p = .09$).

Discussion

The results reported here demonstrate a specific link between language control and performance on a nonlinguistic flanker task, but they also illustrate some powerful limitations on the role of executive control in language selection. Of primary interest is the fact that in older bilinguals, cross-language intrusion rates increased with age and also with error rates on incongruent flanker-task trials (Fig. 1; see also Table 4). However, for both younger and older bilinguals, the rate of cross-language intrusion errors was extremely low (between 0 and 3%; see Fig. 1 and Table 3). Additionally, within-language errors seemed to be influenced by different mechanisms; such errors increased with lower levels of education relatively more than with flanker-task errors (see Tables 4 and 5).

To a large extent, the age effects observed here were found both when contrasting younger with older bilinguals and when looking within the older bilingual group. Each of these approaches had its advantages. The age-group contrasts provided more power for some of the analyses of interest and revealed some striking age effects that could not have been seen without testing younger bilinguals. Most notable in this regard was the contrast between younger and older bilinguals in the flanker task, which was difficult only for older bilinguals; none of the 47 younger bilinguals tested performed in the range at which failures of language-control begin to increase (the age-related increase in errors was particularly large on incongruent trials).

Additionally, the relationship between flanker-task errors and failures of language control was driven entirely by older bilinguals, for whom higher flanker-task error rates were associated with higher cross-language intrusion rates. In contrast, younger bilinguals seemed to all perform the flanker task well enough that even those who had a relatively high error rate (relative to their peers) had intact language control. It is important to note that the absence of a relationship between flanker-task errors and cross-language intrusion rates in younger bilinguals need not imply that only older bilinguals rely on general mechanisms of executive control for nontarget language production. Previously reported bilingual advantages on the flanker task imply that this relationship exists across the life span and that complete failures of language control arise only at a certain level of decline in function.

By itself, the age effect on cross-language intrusion rate could be questioned on grounds that the older members of the older bilingual group (the old-old members) may be more inclined to ignore the instruction to produce words in the target language than are the younger members of the older group (the young-old members). Pragmatically, it makes more sense to use both languages when communicating with a bilingual experimenter (Grosjean, 2008). More telling in this regard was that flanker-task errors also predicted cross-language intrusion rates, and, if anything, cross-language errors seemed to be more related to flanker-task errors than to age when all three variables were considered simultaneously in a regression. The strong association between flanker-task errors and cross-language intrusions increases confidence that these intrusions are true failures of language control.

Considering results exclusively within the older bilingual group largely confirms conclusions drawn by comparing the younger with the older group: The continuous effects of age and flanker-task errors on cross-language intrusions indicate that aging leads to increased failures of bilingual language control. These results support the hypothesis that regions of the brain that support executive-control processes are vulnerable to aging; these findings also support claims that bilinguals rely on general mechanisms of nonlinguistic executive control for language selection. In particular, the continuous-age effects within the older bilingual group increase confidence that the conclusions drawn from the contrast between younger and older bilinguals reflect age-related cognitive decline and are not an artifact of age-group differences.

An important consideration is whether flanker-task errors might reflect overall cognitive ability rather than executive-control functionality specifically; indeed, some older bilinguals produced errors on more than 50% of the incongruent trials on the flanker task. It is important to note that older bilinguals' mean rate of actual (rather than time-out) errors on incongruent trials was only 17.8% (see Table 2), and overall error rate across all trial types was much better than chance levels (25%). Perhaps most important, in older bilinguals, both actual errors ($r = .501$, $p = .04$) and time-out errors ($r = .642$, $p = .01$) were significantly correlated with cross-language intrusion errors, and older bilinguals exhibited highly robust flanker-task effects in all measures. Finally, within-language errors occurred much more often than cross-language intrusions (see Fig. 2), but flanker-task errors only marginally predicted within-language errors in older bilinguals. This marginal correlation seemed to be driven by education but did not approach significance when included with education in a regression analysis ($p = .33$). Indeed, both younger and older bilinguals produced significantly fewer within-language errors as their levels of education increased (see Tables 4 and 5). Together, these results demonstrate some degree of specificity in the association between flanker-task effects and language control. These considerations increase confidence that the flanker task measures executive control specifically, not general cognitive ability, and that executive control is important for preventing cross-language intrusions.

One result that emerged when comparing younger with older bilinguals, but not in continuous analyses within the older group, was an age-related decline in correct responses (see Tables 3 and 4). Age effects that emerge only between groups could reflect cohort differences that are not necessarily related to aging per se. Although we matched older and younger bilinguals for age of acquisition of both languages and for degree of current daily use of both languages, older bilinguals had lower levels of education on average, and they rated their spoken-language proficiency in both languages as significantly lower than younger bilinguals did. In prior work, older bilinguals rated their proficiency lower than younger bilinguals did but performed as well as the younger bilinguals on a picture-naming test (Gollan, Montoya, Cera, & Sandoval, 2008). This difference in ratings could reflect higher standards of excellence in older participants or their sense of a significant age-related decline in fluency.

To further explore possible cohort differences, we asked whether age effects might be modulated by language dominance. Younger bilinguals produced significantly more correct responses than older bilinguals did in their self-rated dominant language, $t(36) = 2.43$, $p = .02$, and the difference between the two groups' correct responses trended in the same direction (of age-related decline) but was not significant for their self-rated nondominant language, $t(36) = 1.60$, $p = .12$. Similarly, older bilinguals intruded the nondominant language into the dominant language more often than did younger bilinguals, $p = .05$, but did not intrude the dominant language into the nondominant language more often than did younger bilinguals, $p = .72$.

Thus, the dominant language may be more sensitive than the nondominant language to age effects. Consistent with this view, our results showed that, looking at age effects within the older bilingual group only, old-old members produced crosslanguage intrusions during dominant-language fluency more often than did young-old members, $r = .47$, $p = .05$, but not when producing their nondominant language, $r = .12$, $p = .64$. Similarly, within the older bilingual group, verbal-fluency trials in the dominant language drove the correlation between flanker-task errors and cross-language intrusions ($r = .529$, $p = .03$), whereas cross-language intrusions of the dominant into the nondominant language were not correlated with flanker-task errors ($r = .190$, $p = .47$). Our finding that the dominant language shows a greater sensitivity to age effects resembles recent reports that Alzheimer's disease affects bilinguals' dominant language more than their nondominant language (Gollan, Salmon, Montoya, & da Pena, 2010). Intruding the dominant into the nondominant language may be relatively normal, with declines in executive control primarily increasing intrusions in the unexpected direction (nondominant into dominant language). However, these conclusions must be considered tentative given the low number of intrusions and the absence of language-dominance effects on cross-language intrusions in either age group tested in this study (both *F*s < 1).

The relation between flanker-task errors and cross-language intrusions establishes an explicit link between executive control and bilingual language production. This link was only implicit in previous reports of bilingual advantages, which were largely unconnected to specific aspects of bilingual language performance, with three possible exceptions. First, Mechelli et al. (2004) found that greater bilingual proficiency was associated with greater cortical density (though bilingual advantages were not investigated). Second, in a study by Blumenfeld and Marian (2010), bilingual proficiency was correlated with inhibition resolution (albeit within and not between languages). Third, Bialystok, Craik, and Ruocco (2006) found that bilinguals who were equally proficient in both of their languages were more advantaged than bilinguals who were not equally proficient in a dual-task paradigm. These studies imply that "more bilingual" is better, but they do not illustrate specifically which aspect of bilingual language use leads to which advantage.

A question that remains is why cross-language intrusions are so rare (particularly compared with within-language errors). Figure 2 illustrates the rate of each error type in younger and older bilinguals. Cross-language intrusions were the least common error type. Even older bilinguals, some of whom had considerable difficulty with the flanker task, experienced failure of language control only about 1% of the time on average. This result suggests the presence of a force independent of executive control, possibly a language-specific control mechanism that prevents cross-language intrusions even in the presence of marked decline in executive control. Particularly notable was 1 bilingual who could not perform the flanker task despite multiple attempts but produced just 3% cross-language intrusions. One possibility is that cross-language errors may simply be easier to detect than other error types. However, in some ways, cross-language intrusions should be hardest to detect given that they fit perfectly into the targeted fluency category (i.e., only language membership excludes them as legitimate responses; Sandoval et al., 2010). Further study of the forces that maintain impressive language control even in aging bilinguals with impaired executive control will inform theories of bilingualism while revealing the role of executive control in language processing in all speakers.

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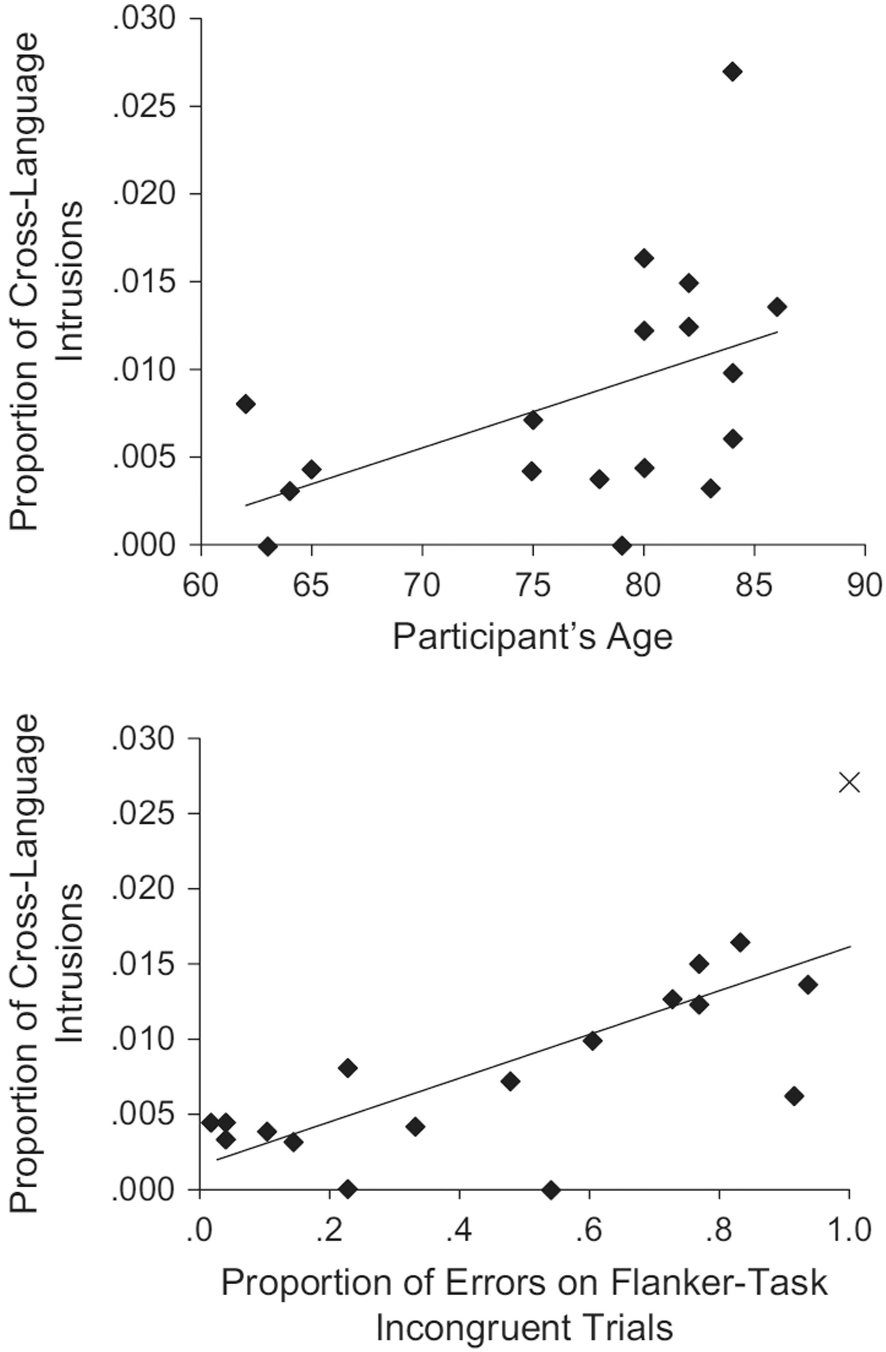

Fig. 1.

Scatter plots (with best-fitting regression lines) showing the proportion of cross-language intrusions on the verbal-fluency task as a function of participant's age (upper panel) and as a function of the proportion of errors on incongruent trials on the flanker task (lower panel). Error rates include both actual errors and time-out errors (see the text for explanation). Data from 1 bilingual (indicated by an "X") who could not pass the accuracy threshold on the practice trials are not included in the calculation of the regression line in the lower panel.

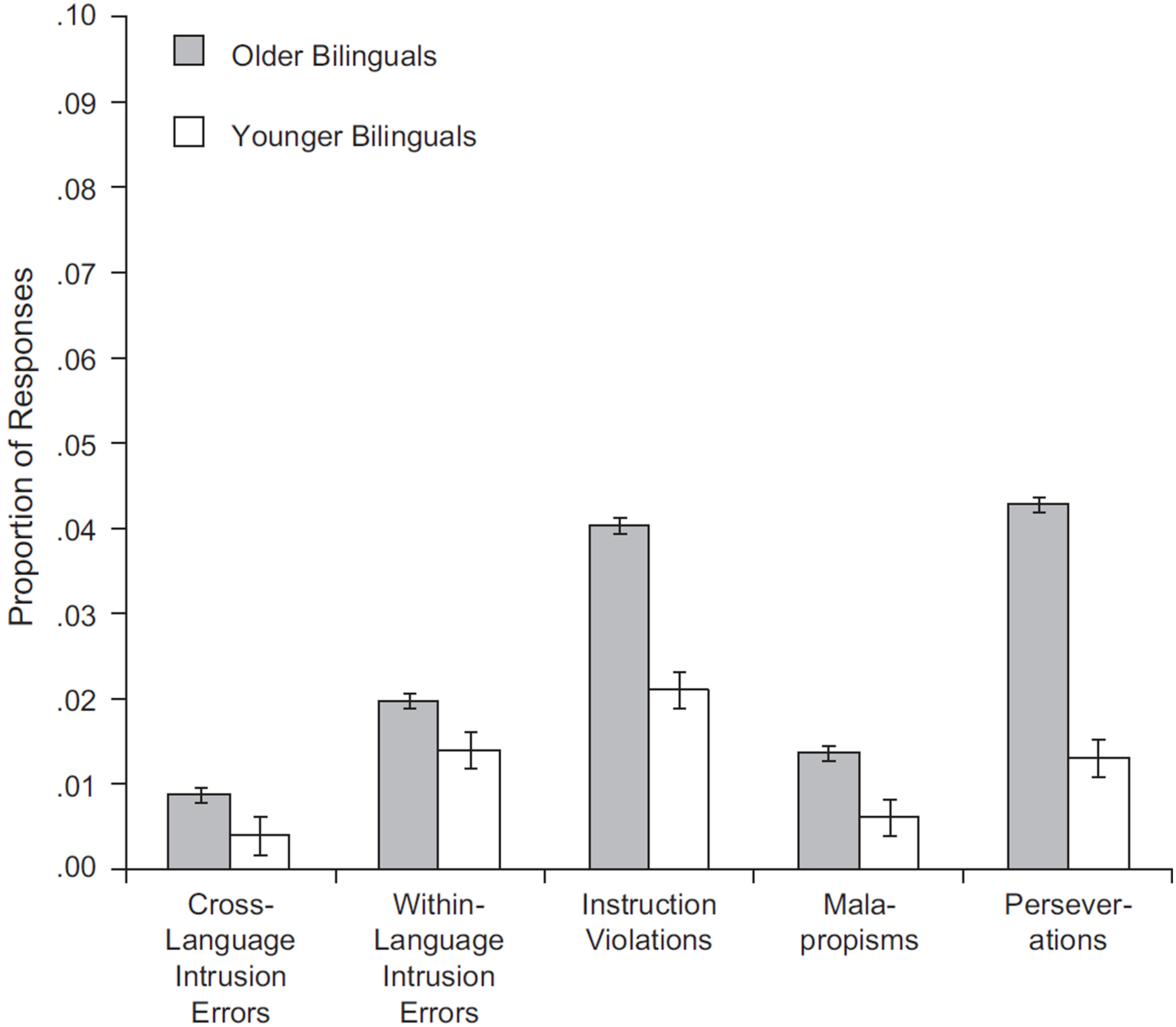

Fig. 2.
Results from the verbal-fluency task: proportion of responses that were classified as each of five error types (see the text), separately for older and younger bilinguals. Error bars show standard errors.

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Table 1

Characteristics of the Older and Younger Participants

	Older bilinguals (*n* = 18)		Younger bilinguals (*n* = 18)			
Characteristic	***M***	***SD***	***M***	***SD***	***t*(34)**	***p***
Age (years)	77.0	8.0	19.7	1.1	30.13	< .01
Education (years)	11.5	2.6	13.9	0.8	3.77	< .01
Daily use of English (%)	54.1	32.9	63.2	14.9	1.05	.30
Age of exposure to English (years)	6.8	5.3	6.1	4.4	<1	.66
Age of exposure to Spanish (years)	0.4	1.8	0.4	1.8	<1	.86
Self-rated spoken proficiency						
English	5.4	1.2	6.1	1.0	1.88	.07
Spanish	5.5	1.3	6.6	0.7	3.12	< .01
Dominant language	6.2	0.8	6.8	0.5	2.79	.01
Nondominant language	4.7	1.2	5.9	0.9	3.25	< .01

Note: Data shown in the table were obtained from the Language History Questionnaire (an instrument we developed for our research). Proficiency-level self-ratings were obtained using a scale from 1 (*little to no knowledge*) to 7 (*like a native speaker*).

Table 2

Comparison of Older and Younger Bilinguals' Performance on the Flanker Task

	Older bilinguals (n = 17)		Younger bilinguals (n = 18)			
Performance measure and trial type	***M***	***SD***	***M***	***SD***	***t*(34)**	***p***
Response time (ms)						
Congruent trials	1,014	208	584	76	8.25	< .01
Neutral trials	1,007	205	568	73	8.53	< .01
Incongruent trials	1,192	192	740	116	8.47	< .01
Incongruent – neutral trials	185	150	173	66	< 1	.76
Time-out errors (%)						
Congruent trials	8.0	11.7	0.1	0.5	5.01	< .01
Neutral trials	9.6	12.6	0.2	0.7	5.61	< .01
Incongruent trials	27.7	27.5	1.0	1.5	7.39	< .01
Incongruent – neutral trials	18.1	17.1	0.8	1.5	7.46	< .01
Actual errors (%)						
Congruent trials	4.3	5.8	0.5	0.9	2.77	.01
Neutral trials	7.0	7.9	0.9	1.6	3.19	< .01
Incongruent trials	17.8	16.6	1.4	1.8	4.15	< .01
Incongruent – neutral trials	10.8	8.7	0.5	0.2	2.57	.01

Note: A time-out error is a failure to respond before the 1,700-ms deadline. An actual error is an incorrect response.

Table 3

Comparison of Older and Younger Bilinguals' Performance on the Verbal-Fluency Task, Collapsed Across Languages

	Older bilinguals (n = 18)		Younger bilinguals (n = 18)			
Measure	***M***	***SD***	***M***	***SD***	$t(34)$	p
Raw numbers						
Correct responses	201.3	56.5	240.9	39.1	2.43	.02
Within-language errors	29.3	13.8	13.6	8.7	3.59	< .01
Cross-language intrusion errors	1.7	1.2	1.0	1.1	2.07	.05
Percentages						
Correct responses	86.4	5.2	94.2	4.0	4.50	< .01
Within-language errors	12.7	5.1	5.4	4.0	4.26	< .01
Cross-language intrusion errors	1.0	1.0	0.4	0.5	2.53	.02

Table 4

Pearson Bivariate Correlations Between Predictor Variables and Task Measures in the Older Bilingual Group, Collapsed Across Languages

	Verbal-fluency task				Flanker task	
Characteristic	Cross-language intrusion rate	Within-language error rate	Correct-response rate	Age	Response time on incongruent trials	Error rate on incongruent trials
Age						
r	.514	.034	−.102			
p	.029	.895	.688			
Flanker-task response time on incongruent trials						
r	.128	.283	−.283	.401		
p	.625	.272	.271	.110		
Flanker-task error rate on incongruent trials						
r	.783	.429	−.487	.595	.314	
p	.000	.086	.047	.012	.219	
Years of education						
r	−.363	−.625	.658	−.146	−.266	−.478
p	.139	.006	.003	.563	.303	.052

Note: Error rates are the sum of actual errors and time-out errors. For all correlations involving the flanker task, $n = 17$; for all other correlations, $n = 18$.

Table 5

Pearson Bivariate Correlations Between Predictor Variables and Task Measures in the Younger Bilingual Group, Collapsed Across Languages

	Verbal-fluency task				Flanker task	
Characteristic	**Cross-language intrusion rate**	**Within-language error rate**	**Correct-response rate**	**Age**	**Response time on incongruent trials**	**Error rate on incongruent trials**
Age						
r	.051	−.556	.543			
p	.842	.017	.020			
Flanker-task response time on incongruent trials						
r	−.297	−.025	.058	.242		
p	.232	.920	.818	.334		
Flanker-task error rate on incongruent trials						
r	−.289	.285	−.249	−.099	.560	
p	.245	.251	.319	.697	.016	
Years of education						
r	−.122	−.530	.537	.804	.060	−.300
p	.629	.024	.022	.000	.813	.226

Note: Error rates are the sum of actual errors and time-out errors. For all correlations, $n = 18$.