Auditory word recognition across the lifespan

Links between linguistic and nonlinguistic inhibitory control in bilinguals and monolinguals

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Recent research suggests that bilingual experience reconfigures linguistic and nonlinguistic cognitive processes. We examined the relationship between linguistic competition resolution and nonlinguistic cognitive control in younger and older adults who were either bilingual or monolingual. Participants heard words in English and identified the referent among four pictures while eye-movements were recorded. Target pictures (e.g., *cab*) appeared with a phonological competitor picture (e.g., *cat*) and two filler pictures. After each eye-tracking trial, priming probes assessed residual activation and inhibition of target and competitor words. When accounting for processing speed, results revealed that age-related changes in activation and inhibition are smaller in bilinguals than in monolinguals. Moreover, younger and older bilinguals, but not monolinguals, recruited similar inhibition mechanisms during word identification and during a nonlinguistic Stroop task. Results suggest that, during lexical access, bilinguals show more consistent competition resolution and recruitment of cognitive control across the lifespan than monolinguals.

Keywords: bilingualism, aging, auditory word recognition, competition resolution, inhibition, eye-tracking

1. Introduction

During word recognition, similar perceptual features across words give rise to temporary phonological ambiguities and competition between lexical representations (e.g., Desroches, Newman, & Joanisse, 2009; Luce & Pisoni, 1998; Marslen-Wilson, 1987; McClelland & Elman, 1986; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982). For example, hearing the word <u>*mar*</u>*ker* activates multiple lexical candidates

that compete for selection (e.g., _marbles_ and _marshmallow_). Resolution of such ambiguities is thought to rely on cognitive control to identify the target word and rule out alternatives (e.g., Gernsbacher, 1993; Gernsbacher & Faust, 1991; Mason & Just, 2007; Swinney, 1979).

Bilinguals are likely to encounter more linguistic ambiguities than monolinguals because they must resolve lexical competition both within-language (e.g., Blumenfeld & Marian, 2011; Marian & Spivey, 2003) and between their two languages (e.g., Blumenfeld & Marian, 2007; 2013; Marian & Spivey, 2003). For example, a Spanish-English bilingual hearing the word _marker_ may activate concepts of _marbles_ but also of _butterflies (mariposas_ in Spanish). It can thus be expected that bilinguals experience increased cognitive demands for competition resolution, both within-language and across languages, and that a lifetime of meeting such demands may yield bilingual-monolingual differences in the recruitment of cognitive control during language processing. In the current study, we examined effects of bilingualism and aging on the ability to resolve linguistic ambiguities within one target language. Specifically, we explored the emergence and resolution of lexical competition across the time course of auditory word recognition. We also investigated the relationship between nonlinguistic Stroop inhibition skills and participants' ability to resolve lexical competition, and thus the extent to which they recruited a similar cognitive control mechanism to resolve both non-linguistic and linguistic competition.

Perhaps due to the competition resolution demands of bilingual processing, bilinguals may demonstrate fine-grained benefits over monolinguals in cognitive control (e.g., Bialystok, 2007; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; Gold et al., 2013; Kroll & Bialystok, 2013, but see Hilchey & Klein, 2011; Kirk, Fiala, Scott-Brown, & Kempe, 2014; Paap & Greenberg, 2013). A possible source of enhanced cognitive control during bilingual processing is bilinguals' simultaneous activation of both languages (e.g., Bartolotti & Marian, 2012; Blumenfeld & Marian, 2007, 2013; Green, 1998; Kroll & Bialystok, 2013; Kroll, Bobb, Misra, & Guo, 2008; Kroll, Dussias, Bogulski, & Valdes Kroff, 2012; Martín, Macizo, & Bajo, 2010). To select the appropriate language for a given context, bilinguals have been shown to suppress the inappropriate language (e.g., Green, 1998), including recruitment of inhibitory control during online auditory word recognition (e.g., Blumenfeld & Marian, 2013; Krizman, Skoe, Marian, & Kraus, 2014; Mercier, Pivneva, & Titone, 2014).

It remains unclear, however, whether bilinguals' ability to resolve lexical competition changes with age. Speed of lexical retrieval declines throughout the lifespan (e.g., Bialystok et al., 2008; Burke, 1997), including speed of auditory word recognition (e.g., Revill & Spieler, 2012), as well as domain-general cognitive control processes (e.g., Bialystok et al., 2004; Hasher & Zacks, 1988). At least some

cognitive control abilities associated with age-related decline may be better pre-served in bilinguals than in monolinguals (Bak et al., 2014; Bialystok, 2011). Yet, even prior to age-related declines in lexical access, word retrieval can be slower in younger bilinguals vs. monolinguals, possibly due to cross-linguistic compe-tition and frequency differences resulting from fewer opportunities to use each language (Bialystok, Craik, Green, & Gollan, 2009; Gollan, Montoya, Cera, & Sandoval, 2008). Consequently, bilingual experience may not protect against age-related changes in lexical retrieval (Bialystok & Craik, 2010; Bialystok et al., 2008, 2009; but see Goral, Libben, Obler, Jarema, & Ohayon, 2008). However, younger and older bilinguals have shown overall faster performance on nonlinguistic tasks where competitors are present (e.g., Hilchey & Klein, 2011), cognitive skills that may partially compensate for slower lexical retrieval. It is thus possible that the *time course* of word activation undergoes different age-related changes in bilin-guals and monolinguals because of differences in both lexical activation speed and cognitive processes recruited for competition resolution.

One way to index the time course of lexical competition is by examining in-hibition of competing word candidates during and following auditory word iden-tification. Blumenfeld and Marian (2011) examined real-time processing during auditory word identification through eye-tracking, combined with placement of priming probes 500ms after target identification to index residual inhibition of competitors (see Figure 1). In monolinguals, a delayed response on the 500ms probe indicated residual inhibition of the previous competitor. Critically, in bi-linguals (but not monolinguals), better nonlinguistic Stroop performance was as-sociated with shorter response times to the competitor priming probe, suggesting faster resolution of linguistic competition (Blumenfeld & Marian, 2011; for similar findings in the nonlinguistic domain, see Mishra, Hilchey, Singh, & Klein, 2012). Similar patterns have recently been identified linking quicker cross-linguistic competition resolution to better nonlinguistic Stroop performance in bilinguals (e.g., Blumenfeld & Marian, 2013; Mercier et al., 2014). Thus, in young bilingual adults, nonlinguistic cognitive control appears to modulate early auditory word recognition.

1.1 Current study

In the current study, we employed Blumenfeld and Marian's (2011) eye-tracking/ priming and nonlinguistic Stroop tasks to examine changes in cognitive control in younger and older bilinguals and monolinguals. The nonlinguistic Stroop task (Figure 2) involves conflict monitoring, attention allocation and competition reso-lution via inhibition (Donohue et al., 2012; Kane & Engle, 2003; Kornblum, 1994; Liu, Banich, Jacobson, & Tanabe, 2004), processes that have been shown to be

involved in younger bilinguals' linguistic competition resolution (Blumenfeld & Marian, 2011, 2013; Mercier et al., 2014; Singh & Mishra, 2014). Participants must monitor two stimulus dimensions on the Stroop task: arrow direction and location. On incongruent trials, the arrow is pointing in the opposite direction of its location on the screen, creating perceptual conflict, and participants must inhibit the *location* of the arrow to respond to its *direction*. Similarly, during word comprehension, participants must also attend to the perceptual features of auditory input that can map onto multiple responses (e.g., the target *plug* can also initially map onto *plum*). To select the target *plug*, participants must inhibit the competitor *plum*. Thus, for both the Stroop and linguistic competition tasks, stimulus dimensions overlap and compete with each other, resulting in more than one possible stimulus-response mapping. Both tasks are consistent with the Stroop task constellation identified in the *Dimensional Overlap Model* (Kornblum, 1994; also see Blumenfeld & Marian, 2014), where overlapping stimulus dimensions compete (*stimulus-stimulus conflict*) with subsequent competing stimulus-response mappings (*stimulus-response conflict*).

Only a few studies to date have explored the association between nonlinguistic and linguistic cognitive processes and age-related decline by using linguistic and nonlinguistic tasks that require the same type of cognitive control (e.g., Weissberger, Wierenga, Bondi, & Gollan, 2012; Gollan, Sandoval, & Salmon, 2011). Gollan et al. (2011) found that errors on the flanker task were associated with cross-linguistic intrusions on the verbal fluency task in older but not younger bilinguals. In Weissberger et al. (2012), a subset of older bilinguals, who were unable to perform a nonlinguistic switch task, also demonstrated larger switch costs on a language-switching task. These results suggest that older bilinguals continue to recruit cognitive control to support linguistic processing, with individual differences in language processing partially determined by these cognitive skills.

To better understand the link between linguistic and cognitive experience throughout the lifespan, we focused on language-related manifestations of cognitive aging: slowing (e.g., Burke, 1997) and decline in inhibition (e.g., Lustig, Hasher, & Zacks, 2007). We examined (1) the time course of linguistic competition resolution during auditory word recognition in younger and older monolinguals and bilinguals, and (2) age-related changes associated with the recruitment of domain-general cognitive control for linguistic competition resolution. We examined the potential link between performance on linguistic and nonlinguistic tasks that both require similar cognitive control processes (i.e., inhibition of an irrelevant stimulus dimension). We hypothesized that more experience with linguistic competition resolution would result in more efficient cognitive control during auditory word comprehension and the recruitment of skills also used in the nonlinguistic domain for language processing. We predicted that bilinguals

would show stronger associations between linguistic and nonlinguistic inhibition than monolinguals throughout the lifespan because younger bilinguals appear to recruit nonlinguistic cognitive processes more consistently during language processing (e.g., Bialystok, 2005; Kroll, 2008; Blumenfeld & Marian 2011; 2013), with language-cognition links also identified in older bilinguals (e.g., Weissberger et al., 2012).

2.   Method

2.1 Participants

Sixty participants were tested across four groups: 15 younger monolinguals (5 males); 15 younger bilinguals (5 males); 15 older monolinguals (6 males); and 15 older bilinguals (5 males). Within the younger and older groups, monolinguals and bilinguals were matched on age. Bilinguals were matched on native language status and percentage exposure to each language. In both younger and older bilinguals, 12 participants were English-Spanish bilinguals and 3 were Spanish-English bilinguals. All groups were matched on years of education (see Table 1).

Participants completed the *Language Experience and Proficiency Questionnaire* (*LEAP-Q*: Marian, Blumenfeld, & Kaushanskaya, 2007), the *Peabody Picture Vocabulary Test-III* (Dunn, & Dunn, 1997), the nonverbal matrix reasoning subtest from the *Wechsler Abbreviated Scale of Intelligence* (PsychCorp, 1999), and the forward digit span subtest from the *Comprehensive Test of Phonological Processing* (Wagner, Torgesen, & Rashotte, 1999), see Table 1. Bilingual participants also completed the Spanish equivalent of the *PPVT*, the *Test de Vocabulario en Imagenes Peabody* (Dunn, Lugo, Padilla & Dunn, 1986). Older and younger monolinguals and bilinguals did not differ on receptive vocabulary and digit span performance, but the two younger groups outperformed the two older groups on matrix reasoning ($p < .05$). Within monolinguals, 7 younger adults and 5 older adults had learned some Spanish (between ages 10–15 in younger adults and 14–58 in older adults), but all reported very low Spanish proficiency and exposure levels on the *LEAP-Q* (see Table 1). All participants had age-typical hearing, as established by threshold testing at 500, 1000, 2000, and 4000 Hz (ASHA, 1997).

Table 1. Demographic and language background characteristics of younger bilinguals and monolinguals as well as older bilinguals and monolinguals.

	Younger participants			Older participants		
	Bilinguals	Monolinguals	*p*	Bilinguals	Monolinguals	*p*
	Mean (*SE*)	Mean (*SE*)		Mean (*SE*)	Mean (*SE*)	
Age	21.7 (1.3)	23.7 (1.1)	>.1	69.3 (2.1)	70.3 (9.5)	>.5
Years of education	15.7 (0.8)	16.3 (0.6)	>.1	18.7 (1.0)	17.6 (0.8)	>.1
Age of English acquisition	1.8 (0.8)	0.3 (0.1)	>.08	2.9 (1.6)	0.7 (0.5)	>.1
Age of Spanish acquisition	3.4 (0.8)	13.4 (0.8)	<.01	14.7 (3.8)	21.3(5.1)	>.1
English proficiency (1–10 scale)	9.1 (0.2)	9.6 (0.1)	<.05	9.7 (0.2)	9.8 (0.1)	>.1
Spanish proficiency (1–10 scale)	7.5 (0.4)	2.3 (0.4)	<.01	7.7 (0.7)	1.5 (0.5)	<.01
% English exposure	76.9 (4.1)	98.1 (0.8)	<.01	65.8 (8.5)	96.2 (2.1)	<.01
% Spanish exposure	17.7 (3.2)	1.9 (3.0)	<.01	21.9 (5.6)	3.7 (2.1)	<.01
Matrix reasoning (WASI)	29.5 (0.6)	29.7 (0.8)	>.1	23.0 (1.3)	23.7 (1.9)	>.1
Forward digit span	17.9 (0.6)	18.2 (0.5)	>.1	16.3 (0.8)	16.8 (0.9)	>.1
English Receptive Vocabulary						
PPVT, raw score	189.3 (1.8)	188.5 (2.8)	>.1	196.8 (0.9)	186.5 (8.3)	>.1
PPVT, % correct[*]	92.8 (0.9)	92.4 (1.5)	> .1	96.5 (0.6)	91.4 (4.6)	>.1
Spanish Receptive Vocabulary						
TVIP, raw score	115.8 (1.4)	N/A		114.1 (4.6)	N/A	>.1
TVIP, % correct[*]	92.6 (1.2)	N/A		91.2 (4.8)	N/A	.1

[*]Percent items completed correctly on the PPVT and TVIP was included to allow more direct comparisons across the two tests (*PPVT* = Peabody Picture Vocabulary Test; *TVIP* = Test de Vocabulario en Imagenes Peabody) since norms are not available for the TVIP past age 18.

2.2 Materials

Materials from Blumenfeld and Marian (2011) were employed. On *picture identification trials*, participants saw a central fixation cross surrounded by four pictures (see Figure 1, column 1). Pictures corresponded to (a) an auditory target word, (b) a similar-sounding competitor word and (c) two unrelated filler words. Each picture was sized approximately 5x5cm and displayed 13cm from the central

fixation; pictures were black line drawings with similar salience and line thickness. To reduce the likelihood that participants would notice the phonological overlap between target and competitor, trials followed a ratio of 1 competitor trial to 2 filler trials, yielding 78 competitor and 156 filler trials.
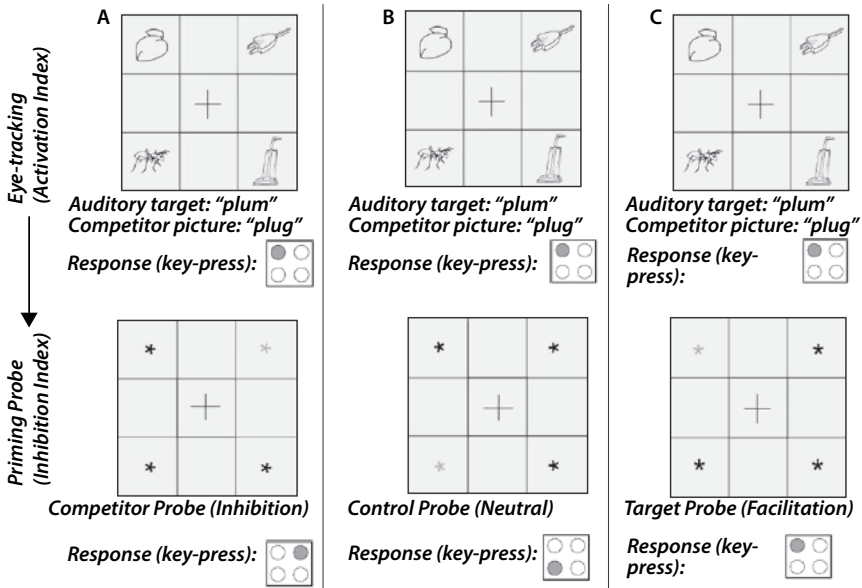

Figure 1. The Eye-Tracking/Negative Priming Paradigm. Participants viewed picture displays (top row) and identified the picture corresponding to the word they heard by pressing one of four keys corresponding to the picture's location. Critical trials contained phonological competitors, and eye-tracking allowed for examination of target-competitor activation effects in real time. Image panels were followed by a 500ms blank screen and a Priming probe trial that indexed residual activation of targets and inhibition of competitors (bottom row). Participants identified gray asterisks as quickly as possible, with faster asterisk identification suggesting residual activation of the preceding image and slower asterisk identification suggesting residual inhibition. Adapted from Blumenfeld and Marian (2011).

A *priming probe trial* immediately followed each picture identification trial, with a fixation cross presented for 500ms between the two trial types. On priming probe trials, asterisks replaced the pictures. Three asterisks were black, and one was gray. The gray asterisk appeared in either the previous target picture location (*target probe* trials, $n = 26$), competitor location (*competitor probe* trials, $n = 26$), or a filler location (*filler probe* trials, $n = 26$). The 78 picture identification trials with competitors were divided into three sub-lists of 26 picture identification trials, and each list was paired with each priming probe trial (target, competitor, filler) for

one third of participants. The three sub-lists were matched on target frequencies, competitor frequencies, and duration of phonological overlap between targets and competitors (all *ps* > .5). The remaining 156 filler trials were also paired with priming probes where gray asterisks occurred in each quadrant an equal number of times. Target and competitor picture locations were counterbalanced across conditions.

A female speaker of American English recorded stimuli in a soundproof booth (Marantz Solid State recorder, 44,100 Hz, 16 bits). Target-competitor pairs shared word onsets (at least 2 phonemes, averaging 279.4ms of overlap, *SE* = 20.8). Competitors had higher lexical frequencies (*M* = 91.9, *SE* = 16.9) than targets (*M* = 15.7, *SE* = 2.3) to create maximal interference with targets, $t(154) = 4.5$, $p < .001$ (e.g., Revill & Spieler, 2012). Filler items did not share word onsets with the target.
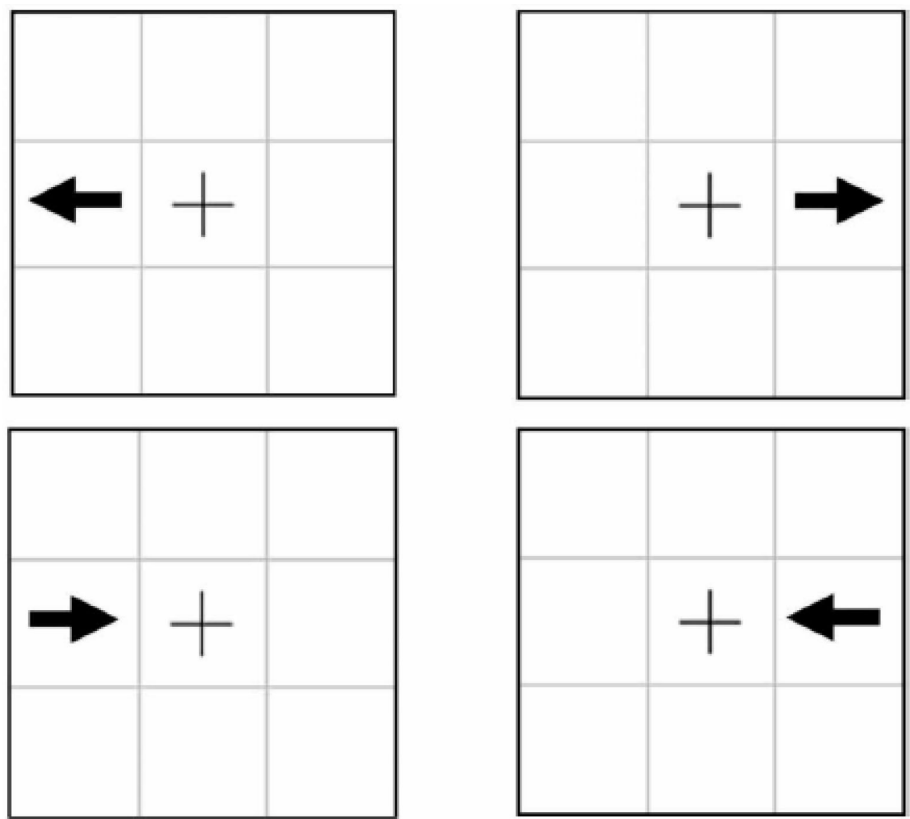

Figure 2. Nonlinguistic Stroop task. Top: Congruent condition where arrow location and direction match. Bottom: Incongruent condition where arrow location and direction do not match.

On the *nonlinguistic Stroop task* (Blumenfeld & Marian, 2011, 2013, 2014), visual displays contained an arrow on either the right or left side of the display (*location*) and pointing either right or left (*direction*). Participants ignored arrow location and responded to arrow direction by pressing a key with their right hand (right-pointing arrow) or left hand (left-pointing arrow), see Figure 2. The task included 120 congruent trials (60 with left-pointing arrows on the left side; 60 with right-pointing arrows on the right side) and 40 incongruent trials (20 with *left*-pointing arrows on the *right* side; 20 with *right*-pointing arrows on the *left* side). Each trial started with a 500ms central fixation cross followed by the stimulus display for 700ms, and a blank screen for 800ms. Participants were able to respond during the 700ms stimulus display as well as during the 800ms interval that followed. Trials followed a fixed pseudo-randomized order.

2.3 Procedure

Participants wore a head-mounted ISCAN eye-tracker or sat in front of an SR Eyelink system. Software tracked pupil location and corneal reflection through an infrared camera tracking the participants' left eye. A scene camera recorded participants' field of view, and images from the infrared and scene cameras were superimposed to track participants' fixations on the visual displays. A 9-point eye-tracker calibration was completed and participants placed their fingers on four response keys, arranged in a square to match the positioning of the four stimulus items on the visual display. Five-hundred milliseconds after onset of the display, participants heard a single word through headphones and identified the picture corresponding to the heard word by pressing the key that matched the picture's location on the display. After a 500ms delay, the priming probe trial started. Participants identified the gray asterisk as rapidly as possible by pressing the key corresponding to its location on the display. Responses on both picture identification and priming probe trials were self-paced. Participants also completed other linguistic and cognitive background tasks (see *Participants* section). In bilinguals, the Spanish *Test de Vocabulario en Imagenes Peabody* was administered during a separate session.

2.4 Data coding

For reaction time (RT) analyses, only target picture trials with correct responses were included. On picture identification and priming probe trials, participants' manual RTs were measured from the onset of the stimulus picture; RTs that exceeded 3*SD* from the participant's mean were excluded. If a picture identifica-

tion trial was removed from analyses, the corresponding priming probe and eye-tracking trials were also excluded.

For each *picture identification* trial, we coded eye-movements per 33ms time frame starting at the onset of the auditory target word, and ending with the participant's manual response via button press. Activation time curves were derived by plotting the proportion of target, competitor, and filler fixations (across trials and participants) over time post word-onset. Two independent coders re-coded 15 percent of all data, yielding high inter-coder reliability (Pearson pair-wise correlations, $r = .90$, $p < .0001$).

3.   Results

3.1   Target identification

3.1.1   *Accuracies and reaction times*

On picture identification trials, two 2 (trial type: competitor, filler) x 2 (age: younger, older) x 2 (language group: bilingual, monolingual) ANOVAs were conducted on accuracy rates and reaction times (see Table 2A for means). For accuracy rates, a main effect of trial type emerged, $F(1,55) = 49.5$, $p < .001$, $\eta_p^2 = .47$, with less accurate responses on competitor trials ($M = 94.9\%$, $SE = 0.6$) than filler trials ($M = 97.9\%$, $SE = 0.4$). In addition, an interaction emerged between trial type and age, $F(1,55) = 4.8$, $p < .05$, $\eta_p^2 = .10$, with larger competition effects (filler trials minus competitor trials) for older ($M = 3.8\%$, $SE = 0.6$) than for younger participants ($M = 2.0\%$, $SE = 0.5$), $t(57) = 2.2$, $p < .05$. Finally, a main effect of age emerged, $F(1,55) = 9.4$, $p < .01$, $\eta_p^2 = .15$, with older adults less accurate ($M = 95.0\%$, $SE = 0.7$) than younger adults ($M = 97.8\%$, $SE = 0.6$). No effects of language group were significant.

Reaction time analyses were performed on means that were adjusted to account for speed differences across age groups (response times for each condition were divided by overall response times within each participant, Brink & McDowd, 1999; West & Baylis, 1998).[1] This adjustment was undertaken to allow direct comparison of competition effects across age groups without the influence of processing speed, because changes in the speed of processing may also yield changes in competition effects (e.g., larger differences between congruent and incongruent

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1.   Speed-adjustments on reaction time analyses (dividing response speed for each condition by overall response speed within each participant) resulted in transformed scores centered around 1.0. Therefore, averaging across conditions within each participant resulted in overall means of 1.0 for all age and language groups. As a result, age and language group could only be examined as part of mixed interactions and in analyses of raw reaction times (see footnotes 2–4).

Table 2. Response accuracies, reaction times, and competition effects for target identification (A) and priming probe identification (B) across younger and older bilinguals and monolinguals.

|	Younger Monolinguals Mean (SE)	Older Monolinguals Mean (SE)	Younger Bilinguals Mean (SE)	Older Bilinguals Mean (SE)
A. Target Identification				
Competitor Trial Accuracy (%)	97.6 (0.4)	93.2 (1.2)	96.0 (0.9)	93.0 (1.7)
Filler Trial Accuracy (%)	99.1 (0.3)	96.5 (1.3)	98.6 (0.4)	97.3 (1.1)
Competition Effect Accuracy (%)	−1.5 (0.5)	−3.3 (0.7)	−2.6 (0.9)	−4.3 (1.1)
Competitor Trial RT (ms)	*2,056 (75)*	*2,382 (90)*	*1,998 (52)*	*2,659 (179)*
Filler Trial RT (ms)	*1,925 (64)*	*2,167 (68)*	*1,854 (44)*	*2,431 (196)*
Competition Effect RT (ms)	*131 (22)*	*215 (29)*	*144 (15)*	*228 (58)*
*Competition Effects, speed-adjusted**	*6.4 (1.0)*	*9.2 (1.0)*	*7.4 (0.7)*	*9.4 (2.0)*
B. Priming Probe Identification				
Positive Priming Effect Accuracy (%)	−0.4 (0.3)	−0.5 (0.8)	0.3 (0.5)	0.6 (0.4)
Negative Priming Effect Accuracy (%)	−0.4 (0.3)	0.7 (1.5)	−0.3 (0.3)	0.8 (0.9)
Positive Priming Effect RT (ms)	*20.4 (9.2)*	*89.3 (20.7)*	*37.3 (8.6)*	*38.0 (16.9)*
Negative Priming Effect RT (ms)	*−23.3 (8.6)*	*7.9 (9.6)*	*−1.1 (7.6)*	*0.4 (11.5)*

*Speed-adjusted scores were calculated within-participant by dividing condition means by overall response speed.

Stroop trials, e.g., Salthouse & Meinz, 1995). Analyses of these speed-adjusted reaction times revealed a main effect of trial type, $F(1,55) = 175.1$, $p < .001$, $\eta_p^2 = .76$, and a marginal interaction between trial type and age, $F(1,55) = 3.87$, $p = .054$, $\eta_p^2 = .07$. Follow-up t-tests suggested larger competition effects for older than younger adults, $t(57) = −2.0$, $p = .051$ (see Table 2A). These findings suggest that linguistic competition effects emerged across accuracies and response times, and age-related increases in these competition effects were present even though speed was accounted for. In addition, analyses of raw reaction times showed faster overall response times for younger than older adults[2] (see Table 2A).

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2. Analyses of raw reaction times revealed a main effect of age, $F(1,55) = 18.4$, $p < .001$, $\eta_p^2 = .25$, with older adults slower than younger adults, as well as a main effect of trial type, $F(1,55) = 112.6$, $p < .001$, $\eta_p^2 = .67$, with slower responses on competitor than filler trials. In addition, an interaction emerged between trial type and age, $F(1,55) = 6.2$, $p < .05$, $\eta_p^2 = .10$, with

3.1.2   *Eye-tracking during target identification*

3.1.2.1   *Target activation.* Eye-movements to target pictures, reflecting target activation, were analyzed using Growth Curve Analysis (GCA; Mirman, 2014) on proportion of looks to the target object from 0 to 1000ms post word onset (see Figure 3A). A second-order polynomial was used to model the data. Age and language group were added to the model simultaneously as fixed effects, which improved the model fit ($\chi^2(9) = 19.8$, $p < .01$, see Figure 3B for model trajectories). In the model, there was a significant effect of age on the linear term ($t = 3.63$,

Eye-movements to the target object during auditory word recognition

A.

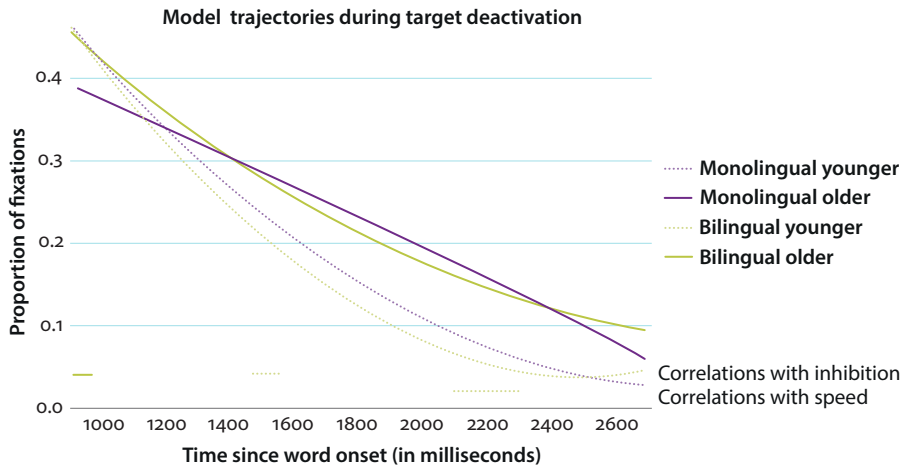**Model trajectories during target activation**
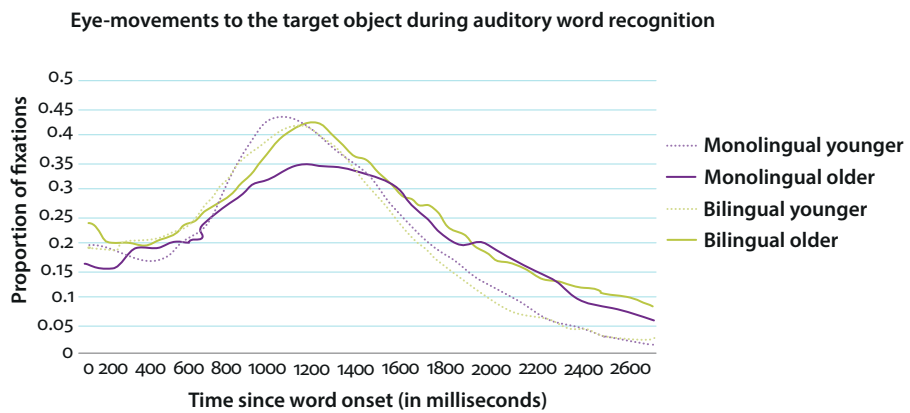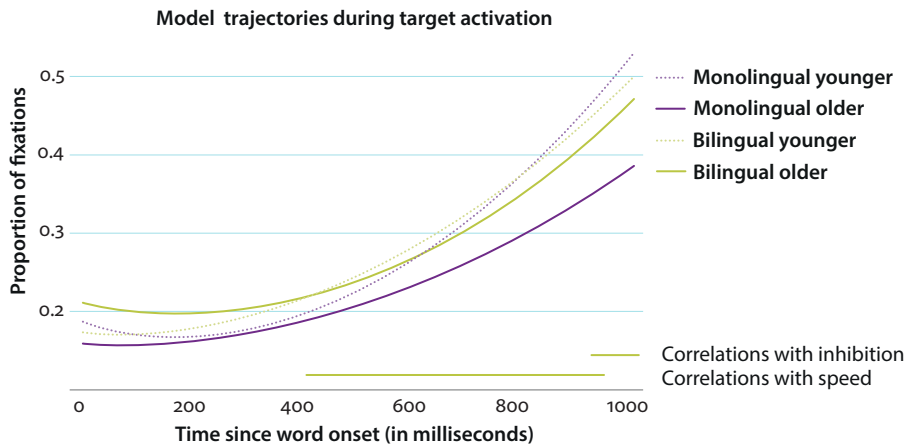
B.

competition effects (filler minus competitor trials) larger for older than younger participants, $t(57) = 2.5$, $p < .05$. No other effects were significant. Planned comparisons yielded similar competition effects for bilinguals and monolinguals.
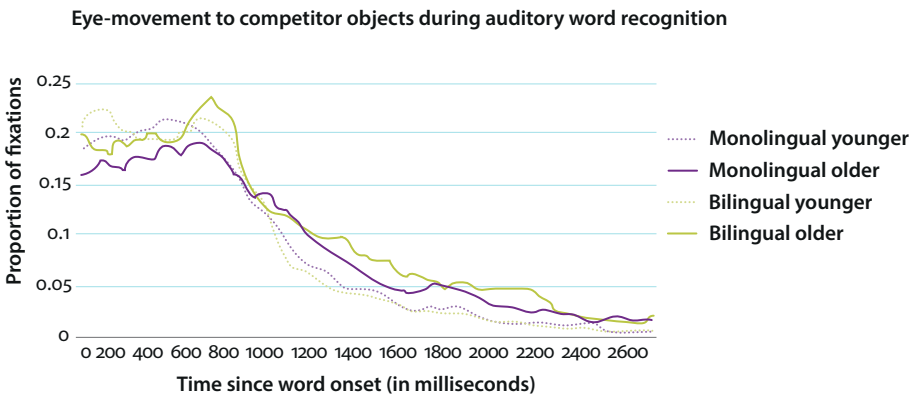
Figure 3. Timecourse of lexical target activation in younger and older bilinguals as well as younger and older monolinguals, including the full timecourse of target activation (A), as well as figures reflecting GCA models of target activation (B) and deactivation (C). On figures B and C, correlations with Stroop inhibition (top line) and processing speed (bottom line) are marked at the bottom of the graph.
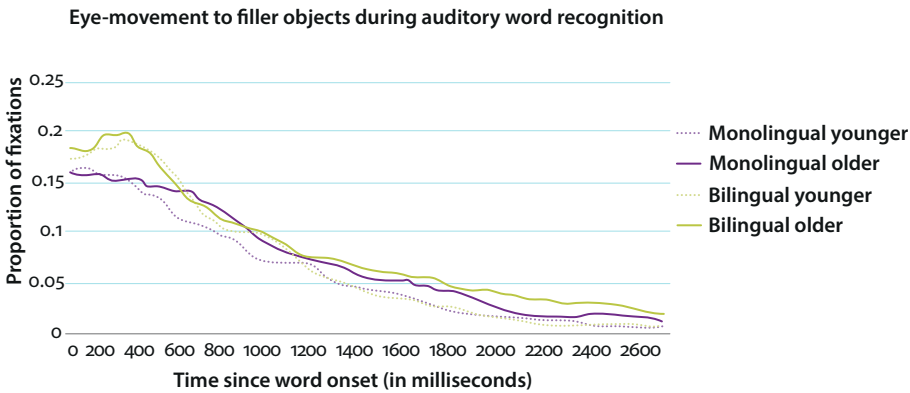
$p < .001$), reflecting shallower slopes (and thus less and/or slower activation of the target) in older compared to younger adults. There was also a significant interaction between age and language group on the quadratic term ($t = 2.04$, $p < .05$), demonstrating less curvature in the older monolinguals relative to younger monolinguals and older bilinguals. This result suggests that less and/or slower activation in older adults is most pronounced in monolinguals.

3.1.2.2 *Target deactivation (peak activation until the end of the trial).* Eye-movements to target pictures during target *deactivation* were analyzed using GCA on proportion of looks to the target from 1,000 to 2,733ms post word onset. A second-order polynomial was used to model the data, with age and language group concurrently added to the model as fixed effects. The addition of age and language group improved the model fit ($\chi^2(9) = 43.9$, $p < .001$, see Figure 3C for model trajectories). There was a significant effect of age on the intercept ($t = 3.36$, $p < .001$), linear ($t = 3.27$, $p < .01$), and quadratic terms ($t = 4.57$, $p < .001$), with older adults' trajectory captured by a higher, shallower, and less curved line, suggesting less and/or slower target deactivation. There was also a significant effect of language group on the quadratic term ($t = 2.98$, $p < .01$), reflecting a more curved-downward trajectory in bilinguals than monolinguals, indicating that bilinguals exhibited faster target deactivation.
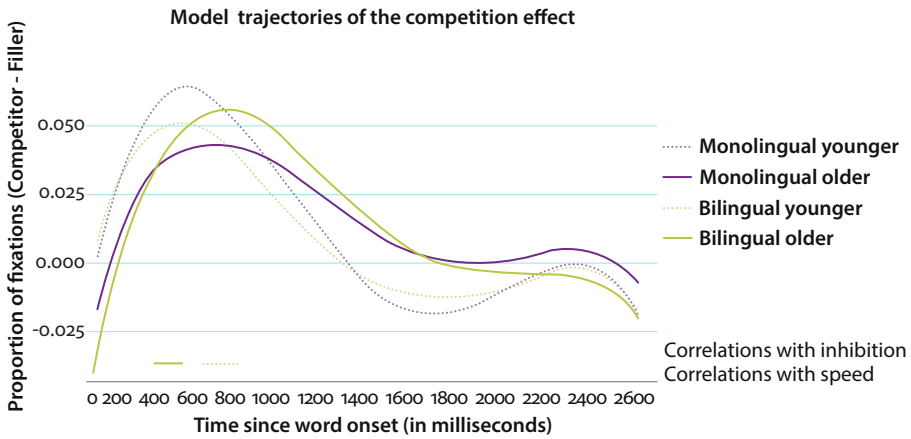
3.1.2.3 *Competitor activation and deactivation.* To examine eye-movements to competitor relative to filler pictures during competitor activation and deactivation, a GCA was conducted on the proportion of looks to competitor minus filler objects (i.e., the competition effect) throughout the entire time-course (see Figures 4A and 4B). A fourth-order polynomial was used to model the data, with age and language group added to the model simultaneously as fixed effects. The inclusion of age and language group marginally improved the model fit ($\chi^2(15) = 22.97$, $p = .085$, see Figure 4C for the model trajectories). In the model, there was a significant effect of age on the quadratic term ($t = 3.67$, $p < .001$), reflecting less curvature in older adults, most pronounced in the first downward slope, suggesting less and/or slower competition resolution in older relative to younger adults. In sum, eye-tracking analyses revealed that older monolinguals showed less and slower target activation, while bilingual groups showed quicker target deactivation, reflecting more lifespan changes in activation for monolinguals than bilinguals. In

Eye-movement to competitor objects during auditory word recognition

A.

Eye-movement to filler objects during auditory word recognition

B.

C.

Figure 4. Timecourse of lexical competitor activation in younger and older bilinguals as well as younger and older monolinguals, including the full timecourse of competitor (A) and filler (B) activation, as well as a figure reflecting GCA models of the competition effect (looks to competitor minus fillers) across time and groups (C). On figure C, correlations with Stroop inhibition (top line) and processing speed (bottom line) are marked at the bottom of the graph.

addition, slower competition resolution was evident in both older groups relative to the younger groups.

3.2 Residual activation/inhibition (after target identification), as indexed by priming probes

To examine residual activation and inhibition of targets and competitors after target identification, two 3 (probe type: baseline, target, competitor) × 2 (age: younger, older) × 2 (group: bilingual, monolingual) ANOVAs were conducted on accuracy rates and reaction times from priming probe trials. Recall that faster and more accurate identification of asterisks in previous target positions (positive priming) suggests residual activation of the target while slower and less accurate identification of asterisks in competitor positions (negative priming) suggests residual inhibition of the preceding competitor. For accuracy rates, only a main effect of age emerged, $F(1,55) = 5.6$, $p < .05$, $\eta_p^2 = .09$, with older adults less accurate ($M = 98.0\%$, $SE = 0.5$) than younger adults ($M = 99.8\%$, $SE = 0.5$). Reaction time analyses were performed on adjusted means (response times for each condition, divided by overall response times within each participant) to account for speed differences across age groups. Analyses revealed a main effect of priming probe, $F(2,54) = 43.60$, $p < .001$, $\eta_p^2 = .44$, with quicker identification of target than

baseline probes, $t(58) = 6.89$, $p < .001$, but no response time differences between competitor and baseline probes, $t(58) = 1.35$, $p > .1$. There was also a 3-way interaction between priming probe, age, and language group, $F(2,54) = 3.31$, $p < .05$, $\eta_p^2 = .06$. Follow-up t-tests revealed that, compared to younger monolinguals, older monolinguals had larger positive priming effects, $t(28) = -2.3$, $p < .05$, and smaller negative priming effects, $t(28) = -2.4$, $p < .05$. Younger and older bilinguals showed no differences on positive priming effects, $t(28) = 1.1$, $p > .1$, or negative priming effects, $t(28) = 0.02$, $p > .1$. These findings again suggested greater changes across the lifespan in monolinguals than in bilinguals, with younger monolinguals showing stronger competitor inhibition, as indexed by larger negative priming effects, and older monolinguals showing stronger target facilitation, as indexed by larger positive priming effects. Analyses of raw reaction times also revealed faster responses in younger than older adults.[3]

3.3 Relation between linguistic processing and nonlinguistic Stroop performance

First, nonlinguistic Stroop inhibition was analyzed with two 2 (trial type: incongruent, congruent) × 2 (age: younger, older) × 2 (language group: bilingual, monolingual) ANOVAs on accuracies and reaction times. For accuracies, only a main effect of trial type emerged, $F(1,56) = 91.2$, $p < .001$, $\eta_p^2 = .62$, with responses on incongruent trials less accurate ($M = 83.1\%$, $SE = 1.8$) than on congruent trials ($M = 98.4\%$, $SE = 0.5$). Reaction time analyses were performed on adjusted means (response times for each condition, divided by overall response times within each

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3. Analyses of raw reaction times revealed a main effect of age, $F(2,55) = 60.7$, $p < .001$, $\eta_p^2 = .53$, with older adults responding slower ($M = 746.8$, $SE = 22.4$) than younger adults ($M = 502.5$, $SE = 22.0$). In addition, there was a main effect of probe type, $F(2,55) = 34.8$, $p < .001$, $\eta_p^2 = .39$, with quicker identification of target than baseline probes, $t(58) = 5.8$, $p < .001$, but no response time differences on competitor vs. baseline probes, $t(58) = -.9$, $p > .1$. Finally, interactions were present between trial type and age, $F(2,55) = 3.4$, $p < .05$, $\eta_p^2 = .06$, as well as between trial type, age, and language group, $F(2,55) = 3.3$, $p < .05$, $\eta_p^2 = .06$. Follow-up 1-way ANOVAs and planned follow-up t-tests compared the four groups on positive priming (baseline minus target probes) and negative priming effects (baseline minus competitor probes). Significant differences emerged between groups on positive priming effects, $F(3,58) = 4.2$, $p = 01$, with LSD follow-up t-tests showing greater positive priming effects for older monolinguals than for younger monolinguals, $p < .01$, or older bilinguals, $p < .05$. For negative priming effects, the 1-way ANOVA yielded no significant differences between groups, $F(3,58) = 2.1$, $p > .1$. However, planned LSD post-hoc contrasts showed stronger residual inhibition in younger than older monolinguals, $p < .05$. No other contrasts were significant. While significant positive priming effects were present in all four groups, $p < .05$, a significant negative priming effect only emerged in younger monolinguals, $p < .05$.

participant) to account for speed differences across age groups. Analyses revealed a main effect of trial type, $F(1,56) = 619.03$, $p < .001$, $\eta_p^2 = .92$, with responses on incongruent trials slower than on congruent trials. In addition, an interaction emerged between trial type and age, $F(1,56) = 8.3$, $p < .01$, with older adults showing larger inhibition effects (i.e., larger differences between incongruent and congruent trials) than younger adults, $t(58) = -2.9$, $p < .01$. Analyses of raw reaction times also revealed faster response times for younger than older adults.[4]

To investigate whether nonlinguistic and linguistic competition resolution were related, we calculated correlations between nonlinguistic Stroop effects (response times on incongruent minus congruent trials) and online within-language competition resolution (proportion of looks to competitors minus fillers in each time frame). Because we were interested in recruitment of inhibition, independent of processing speed, Stroop effects were corrected for individual differences in processing speed within each participant by dividing the Stroop effect by the average reaction times across congruent and incongruent trials. In the *older bilinguals*, negative correlations emerged between Stroop and linguistic competition between 400–500ms post word onset ($p < .05$, average $r = -.69$), suggesting that better Stroop performance was initially associated with more looks to competitors. *Younger bilinguals* showed windows of positive correlations between 677–733ms and 767–833ms post word onset ($p < .05$, average $r = .58$), suggesting that better Stroop performance was associated with fewer looks to competitors. In contrast, older and younger monolinguals did not show significant correlations between Stroop performance and linguistic competition in any adjacent time-windows during competitor activation (all ps > .05). Critically, when looks to competitors vs. fillers were correlated with overall Stroop processing speed, no significant correlations emerged, confirming that all correlations with Stroop processing could be attributed to individual differences in inhibition skill.

In addition, correlations between *looks to targets* and nonlinguistic Stroop effects in younger and older monolinguals were not significant. In *older bilinguals*, there was a *negative* correlation from 900–1033ms ($p < .05$, average $r = -.59$), suggesting that a smaller Stroop effect was also associated with more looks to targets

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4. For raw RTs, a main effect of age was observed, $F(1,56) = 37.7$, $p < .001$, $\eta_p^2 = .40$, with older participants slower ($M = 531.5$ms, $SE = 12.1$) than younger participants ($M = 426.6$, $SE = 12.1$). A main effect of trial type was also present, $F(1,56) = 518.6$, $p < .001$, $\eta_p^2 = .90$, with responses on incongruent trials slower ($M = 534.8$ms, $SE = 9.7$) than on congruent trials ($M = 423.2$ms, $SE = 8.0$). Finally, an interaction between trial type and age, $F(1,56) = 24.9$, $p < .001$, $\eta_p^2 = .31$, revealed smaller Stroop effects in younger participants (congruent minus incongruent trials, $M = -87.1$ms, $SE = 6.4$) than older participants ($M = -136.0$ms, $SE = 7.5$), $t(58) = 5.0$, $p < .001$. No other effects were significant, with statistically equivalent Stroop effects for bilinguals ($M = -116.9$ms, $SE = 8.7$) and monolinguals ($M = -106.2$ms, $SE = 7.7$), $t(58) = 0.9$, $p > .1$.

during this time window. However, in *younger bilinguals*, there was a positive correlation from 1533–1600ms ($p < .05$, average $r = .61$), suggesting that participants with smaller Stroop effects were less likely to continue fixating the target in this time-window. When the Stroop processing speed measure was correlated with looks to the target, there were additional correlations in bilinguals, with younger bilinguals showing a positive correlation between 2133–2333ms post word onset ($p < .05$, average $r = .54$), and older bilinguals showing a negative correlation between 400–933ms ($p < .05$, average $r = -.74$) and a positive correlation between 2667–2733ms ($p < .05$, average $r = .63$). In summary, nonlinguistic inhibition skills
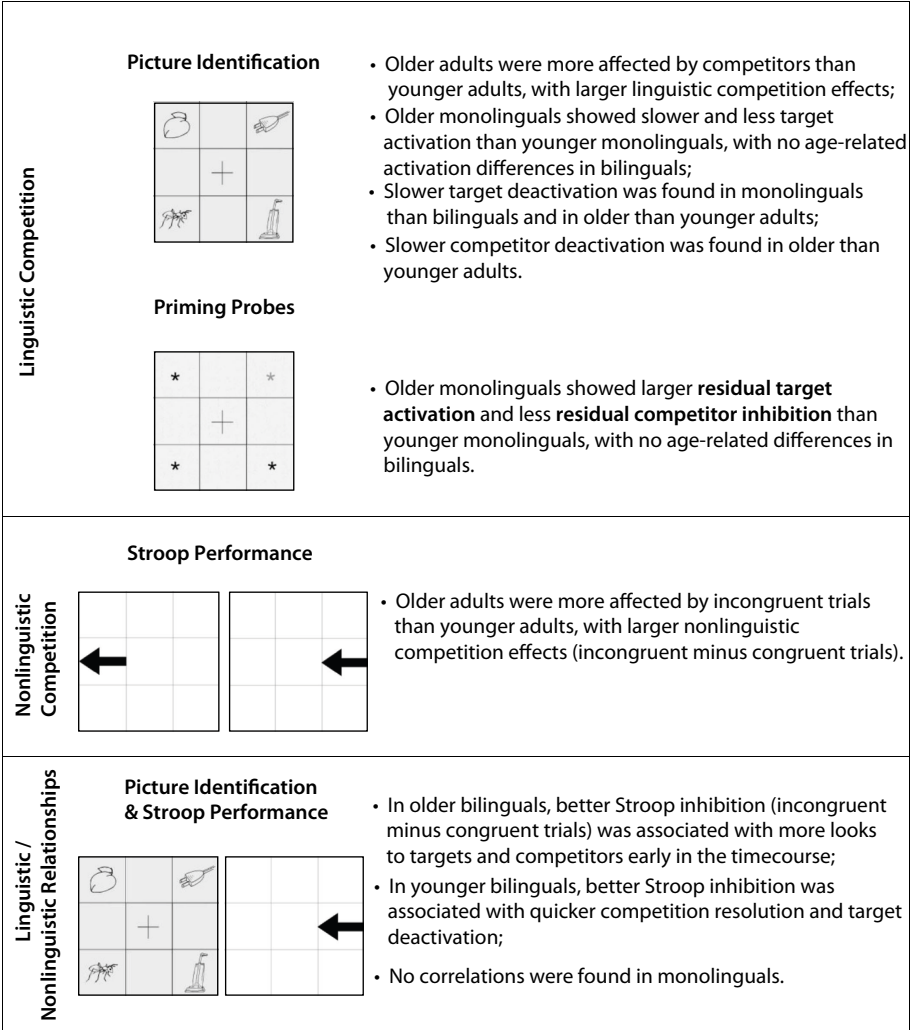

Linguistic Competition

Picture Identification

- Older adults were more affected by competitors than younger adults, with larger linguistic competition effects;
- Older monolinguals showed slower and less target activation than younger monolinguals, with no age-related activation differences in bilinguals;
- Slower target deactivation was found in monolinguals than bilinguals and in older than younger adults;
- Slower competitor deactivation was found in older than younger adults.

Priming Probes

- Older monolinguals showed larger **residual target activation** and less **residual competitor inhibition** than younger monolinguals, with no age-related differences in bilinguals.

Nonlinguistic Competition

Stroop Performance

- Older adults were more affected by incongruent trials than younger adults, with larger nonlinguistic competition effects (incongruent minus congruent trials).

Linguistic / Nonlinguistic Relationships

Picture Identification & Stroop Performance

- In older bilinguals, better Stroop inhibition (incongruent minus congruent trials) was associated with more looks to targets and competitors early in the timecourse;
- In younger bilinguals, better Stroop inhibition was associated with quicker competition resolution and target deactivation;
- No correlations were found in monolinguals.

Figure 5. Summary of key findings across linguistic and nonlinguistic competition tasks.

modulated competitor and target activation (older bilinguals) as well as competitor and target deactivation (younger bilinguals). Further, processing speed also modulated target activation (in older bilinguals) and late target de-activation (in all bilinguals), but had no influence on competitor activation or deactivation dynamics.

4.   Discussion

In the present study, participants listened to words and identified corresponding pictures from displays that contained within-language phonological competitors (e.g., *cat-cab*). Responses and eye-movements to pictures were monitored, and priming probes indexed residual activation of targets and inhibition of competitors 500ms after word identification. Within this framework, we examined age-related and bilingualism-related changes in lexical activation and competition resolution. For an overview of key findings, see Figure 5. Overall, results showed an aging effect on lexical activation and competition, with decreased accuracy, slower response rates, and increasing susceptibility to competition effects for older than younger participants even after accounting for differences in processing speed. These age-related effects were most pronounced for monolinguals with fewer significant differences between younger and older bilinguals, suggesting monolingual-bilingual differences in how competition resolution changes across the lifespan. Similarly, monolinguals but not bilinguals, showed age-related differences in residual activation and inhibition of targets and competitors, as indexed by priming probes presented after target identification. In contrast, when we examined the relationship between linguistic and nonlinguistic cognitive control, effects emerged for bilinguals but not monolinguals: Stroop skills modulated target/competitor activation in older bilinguals and modulated competition resolution in younger bilinguals. In the following sections, we discuss each of these findings in turn.

4.1   Within-language lexical activation and competition

As expected (e.g., Salthouse, 1996), lexical activation and **target identification** were subject to age-related slowing. We also examined activation beyond the maximum target peak, which is considered the point of cognitive (not manual) target identification. Examination of the target curve beyond the maximum activation point reflected stronger activation and slower rates of deactivation in older adults. Such late target activation likely reflects a combination of looks due to late target identification on some trials (i.e., variable efficiency of lexical access) and

maintained activation of successfully identified items. The latter effect is reminiscent of stronger reliance on previous contexts (Gorfein & Brown, 2007; Wingfield, 1996) or of cognitive perseveration (Foldi et al., 2003), both effects that can be linked to age-related cognitive decline. Timecourse analyses of **competition resolution** similarly reflected aging effects. Older adults showed longer competition effects and a less steep time course of competition resolution relative to younger adults, suggesting less efficient deactivation of competitors.

Age-related slowing also interacted with bilingual experience along the time course of target activation. The **target activation** curve was steeper in younger than older monolinguals, suggesting slowed lexical access in older monolinguals. Yet, no differences emerged in the target activation curves of younger vs. older bilinguals, suggesting stability in speed of lexical access across bilinguals' lifespan. Notably, these different patterns in bilinguals' vs. monolinguals' lexical access emerged even though the two older groups were equivalent on basic processing speed, as indexed through overall response times on the Stroop and linguistic tasks. Bilinguals also showed faster target deactivation across both age groups (greater curvature, Figure 4C). It is possible that this effect reflects bilingual efficiency in disengaging from previously relevant information, a skill that may be particularly useful in bilinguals who may have more experience in inhibiting previous information during language switches (e.g., Prior & Gollan, 2011).

4.2 Residual activation

To examine residual activation and inhibition patterns further downstream (500ms after manual picture identification), priming probes were examined in locations previously occupied by targets, competitors, and fillers. Robust **residual target activation**, as indexed by a positive priming effect, was present in all four groups in both accuracy and speed of response, with older monolinguals showing the greatest magnitude of residual target activation, an effect that remained even after processing speed was accounted for.

Further, younger monolinguals showed a stronger **residual competitor inhibition** effect than older monolinguals, as indexed by negative priming. This effect also maintained after processing speed had been accounted for. More robust inhibition effects in younger than older adults can be expected based on theories of age-related inhibition deficits (e.g., Hasher & Zacks, 1988). As has been argued based on data from the nonlinguistic domain (e.g., Bialystok, 2007; Bialystok et al., 2004; Bialystok, Craik, & Luk, 2008; Gold et al., 2013), it is possible that inhibition mechanisms undergo more age-related change in monolinguals than bilinguals, perhaps because of the demands associated with bilingual processing (Kroll & Bialystok, 2013). Consistent with previous findings (Blumenfeld & Marian, 2011),

a significant negative priming effect only emerged in younger monolinguals. It has been suggested that bilinguals may disengage inhibition earlier than monolinguals (Blumenfeld & Marian, 2011; Mishra et al., 2012), and bilinguals might have already resolved competitor inhibition by the time they had encountered the priming probe. Future research can further examine the time course of language-related inhibitory control immediately after word identification in bilinguals vs. monolinguals and across the lifespan. Together, current findings suggest that age-related changes in auditory comprehension are in part due to a decline in inhibitory control, above and beyond processing speed, with age-related changes more pronounced for monolinguals than bilinguals.

4.3 Links between linguistic and nonlinguistic cognitive control

Even though bilinguals' linguistic competition resolution was associated with their Stroop inhibition skills during word identification, results on the nonlinguistic Stroop task showed no effects of group (only an overall effect of age) once processing speed was accounted for. Bilingual inhibition advantages have not always been identified (e.g., Blumenfeld & Marian, 2014; Hilchey & Klein, 2011), although they appear more frequently in older adults (e.g., Hilchey & Klein, but see Kirk et al., 2014). Our objective was not to identify a bilingual advantage (a task that typically requires larger samples), but to identify relationships between nonlinguistic and linguistic cognitive control. Findings suggested that, during auditory word identification, bilinguals (but not monolinguals) recruited inhibition similar to that indexed by nonlinguistic Stroop performance. In older bilinguals, better Stroop performance was associated with more looks to **competitor and target** pictures early in the time course. Thus, in older bilinguals, efficient orientation towards relevant items was associated with cognitive control above and beyond processing speed. Interestingly, within the 900–1033ms time window where older bilinguals with smaller Stroop effects demonstrated more consistent fixations of the target, older monolinguals showed reduced activation of the target. It is thus possible that use of Stroop-related cognitive control mechanisms boosted older bilinguals' processing during this phase of target activation. Processing speed also influenced older bilinguals' target activation, with more looks (and steeper curvature) during target activation associated with less cognitive slowing. It is thus likely that a combination of processing speed and cognitive control modulate lexical activation in older bilinguals.

In contrast to older bilinguals, in younger bilinguals, the association between looks to the competitor and Stroop inhibition was time-locked to deactivation of the **competitor**, suggesting that Stroop skills modulated competition resolution. The time windows where bilinguals recruited inhibitory control mirrored

previous findings where college-aged bilinguals with smaller Stroop effects showed *more* early looks but *fewer* later looks to cross-linguistic competitors (Blumenfeld & Marian, 2013). Thus, current differences in when inhibition was recruited in older bilinguals (Stroop recruited earlier) compared to younger bilinguals (Stroop recruited later) suggest subtle age-related shifts in inhibition (also see Gollan & Ferreira, 2009) but are consistent with processing components present in younger bilinguals. Specifically, across the current and previous studies, Stroop performance has been *negatively* related with competitor activation (where more early looks to the competitor are associated with smaller Stroop effects) and *positively* related with competitor deactivation (where fewer late looks to the competitor are associated with smaller Stroop effects). The reversal in correlations across age groups can thus be explained in terms of the time window where processing was associated with Stroop performance (early and thus negative in older adults; late and thus positive in younger adults). Both competitor activation and deactivation require the participant to rule out irrelevant options on the display: filler images are ruled out during competitor activation and the competitor is ruled out during competitor deactivation. In the current study, a shift in the correlation windows may reflect age-related changes in bilinguals' language-related cognitive control that can be further examined in future research.

It is likely that the lack of correlations between linguistic and nonlinguistic competition resolution in monolinguals (also see Blumenfeld & Marian, 2011) is due to relatively consistent and effortless processing, given more extensive lexical experience in English (e.g., Gollan et al., 2011). Our data also speak to the role of individual differences within the bilinguals in influencing language control. Previous research indicates that language proficiency impacts the language selection mechanism (Costa et al., 2006; Kroll et al., 2006), and that stronger executive function is related to less cross-linguistic interference during naming (Festman et al., 2010). Here, we extend this finding to receptive language processing and to older adults, suggesting that more efficient Stroop performance was associated with more efficient lexical performance.

Taken together, our results converge with previous findings of stronger correlations between nonverbal and verbal cognitive skills in bilinguals than monolinguals (e.g., Blumenfeld & Marian, 2011; Kaushanskaya et al., 2011; Linck, Hoshino & Kroll, 2008; Prior & Gollan, 2011). Strong language-cognition links in bilinguals are also reflected in the neuroimaging literature, where bilingual activation overlaps between brain areas that control language and those that control general cognitive functioning (Abutalebi & Green, 2008; Garbin et al., 2010; Gold, Kim, Johnson, & Smith, 2013). In contrast, monolinguals do not appear to show this same overlap in cortical activation (Garbin et al., 2010). The current findings fit well with these previous results by suggesting that bilinguals, but not

monolinguals, continue to successfully recruit inhibition during auditory word recognition at older ages.

Current models of bilingualism offer an explanatory framework for the recruitment of cognitive control in bilingual processing. The adaptive control hypothesis (Green & Abutalebi, 2013) predicts that bilinguals will more rapidly adapt to the control demands of a given task when the control demands match those of bilingual processing contexts. The nonlinguistic Stroop task arguably taxes monitoring, goal maintenance, and interference control to which our bilingual participants would regularly be exposed in daily interactions. Consequently, bilinguals should be particularly skilled in resolving interference in comparison to monolinguals, and older bilinguals arguably more so due to their increased language experience. Indeed, imaging and ERP results show that bilinguals more efficiently recruit neural resources while monitoring nonlinguistic cognitive conflict (Abutalebi et al., 2011; Morales, Yudes, Gómez-Ariza, & Bajo, 2015) and while resolving linguistic competition when listening to words (Marian, Chabal, Bartolotti, Bradley, & Hernandez, 2014). Our results support this idea, and could explain why older bilinguals with better Stroop inhibition skills were faster to orient to relevant stimuli on the display, perhaps suggesting that monitoring for conflict contributes to cognitive strengths in older bilinguals.

While it is tempting to explain our results as a function of bilingual experience in inhibiting activation from the non-target language, several studies challenge the idea that inhibition alone is responsible for the bilingual advantage in executive control (e.g., Kovács & Mehler, 2009; Hilchey & Klein, 2011). We found correlational links with inhibition; yet, we cannot rule out that other cognitive mechanisms may modulate bilinguals' auditory word recognition, and must be cautious in assigning causation to any one aspect of the bilingual experience. Diverse language backgrounds and contexts of use may all contribute to the cognitive consequences of bilingualism (Green & Abutalebi, 2013; Kroll & Bialystok, 2013; Luk & Bialystok, 2013). Future research can further explain the role of these variables as predictive factors in bilingual linguistic-cognitive processing.

Our results add to a small but growing body of knowledge about bilingualism and aging. Compared to older monolinguals, older bilinguals demonstrated fewer age-related changes in their use of cognitive resources, consistent with work identifying cognitive reserves in older bilinguals that protect against age-related cognitive decline (e.g., Bialystok, 2011). Compared to monolinguals, bilinguals with conditions such as Alzheimer's remain asymptomatic 4 to 5 years longer than monolinguals (e.g., Alladi et al., 2013; Bialystok, Craik, Binns, Ossher, & Freedman, 2014; Bialystok, Craik, & Freedman, 2007; Craik, Bialystok, & Freedman, 2010). Analogously, bilinguals may engage inhibitory processes during auditory comprehension that increase the efficiency of the cognitive system

as a whole. Yet, it remains an open question whether subtle age-related changes in processing, such as the ones observed in the current findings, ultimately relate to more concrete benefits of bilingualism in later life, such as better performance on inhibitory control tasks (Bialystok, 2007; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; Gold et al., 2013) or even later onset of the symptoms associated with dementia.

4.4 Conclusion

While older bilinguals are not immune to effects of aging, the current findings suggest that their language processing patterns may more closely approximate those of younger bilinguals, indicating subtle benefits of lifelong bilingualism to lexical processing. In the present study, monolinguals showed more pronounced effects of aging than bilinguals, with greater changes in language processing across the lifespan. The active use of two languages across the lifespan may in part preserve the ability to identify relevant linguistic information and to disengage from once-relevant information. In summary, while older bilinguals did not show non-linguistic inhibition advantages, they did show advantages over monolinguals in linguistic target activation and competition resolution. These findings contribute to understanding the intersection between cognitive aging (including slowed processing and reduced inhibition skills) and bilingualism in the context of auditory word recognition.

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