Spoken Word Processing in Bilingual Older Adults:

Assessing Within- and Cross-Language Competition using the Visual World Task

Debra Titone[1,2], Julie Mercier[1,2], Aruna Sudarshan[2,3], Irina Pivneva[1,2], Jason Gullifer[1,2], & Shari Baum[2,3]

Department of Psychology[1]
Centre for Research on Brain, Language and Music[2]
School of Communication Sciences and Disorders[3]
McGill University

Author note:

Data and code can be accessed from https://osf.io/vsk8u.

Preprint for Titone, D., Mercier, J., Sudarshan, A., Pivneva, I., Gullifer, J., & Baum, S. (in press). Spoken Word Processing in Bilingual Older Adults: Assessing Within- and Cross-Language Competition using the Visual World Task. *Linguistic Approaches to Bilingualism*.

Address for correspondence:

Debra Titone, Ph.D.
Department of Psychology, McGill University
2001 McGill College Ave.
Montreal, QC, H3A 1G1
Canada
514-398-1778
debra.titone@mcgill.ca

Abstract

We investigated whether bilingual older adults experience within- and cross-language competition during spoken word recognition similarly to younger adults matched on age of second language (L2) acquisition, objective and subjective L2 proficiency, and current L2 exposure. In a visual world eye-tracking paradigm, older and younger adults, who were French-dominant or English-dominant English-French bilinguals, listened to English words, and looked at pictures including the target (*field)*, a within-language competitor (*feet*) or cross-language (French) competitor (*fille*, “girl”), and unrelated filler pictures while their eye movements were monitored. Older adults showed evidence of greater within-language competition as a function of increased target and competitor phonological overlap. There was some evidence of age-related differences in cross-language competition, however, it was quite small overall and varied as a function of target language proficiency. These results suggest that greater within- and possibly cross-language lexical competition during spoken word recognition may underlie some of the communication difficulties encountered by healthy bilingual older adults.

Keywords: spoken word recognition, bilingualism, aging, visual world, eye-tracking

To understand spoken language, people must map a temporally unfolding and noisy acoustic signal onto stored knowledge about words in memory. This noisy acoustic signal not only activates the intended word (i.e., a target word, such as, *candle*), but also words that sound similar to the intended word (i.e., competitor words, such as, *candy*). Although spoken word recognition models vary, they generally agree that successful comprehension requires that target word activation be enhanced and competitor word activation be inhibited (Luce & Pisoni, 1998; Marslen-Wilson & Welsh, 1978; McClelland & Elman, 1986; McQueen & Cutler, 2001; Norris, 1994). These are hypothetically distinct processes that are linked insofar as challenges to word identification caused by competitor word activation are more likely to occur when initial target word activation is compromised.

Of relevance here, healthy older adults who are monolingual often show deficits in spoken language comprehension that are not attributable to peripheral hearing loss (e.g., Ben-David et al., 2011; Sommers, 1996; Sommers & Danielson, 1999; Taler, Aaron, Steinmetz, & Pisoni, 2010; Wingfield, Aberdeen, & Stine, 1991, reviewed in Baum & Titone, 2014; Titone, Gullifer, Subramaniapillai, Rajah, & Baum, 2017). Such deficits, which may arise because of age-related changes in the initial activation of target and competitor words or in the ability to inhibit competitors, could ultimately lead to interpersonal communication difficulties (Benichov, Cox, Tun, & Wingfield, 2012; Pichora-Fuller, 2003). However, it is unclear whether age-related decrements in spoken language processing are similar during bilingual spoken language comprehension, where competitor words can be activated both within- and across-language, and where target activation may be compromised, particularly when listening to one's second language. Indeed, it is possible that past studies pertaining to presumably "monolingual" language processing, have in fact tested bilingual individuals in what comprises their first "native" language. Thus, in the present study, we use the visual world eye-tracking method to investigate whether age-related differences occur during bilingual spoken language processing in healthy older adults.

There is compelling evidence from the monolingual literature that older adults are less efficient in understanding spoken words, particularly for demanding communicative situations. For example, older adults show impaired comprehension when words are less frequent (Revill & Spieler, 2012) or less predictable (Sommers, 1996; Sommers & Danielson, 1999; Wingfield et al., 1991), and when words are acoustically similar to many other words (Taler et al., 2010) or presented in noisy conditions (Ben-David et al., 2011; Taler et al., 2010). These age-related effects are exemplified by two recent studies that used the eye-tracking methods of the present study, namely, the visual world task (Ben-David et al., 2011; Revill & Spieler, 2012). In a basic version of the visual world task (e.g., Allopenna, Magnuson, & Tanenhaus, 1998), participants hear instructions ("*Click on the field*") while they view competitor displays that include pictures of the target word (*field*), a within-language word-onset competitor (*feet*), and two unrelated words (*car* and *church*). During the entirety of the trial, participants' eye movements are monitored, which allows us to assess whether people look at the competitor images, which would be indicative of activation of competitor word representations. This task is well suited to studying spoken language processing in older adults, as eye movement measures offer good temporal resolution for tracking activation of intended and competitor words in a relatively natural and undemanding task environment (Allopenna et al., 1998; Cooper, 1974; Dahan, Magnuson, & Tanenhaus, 2001; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; see Huettig, Rommers, & Meyer, 2011, for review and critical evaluation).

Using the visual world task, Ben-David et al. (2011) tracked older and younger adults' eye movements to pictures as they listened to native-language target words (e.g., *candle*). They found that older and younger adults comparably activated word-onset competitors (*candy*), but that older adults also activated more phonologically distinct (with respect to the word onset) rhyming competitors (*sandal*) to a greater degree than younger adults. This suggests that older adults may have experienced a wider spread of word-onset competitor activation upon hearing a spoken word compared to younger adults, such that both near and distant lexical competitors were activated. Thus, sensitivity to the degree of phonological overlap between target and competitor words may be an important way that spoken language processing differs for older and younger adults.

In another study using the visual world eye-tracking method, Revill and Spieler (2012) found that older adults' spoken activation of target and competitor words was more affected by word frequency than that of younger adults. Specifically, older adults fixated high compared to low frequency target pictures to a greater extent than younger adults, and the same was true for high compared to low frequency competitor pictures. This suggests that older adults may have been less likely than younger adults to generate initial activation for low frequency words, or that they were less likely to disregard highly frequent competitor words (see also Sommers & Danielson, 1999; and Taler et al., 2010, for evidence linking individual differences in inhibitory control among older adults to these kinds of effects).

Of interest here is whether such impairments extend to bilingual older adults who speak more than one language. Spoken language processing for bilinguals may be especially demanding for two important reasons. First, bilingual spoken language processing is thought to involve the co-activation of two known languages (Blumenfeld & Marian, 2007; Canseco-Gonzalez et al., 2010; Marian & Spivey, 2003a, 2003b; Marian, Spivey, & Hirsch, 2003; Shook

& Marian, 2012), especially when bilinguals listen using their second compared to their first language (L2 vs. L1, respectively; Canseco-Gonzalez et al., 2010; Cutler, Weber, & Otake, 2006; Weber & Cutler, 2004). For example, in a now classic study, Spivey and Marian (1999) presented younger adult Russian-English bilinguals with objects including a target (*marker*), a phonologically similar cross-language competitor (*marku*, "stamp" in Russian), and two phonologically and semantically unrelated distracters. They found that bilinguals fixated cross-language competitor pictures significantly more than distracter objects, providing evidence of cross-language competition during L2 spoken language processing. Thus, bilinguals have more sources of lexical competition than people who know only one language (reviewed in Baum & Titone, 2014; Titone et al., 2017; Dijkstra, Van Jaarsveld, & Ten Birken, 1998; Green, 1998; Libben & Titone, 2009; Titone, Libben, Mercier, Whitford, & Pivneva, 2011).

Second, spoken word processing may also be more demanding for bilinguals because L2 phonemic categories are notoriously difficult to acquire (Best, 1995), especially when they differ from L1 phonemic categories (Broersma & Cutler, 2011; Cutler et al., 2006; Weber & Cutler, 2004). This, in turn, could lead to inaccurate L2 phoneme perception (Strange, 1995), and poorer initial activation of L2 words during spoken comprehension (Broersma & Cutler, 2011; Cutler et al., 2006; Weber & Cutler, 2004), consistent with the observation that bilingual younger adults have more difficulty recognizing L2 words in noisy environments (Rogers, Lister, Febo, Besing, & Abrams, 2006). Moreover, bilinguals may also have "weaker links" between word forms and lexical-semantic information in memory compared to monolinguals because they use words from each language relatively less frequently than monolinguals by virtue of sharing their time between two languages (Gollan, Montoya, Cera, & Sandoval, 2008; Gollan, Slattery, et al., 2011), as a function of the degree of L2 usage (Whitford & Titone, 2012, 2014; 2016; 2017). This would also increase the demands associated with bilingual spoken word processing.

In the present study, we used the visual world eye-tracking method to investigate whether healthy older adults would experience greater within- and cross-language lexical competition during spoken word recognition, compared to a sub-sample of younger adults that we tested in a prior study (Mercier, Pivneva, & Titone, 2014). This younger adult sub-sample was matched to the older adults in terms of age of L2 acquisition, objective and subjective L2 proficiency, and percentage of current L2 exposure. We were particularly interested in whether both target word and competitor word activation would be greater among older adults. As well, given the findings of Ben-David et al. (2011) described above for older adults and our past work for younger adults (Mercier et al., 2014), we investigated target and competitor word activation as a function of the amount of phonological overlap between target and competitor words. With respect to this variable, we previously observed that younger adults showed greater word-onset competition when there was a high degree of phonological overlap between a target word and a word corresponding to the name of a competitor picture (Mercier et al., 2014; see also Dufour & Peereman, 2003; Slowiaczek & Hamburger, 1992). Thus, we expected this variable to be of similar relevance when investigating spoken word processing in older adults. Finally, we were also interested in whether individual differences among older adults in English language proficiency would modulate within- and cross-language competition in older adults, given that English was the target language of the task.

Our general prediction, based upon prior work with monolinguals, was that older adults would show greater within- and cross-language competition than younger adults. We investigated this hypothesis in three ways. First, we compared older and younger adults on their fixation patterns to target word pictures (when they heard the target word) as a function of whether (within- or cross-language) competitor pictures were included in the visual display (i.e., target fixations should be reduced when competitor pictures were included). Second, we compared older and younger adults on their fixation patterns to competitor pictures, as a function of whether people heard a target word or an acoustically unrelated control word (i.e., competitor fixations should be greater when people heard target words compared to when they heard unrelated control words). Finally, we compared older and younger adults in how long it took them to mouse-click on the correct picture (when displays containing competitor pictures were included), as a function of whether they heard a target word or a control word (i.e., mouse click latency should be longer when people heard target words). Presumably, these different ways of assessing lexical competition should converge, though they each provide potentially different sources of information about the time-course of comprehension as it unfolds, and the ultimate outcome of comprehension signaled by the mouse-click (e.g., Allopenna et al., 1998; Magnuson, Dixon, Tanenhaus, & Aslin, 2007).

Methods

Participants. Forty-eight older adults from the greater Montreal community participated for $10/hour. Participants were L1 French-L2 English (*n* = 34, *M* = 66.4 years, *SD*= 5.8 years, 23 women, 11 men) or L1 English-L2 French (*n* = 14, *M* = 65.2 years, *SD*= 7.3 years, 8 women, 6 men) bilinguals. Thus, 34 older adults performed the task in their L2, whereas 14 older adults performed the task in their L1, an individual difference that we later captured statistically by examining continuous differences among bilinguals in objective English relative to French proficiency. All but four participants were sequential bilinguals, who acquired their L1 and L2 before 1 year of age (2 French-dominant and 2 English-dominant participants). All participants reported being formally educated in, and dominant for the language designated as their L1 for the study. Older adults were matched to a subset of 48 younger adult bilinguals younger adults taken from our prior study (Mercier et al., 2014): 34 French-dominant (*M* = 24.0 years, *SD*= 3.7 years, 23 women, 11 men) and 14 English-dominant (*M* = 23.5 years, *SD*= 4.2 years, 11 women, 3 men). Younger adults were matched to older adults in terms of age of L2 acquisition, current objective and subjective L2 proficiency levels, and current percentage of L2 exposure (see Table 1). Participants were excluded if they had a history of learning or neurological disorders, or currently taking any psychoactive medications.

Insert Table 1 about here

Older adults were screened for hearing and cognitive impairment to minimize the possibility that group differences, where found, would be attributable to hearing or general cognitive function. Pure tone air conduction thresholds were determined at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz using an audiometer (Maico Diagnostics, Eden Prairie, MN). Average pure tone thresholds obtained at 500, 1000, and 2000 Hz were lower than 35 dB for each ear ($M_{left\ ear}$ = 19 dB, $SD_{left\ ear}$ = 8 dB; $M_{right\ ear}$ = 20 dB, $SD_{right\ ear}$ = 7 dB) for all but two participants. The remaining two with average hearing thresholds of 36 dB reported good hearing and no difficulties performing the task, and were thus retained. All participants obtained scores of 26/30 or above (M = 28.2, SD = 1.4) on the Montreal Cognitive Assessment (Nasreddine et al., 2005), which was administered in the first and most dominant language.

Additional individual difference measures were administered, which included an L1 vocabulary task (Wechsler Abbreviated Scale of Intelligence, WASI; Wechsler, 1999; French L1 participants performed this test in French, and English L1 participants performed this test in English), a language experience questionnaire (modified version of LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007), an objective measure of proficiency in the form of a speeded animacy judgment task performed in English and French (Segalowitz & Frenkiel-Fishman, 2005), and several measures of executive control. Executive control measures included a computerized version of the Backward Digit Span (BDS) from the Wechsler Adult Intelligence Scale (Wechsler, 1999); a Simon task (Blumenfeld & Marian, 2007; Simon & Rudell, 1967), a Stroop task (Liu, Banich, Jacobson, & Tanabe, 2004; Stroop, 1935), and a mixed anti-saccade task (Hallett, 1978). Presentation order of these tasks was counterbalanced across participants.

Materials. Materials consisted of 20 item sets that included auditory target and control words, and six target pictures (target, within- and cross-language competitors, and 3 distracter pictures; see Appendix A for all stimuli, and Mercier et al. (2014), for greater detail about how stimuli were selected and normed).

For each of the 20 stimulus sets, there were 4 display conditions, each seen in combination with 2 spoken word conditions, for a total of 160 trials (62.5% of trials involved no-competitor displays). Spoken word stimuli consisted of the target (*field*) and control (*car*) words, which were preceded by instructions directing participants to click on the heard word ("*Click on the field"*). The 4 different display types consisted of the within-language competitor display (where the picture of an English competitor was presented, e.g., *feet*, along with the target and unrelated distracters), the cross-language competitor display (where the picture of a French lexical competitor was presented, e.g., *fille*, along with the target and unrelated distracters), the combined within- and cross-language competitors display (presenting both competitor types along with the target and 1 unrelated distracter), and the no-competitor control display (which consisted only of the target and 3 unrelated distracters; see Appendix B). Control trials were presented to prevent participants from potentially expecting competitors on every trial (Tanenhaus, 2007). Combined within- and cross-language competitor display trials were not included in the analyses reported below because our prior work with younger adults (and inspection of the data here with older adults) showed it to pattern similarly with the within-language competitor display but in a more variable fashion (see Mercier et al., 2014).

The inner corner of each picture was 2.33 degrees of visual angle away from the center of the screen. Picture height and width varied but had an approximate surface area of 51 cm. Four pseudo-randomized trial lists were created so that the target, competitor and distracter pictures were presented in all four quadrants across participants in a counterbalanced fashion. Displays from each stimulus set were distributed in the lists so they were equally spaced in time, and the same display was presented once with each word heard.

Spoken instructions were digitally recorded by a female, native speaker of Canadian English, and down-sampled to 16 kHz using Sony Sound Forge 8.0. There were no significant differences in length (in milliseconds) between targets ($M = 728$, $SD = 102$) and control words ($M = 750$, $SD = 119$; $p = 0.53$). We determined the degree of phonemic overlap between the target and competitor words of each type (i.e., within- and cross-language) for each stimulus set individually, using a gating procedure (Grosjean, 1980). Specifically, coders (one English-French and one French-English bilingual) listened to incrementally longer sections of the target word files using a waveform editor, and determined the point in time when the target stimuli no longer sounded like within- and cross-language competitors (reliability across raters was $r = .88$). The mean duration of word-initial overlap between target and within-language competitors was 299 ms; that between target and cross-language competitors 290 ms, a difference that was not statistically significant.

Apparatus. Eye movement data were acquired with an Eye-Link 1000 tower mounted system (SR-Research, Ontario, Canada) with a sampling rate of 1 kHz using Experiment Builder (SR-Research, Ontario, Canada). Viewing was binocular, but eye movements were recorded from the right eye only. Calibration consisted of a standard 5-point grid. The stimuli were presented on a 21-inch (50.8-cm) CRT monitor located 71 cm away from participants.

Procedure. The experiment was carried out in English, and language assessment tests (vocabulary task, speeded lexical judgment task, language questionnaire) were administered after the visual world task to reduce the probability of inadvertently activating the non-target language (French) and thus altering baseline activation levels of English and French during the task. Older participants were tested over two sessions spanning about a week. The visual world task was administered on the same day as the executive control tasks, background questionnaire, and audiometric screening. The animacy judgment task and WASI Vocabulary test were administered to the same participants during a second experimental session on a different day.

Each trial began with the presentation of a fixation point in the middle of the screen (see Figure 1), followed by a centrally located red square. Participants moved the cursor (green circle) and clicked on the red square to trigger appearance of a picture display and the spoken sentence. Participants were instructed to naturally scan the pictures and click on the appropriate one after hearing the instructions. The pictures disappeared following a mouse click, and the calibration circle reappeared, signaling the beginning of a new trial.

Insert Figure 1 about here

Results

Fixation data were analyzed using linear mixed effects (LME) models within the lme4 package of R (version 3.0 for Mac OS X; Baayen, Davidson, & Bates, 2008; Bates, 2007; Bates, Kliegl, Vasishth, & Baayen, 2015; R Development Core Team, 2012). The onset of each fixation was measured from the onset of the saccade leading to it (Altmann & Kamide, 1999). We discarded trials where participants clicked on a wrong picture, made no fixations to the named picture, or took less than 200 ms to respond (3.5% of the data). Overall, participants' mouse-click accuracy was above 95%, and older adults were significantly less accurate and slower than younger adults.

To reiterate the overall design, older and younger adults heard either target words or control words, and saw displays containing competitors (within- or cross-language) or not. Dependent variables included the proportion of fixations to a target picture when competitors were absent or present in a display (the no-competitor and within/cross-language competitor display condition, respectively); the proportion of fixations to a lexical competitor (within- or cross-language) when the target or control word was heard for competitor-bearing displays; and the latency of a mouse-click to a target picture when the target or control word was heard for competitor-bearing displays. Again, we were particularly interested in determining the effect of English-proficiency on within- and cross-language competition for older adults alone to complement our past work detailing the larger group of bilingual young adults (Mercier et al., 2014).

For these reasons, our data analytic approach was as follows. First, we examined whether age-related differences would emerge in within-language competition between target and competitor words for each dependent variable and model contrast mentioned above. Second, we examined whether individual differences in English proficiency modulated these effects in older adults alone. For these secondary analyses of older adults alone, we were only interested in the presence or absence of interactions between English proficiency and key independent variables in the analyses, such as whether a display contained competitors or not, or whether a target or control word was heard for the relevant model. For our objective measure of L2 proficiency, we used the ratio of English-to-French reaction time on the speeded animacy judgment task (Segalowitz & Frenkiel-Fishman, 2005). Here, greater ratios suggest lower proficiency in

English relative to French (see Bialystok, Craik, & Luk, 2008, and Gollan, Salmon, Montoya, & Galasko, 2011, on the benefits of objective proficiency measures). This ratio measure was significantly correlated with percentage of English daily exposure for the older adults ($r=-0.58$, $p<.01$) and younger adults ($r=0-.39$, $p<.01$) tested here, and affected the degree of lexical competition experienced by bilingual younger adults in our previous work (Mercier et al., 2014; Whitford & Titone, 2012). The same analytic procedure just described was also used to examine cross-language competition.

We chose 200 ms as a lower bound for the analysis based on visual examination of fixations over time, consideration of the time needed to program and launch a saccade (Altmann & Kamide, 2004; Fischer, 1992; Hallett, 1978; Matin, Shao, & Boff, 1993; Saslow, 1967), and other visual world studies (Dahan et al., 2001; Magnuson et al., 2007; Salverda et al., 2007; Yee, Blumstein, & Sedivy, 2008; but see Altmann, 2011, for saccade programming estimates of approximately 100 ms). The 1000-ms upper boundary was chosen based on inspection of the data, and previous visual world studies showing that fixations to targets typically asymptote at this time (e.g., Allopenna et al., 1998). For subsequent analyses, we computed the average proportion of fixations to each picture for time bins extending from 200 to 600 ms and from 600 ms to 1000 ms. The rationale for splitting the larger 200-1000 ms time bin was to obtain greater temporal sensitivity in characterizing age-related effects in the time course of word recognition.

To reduce collinearity, all continuous variables were centered and scaled. We report results for models with complex random structures where appropriate (Barr, Levy, Scheepers, & Tily, 2013), along with *p-values* calculated using the Satterthwaite approximation implemented in the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2016).

Within-language competition. Figure 2 presents the proportion of fixations to target and within-language competitor pictures as a function of display (i.e., competitor vs. no-competitor) and spoken word condition (i.e., target word heard, control word heard). For the eye movement data, we first present the results for the 200 – 600 ms time bin, followed by results from the 600 – 1000 ms time bin.

Insert Figure 2 about here

Fixations to target pictures as a function of display (competitor display vs. no-competitor display), only when the target was heard. The overall model for target fixations between 200 and 600 ms consisted of a 2 (Age group: older, younger) x 2 (Display type: with competitor, without competitor) x Phonological overlap (scaled, continuous), with trial order and WASI score as continuous control variables. There was a significant interaction between display viewed (within-language competitor vs. no-competitor display) and group (older vs. younger) ($b = -0.06$, $SE = 0.03$, $p = .037$). Models for each group separately showed a main effect of display for older ($b = -0.08$, $SE = 0.02$, $p < .001$) but not younger ($b = -0.02$, $SE = 0.02$, $p = .211$) adults, suggesting that only older adults experienced reliable within-language competition for this window. This can be seen in Figure 2 by the fact that the target fixation lines diverge earlier for older adults than for younger adults as a function of whether a competitor picture was included in the display.

The same model as above was applied to target fixations between 600 and 1000 ms. There was a marginal effect of display ($b = -0.04$, $SE = 0.02$, $p = .065$). The group interaction was not significant; however, the effect of display was again reliable only for older (older: $b = -0.05$, $SE = 0.02$, $p = .043$) but not younger adults ($b = -0.02$, $SE = 0.02$, $p = .236$).

Fixations to within-language competitor pictures as a function of word heard (target vs. control), only when competitor displays were presented. The overall model for competitor fixations between 200 and 600 ms consisted of a 2 (Age group: older, younger) x 2 (Word heard: target, control) x Phonological overlap: (scaled, continuous), with trial order and WASI score as continuous control variables. There was a main effect of word heard (b = 0.09, SE =0.02, p < .001), suggesting that both groups looked at within-language competitor pictures significantly more when they heard the target word than when they heard a control word, irrespective of phonological overlap (older adults alone: b = 0.08, SE =0.02, p = .002; younger adults alone: b = 0.10, SE =0.02, p < .001).

The same model as above was applied to competitor fixations between 600 and 1000 ms. There was a significant three-way interaction between word heard, phonological overlap, and group (b = -0.03, SE =0.01, p = .006). Models for each group separately suggested that this three-way interaction was driven by a significant two-way interaction between word heard and phonological overlap for younger (b = 0.05, SE =0.02, p < .001) but not older adults, for whom only a main effect of word heard occurred (b = 0.06, SE =0.01, p < .001). Thus, it appears that older adults showed significant within-language competition irrespective of phonological overlap between target words and competitor words (i.e., for all items). In contrast, younger adults only showed significant within-language competition when phonological overlap was high (i.e., only for items most likely a priori to induce a competition effect; see Figure 3).

Insert Figure 3 about here

Correct mouse clicks for within-language competitor-display trials as a function of word heard (target vs. control). The overall model for correct mouse clicks on competitor display trials consisted of a 2 (Age group: older, younger) x 2 (Word heard: target, control) x Phonological overlap (scaled, continuous), with trial order and WASI score as continuous control variables. Older adults clicked on the target picture more slowly than younger adults (*b* = 284.33, *SE* = 71.31, *p* <.001). There was a significant two-way interaction between word heard and phonological overlap (*b* = 71.64, *SE* = 25.68, *p* = .005), suggesting more within language competition as phonological overlap increased. Although the three-way interaction was not significant, the two-way interaction between word heard and phonological overlap was significant for younger adults (*b* = 91.39, *SE* = 29.41, *p* = .002) but not older adults (*b* = 54.15, *SE* = 42.42, *p* = .202), patterning with the fixation results above.

Interactions with English-language proficiency for older adults alone. The same models enumerated above were rerun with the following changes: Age group was dropped as a fixed effect because only older adults were included (i.e., younger adults were omitted from this analysis) and English-language proficiency was included as a continuous fixed effect (i.e., the English/French ratio described above; see Mercier et al., 2014, for a detailed account of the effects of language proficiency in a larger younger adult sample). There were no significant interactions with the objective measure of English-to-French proficiency.

Within-language competition summary. There were two indications that within-language competition was greater for older compared to younger adults. First, for the early time-bin, fixations to target pictures were significantly lower for older adults when the display contained competitors compared to when it did not. Second, for the later time bin, fixations to competitor pictures occurred irrespective of target/competitor phonological overlap for older adults; in contrast, younger adults only fixated competitor pictures if they had high target/competitor phonological overlap (this pattern was hinted at in the mouse click anlaysis). Interestingly, there was no interaction between English proficiency and within-language competition for English among older adults.

Cross-language competition. Figure 4 presents the proportion of fixations to the target and cross-language competitor pictures as a function of display (i.e., competitor vs. no-competitor) and spoken word condition (i.e., target word heard, control word heard).

Insert Figure 4 about here

Fixations to target pictures as a function of display (competitor display vs. no-competitor display), only when the target was heard. The overall model for target fixations between 200 and 600 ms consisted of a 2 (Age group: older, younger) x 2 (Display type: with competitor, without competitor) x Phonological overlap (scaled, continuous), with trial order and WASI score as continuous control variables. The same model was applied to target fixations between 600 and 1000 ms. In neither case was there evidence of cross-language competition. Only a main effect of phonological overlap occurred, potentially due to differences across items that may have correlated with phonological overlap, most notably word length (i.e., phonological overlap increased as target word length in number of phonemes decreased; e.g., *knees* - *nid* vs. *bathtub* - *bâton*). Thus, despite the visual indication of a display effect in Figure 4 for both groups (using standard error of the mean error bars for subject-averaged data), there was no statistical evidence using linear mixed effects modeling of a display effect.

Fixations to cross-language competitor pictures as a function of word heard (target vs. control), only when competitor displays were presented. The overall model for competitor fixations between 200 and 600 ms consisted of a 2 (Age group: older, younger) x 2 (Word heard:

target, control) x Phonological overlap (scaled, continuous), with trial order and WASI score as continuous control variables. There was a significant interaction between word heard and phonological overlap (b = 0.04, SE =0.01, p = .007), indicating that both older and younger adults showed greater cross-language competition as phonological overlap increased (older adults alone: b = 0.04, SE =0.01, p = .011; younger adults alone: b = 0.05, SE =0.02, p = .005).

The same model as above was applied to competitor fixations between 600 and 1000 ms. The two-way interaction between word heard and phonological overlap was significant for older adults (b = 0.04, SE =0.01, p = .010), showing that cross-language competition increased as phonological overlap increased. This two-way interaction was only at trend levels for younger adults (b = 0.02, SE =0.01, p = .09) and did not support the idea that cross-language competition increased as did phonological overlap. Figure 5 plots this effect.

Insert Figure 5 about here

Correct mouse clicks for cross-language competitor-display trials as a function of word heard (target vs. control). The overall model for correct mouse clicks on competitor display trials consisted of a 2 (Age group: older, younger) x 2 (Word heard: target, control) x Phonological overlap (scaled, continuous), with trial order and WASI score as continuous control variables. There was an interaction between word heard and phonological overlap (b = 138.18, SE = 63.81, p = .044), indicating greater cross-language competition as phonological overlap increased for both groups (older adults alone: b = 130.25, SE = 63.69, p = .056; younger adults alone: b = 146.62, SE = 68.42, p = .046).

Interaction with English-language proficiency in older adults. Again, the same models enumerated above were rerun with the following changes: Age group was dropped as a fixed effect because only older adults were included (i.e., younger adults were omitted) and English-language proficiency was included as a continuous fixed effect (i.e., the English/French ratio described above). The only interaction of note was that older adults showed more cross-language competitor fixations when the target was heard than when the competitor was heard in the 600 – 1000 ms time window as English proficiency decreased ($b = 0.03$, $SE = 0.01$, $p < .001$). Figure 6 re-plots the older adult data in Figure 5 to highlight this effect.

Insert Figure 6 about here

Cross-language competition summary. First, there was no statistical evidence of cross-language competition with respect to target fixations for either group. Second, there was evidence of cross-language competition for words that had high target/competitor phonological overlap with respect to competitor fixations. This effect did not differ between younger and older adults for the early time bin, and there was only a non-significant trend for an age-group interaction at the later time bin. Third, there was evidence of cross-language competition when target/competitor phonological overlap was high with respect to mouse-click latency for competitor displays, but this did not differ between groups. Finally, there was greater evidence of cross-language competition for competitor fixations in the late time window among older adults as English proficiency decreased.

Discussion

We investigated whether bilingual older adults would experience more within- and cross-language competition during spoken word processing compared to a sample of younger adults matched in their degree of bilingualism. We predicted that older adults would show greater within- and cross-language competition than what would be observed for younger adults. We also predicted that older adults would show a greater spread of competitor activation than younger adults, which would specifically include competitor words that were both phonologically close and distant (assessed here in terms of the amount of phoneme overlap between target and competitor words), as opposed to only competitors that were phonologically close. Finally, we predicted that individual differences in English language proficiency, which was the language of the task, would relate to the amount of cross-language competition observed in older adults alone.

We found only partial support for these predictions. First, with respect to within-language competition, older adults as a group showed clear evidence of within-language competition, consistent with several studies of monolingual spoken language processing (e.g., Allopenna et al., 1998; Blumenfeld & Marian, 2011; Dahan & Gaskell, 2007) and bilingual spoken language processing (e.g., Canseco-Gonzalez et al., 2010; Marian & Spivey, 2003a, 2003b). Thus, when hearing a target word (*field*), older adults showed reduced target fixations when the visual display contained pictures of within-language competitors (*feet*) compared to when it did not. Similarly, when seeing a visual display that contained pictures of within language competitors, older adults showed more fixations to within-language competitors (*feet*) when they had heard the target word (*field*) compared to when they had heard an unrelated control word (*car*). With respect to this latter contrast, within the older adult group, the latency of mouse clicks was also longer when the display contained a within-language competitor.

With respect to age-group interactions, older adults showed disproportionately more within-language competition when compared to a matched sample of younger adults taken from a prior study (Mercier et al., 2014), also consistent with prior visual world work on monolingual (or native language) processing (Ben-David et al., 2011; Revill & Spieler, 2012). In particular, they showed greater within-language competition in terms of target fixations when competitor pictures were present compared to when they were absent, especially early in the course of word recognition (i.e., 200-600 ms following word onset). As expected, older adults also showed a greater spread of within-language competitor activation than younger adults in that they showed comparable within-language competition for all words, in contrast with younger adults who only showed within-language competition in the 600-1000 ms time for words that had high target/competitor phonological overlap. Both groups showed relatively greater within-language competitor activation for the early 200-600 ms time window for high phonological overlap items. Thus, whereas younger adults only activate within-language competitors that are phonologically close throughout the time-course of comprehension, older adults initially do the same, but then competition spreads to include more distant competitors as well. Interestingly, older and younger adults were comparably slowed by the presence of within-language competitors in the display with respect to mouse-click latencies, which signaled that word identification was complete, though older adults were slower overall in making their responses.

Our findings with respect to within-language competition are generally consistent with this prior work on older adults and extend this work to a fully bilingual older adult sample. For example, our results are compatible with what Ben-David et al. (2011) found for rhyming words that did not share the initial phoneme with a target, for which older adults experienced more lexical competition than younger adults. However, our results slightly differ from those of Ben-David et al. (2011), where both older and younger adults more easily discriminated target and word-onset competitors when competitor/target phonological overlap was relatively low (i.e., following the presentation of disyllabic vs. monosyllabic words, where disyllabic words had a lower proportion of overlapping phonemes between targets and competitors than monosyllabic words). This discrepancy could conceivably have arisen because our task language was the L2 for the majority of participants, in contrast with Ben-David et al. (2011), where all participants performed the task in their L1, and some individuals could have been fully monolingual. However, given that individual differences among older adults in English proficiency (which is highly correlated with whether the task was the L1 or the L2 across participants) did not statistically modulate the amount of observed within-language competition, it is possible that simply being bilingual may have led to the difference across studies. For example, as discussed earlier, bilinguals likely differ from monolinguals, even during L1 processing, due to one of several inter-related factors (reviewed in Baum & Titone, 2014; Titone et al., 2017). These include language co-activation, more variable phonemic categories (e.g., Best, 1995; Strange, 1995), or weaker links between word forms and meaning generally (e.g., Gollan et al., 2008; Whitford & Titone, 2012, 2014, 2016; 2017). However, future work that directly compares bilingual and monolingual older adults would be necessary to speak more directly to these points.

Our second key finding pertained to cross-language competition among older adults. Consistent with other visual world studies, there was some evidence for cross-language competition among older adults (Blumenfeld & Marian, 2007; Canseco-Gonzalez et al., 2010; Marian & Spivey, 2003a, 2003b; Mercier et al., 2014; Spivey & Marian, 1999). However, the magnitude of the cross-language effect observed here was dependent on target language proficiency (see Figures 3 & 4), which coheres with our prior work with younger adults (Mercier et al., 2014) and several other studies (Blumenfeld & Marian, 2007; Canseco-Gonzalez et al., 2010; Cutler et al., 2006; Weber & Cutler, 2004). We found no statistical evidence for cross-language competition in terms of target fixations (despite an indication to the contrary in Figure 4), although older adults showed increased cross-language competitor fixations, particularly when phonological overlap between target words and cross-language competitors was high, and when English proficiency was low.

With respect to age-group interactions, there was a non-significant trend towards more cross-language competition for older adults in terms of competitor fixations than younger adult controls between 600 and 1000 ms following word onset. This age effect with respect to cross-language competition was not overwhelming, and we believe it arises from the fact that cross-language competition was minimal overall. As such, this result is in line with other visual world studies showing cross-language competition to be quite fragile insofar it is dependent upon many factors, such as whether the task is performed in the L1 or L2 (i.e., Marian & Spivey, 2003a, 2003b), age of acquisition for the task language, and the degree of L2 experience (Blumenfeld & Marian, 2007; Canseco-Gonzalez et al., 2010).

Indeed, it is highly likely that the experimental situation created by the present study reduced the likelihood of observing cross-language competition in that we took active steps to emphasize English, the task language, to experimentally simulate an English-only communicative context. Accordingly, the experimenters interacted with all study participants in English, none of the bilingual language assessment measures were presented prior to the visual world task itself, and the target words were all produced and recorded by a native English speaker, which would minimize any subtle acoustic cues to the other language and thus reduce cross-language effects (Cutler et al., 2006; Weber & Cutler, 2004). For example, Cutler et al. (2006) and Weber and Cutler (2004) found that cross-language competition was significantly reduced when target word vowels were more acoustically similar to the target language rather than the non-target language, a situation that is potentially true of the present study.

Two other features of the current study are also worth noting. The first regards phonological overlap, which we defined as the relative proportion of shared word-onset phonemes between a target word and its competitor. To the extent that this variable correlated with other features of the stimuli, this could undermine our interpretation of phonological overlap effects. While phonological overlap did not significantly correlate with word frequency or attributes of the pictures in the display (e.g., visual complexity ratings), it did correlate with target word length (i.e., target words with high phonological overlap were shorter than those with low phonological overlap on average). Future work could thus disentangle these two variables. However, it is difficult for us to do so here, given that we exhausted many if not all of the possible words overlapping at onset in English and French that were also imageable. Moreover, reframing interpretation of the interaction as a target length effect (rather than a phonological overlap effect) would be similar in spirit to the hypothesized underlying perceptual mechanism at play, namely, the ability to perceptually disentangle target words from competitor words, which would also be more difficult to do for shorter compared to longer words.

A second potential issue is whether baseline differences in fixation proportion across the groups (i.e., fixations occurring prior to 200 ms) could be responsible for the age interactions we observed for within-language competition. Looking at Figure 2, two baseline differences between older and younger adults are evident – one is the difference for older adults (not seen for younger adults) between both target fixation lines and competitor fixation lines, and the second is the divergence in target fixations between the competitor-display and no-display lines prior to 200 ms. Regarding the first difference, we can only speculate why this occurred, however, we do not believe it drove any observed age interaction reported here because we never statistically compared target fixations directly to competitor fixations. Moreover, to the extent that older adults would have been more attuned to targets in the visual display compared to younger adults, this would have worked against the hypothesis (and actual finding) that they were more affected than younger adults by the presence of within-language competitor pictures. Regarding the second difference between the two target fixation lines themselves, we can again only speculate as to why this occurred, though the 200 ms estimate of how long it could take for a cognitive effect to manifest in eye fixation data is not without debate (e.g., see Altmann, 2011, who proposes a lower limit of 100 ms). Perhaps more importantly, the conclusion of greater within-language competition for older adults does not rely on the target fixation effect, in that we also report an age interaction in the competitor fixation data. Thus, we believe that baseline differences do not undermine the current interpretation of the data.

Thus, the clearest take-home message of this study is that older adults show greater within-language competition compared to matched younger adults, and an overall pattern of cross-language competition that trended towards being greater than that of matched younger adults. Given that our older adult sample was on the "young end" of typical aging studies (e.g., mean age 65 years), it is possible that this difference would be more pronounced for an older adult sample that trended towards being relatively older. This leads to the important question of why this pattern of differences and similarities occur. One possibility, and indeed, the hypothesis that originally led us to conduct this study, is that age-related differences in executive or inhibitory control capacity would cause older adults to show greater within- and cross-language effects. Such a conjecture would be consistent with prior work that has documented age-related changes in executive control (Braver & Barch, 2002; Hasher, Lustig, & Zacks, 2007; Hedden & Gabrieli, 2004; Raz, 2000; West, 1996), prior work showing spoken language comprehension to be more effortful in older relative to younger adults (Ben-David et al., 2011; Sommers, 1996; Sommers & Danielson, 1999; Taler et al., 2010; Wingfield et al., 1991), prior work linking independent measures of executive control performance to spoken language processing success in older adults (e.g., Sommers & Danielson, 1999; Taler et al., 2010).

Consistent with this hypothesis, older adults showed evidence of less efficient executive control performance compared to the matched younger adults (i.e., on the Backward Digit Span and Non-verbal Stroop tasks), but this result was not consistent across other executive control tasks (e.g., the Simon and Antisaccade tasks). Moreover, post-hoc analyses exploring whether differences in executive control among older adults modulated within- and cross-language competition did not reveal a clear pattern, in contrast to our prior study with younger bilinguals (Mercier et al., 2014; see also Pivneva, Mercier, & Titone, 2014 for such a link during bilingual reading, and Pivneva, Palmer & Titone, 2012, for the same during natural bilingual language production). It is possible that studies involving larger sample sizes, or older adults who are less high functioning than the present sample might find a link between executive control and within- or cross-language competition. It is also possible that future studies deliberately designed to maximize cross-language competition would be more likely to find such a link.

As well, a direct link to executive control among older adults may be less operative because spoken language processing impairments can be attributable to other sources of age-related declines. These could include reduced target activation rather than decreased competitor inhibition; competitor inhibition is uniformly poor among all older adults; or other age-related changes in cognition may be responsible. With respect to the latter possibility, sensory/perceptual factors may also be at play (e.g., Pichora-Fuller, 2003). For example, older adults with poor hearing acuity need a greater amount of word onset information to recognize words presented in a neutral contexts compared with older adults with good hearing acuity and young adults (Lash, Rogers, Zoller, & Wingfield, 2013). Nonetheless, with respect to the present study we found no evidence that individual differences in hearing levels modulated our results when we computed post-hoc models, suggesting that the nature of the age difference in lexical competition was probably more cognitive than perceptual.

With respect to other cognitive factors, older adults may have experienced greater within-language competition than younger adults because of age-related slowing (e.g., Salthouse, 1996). Slower processing may impair listeners' ability to keep up with the auditory signal, and a slower integration of phonological information may result in a more limited ability to use phonologically divergent information to constrain the scope of lexical competition, thus resulting in greater lexical competition. Of course, disentangling the consequences of cognitive slowing from other approaches, such as the executive or inhibitory control account, is quite challenging, as these two theories may not be mutually exclusive or empirically distinguishable in a clear way (Albinet, Boucard, Bouquet, & Audiffren, 2012). Taken together, the theories suggest that the aging brain undergoes a wide array of functional and structural changes with healthy aging (for a review, see Hedden & Gabrieli, 2004), which may account for differences in overt behavior of the kind seen here in older adults.

To conclude, similar to past work on monolingual older adults, bilingual older adults show increased within-language competition during spoken language processing. In contrast, there was weak evidence of greater cross-language competition in older adults. These results suggest that greater within-language lexical competition during spoken word recognition is more likely than cross-language competition to underlie some of the communication difficulties encountered by healthy bilingual older adults, yet it remains unclear whether such low-level effects would be reduced in more naturalistic contexts where greater top-down, knowledge-driven processing is possible. Indeed, such questions may be fruitfully explored using more naturalistic measures of spoken comprehension or bilingual dialogic interaction (e.g., Pivneva et al., 2012). Whether the age-related differences in within-language competition are attributable to other specific changes in cognition with normal healthy aging, such as executive control or cognitive slowing, remains an important question for future work.

Author Note

This research was supported by a Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Award (Titone) and a Social Sciences and Humanities Research Council (SSHRC) grant (Baum). The authors gratefully acknowledge additional support from a Canada Graduate Scholarships (CGS) Doctoral Award from the Canadian Institutes of Health Research (CIHR) (Mercier), a Frederick Banting and Charles Best CGS, Master's Award from the CIHR (Pivneva), and the Canada Research Chairs Program (Titone). The authors are also grateful to Mohsen Akbari, Ashley Benatar, Stéphane Coulombe Bisson, Matthieu Couturier, Dr. Corinne Haigh, Karen Jarboe Singletary, and Emily Quinan for their help with stimuli development and data processing.

Table 1.
Demographics and self-assessed and objective L1 and L2 measures.

	Bilingual Younger Adults (n = 48)		Bilingual Older Adults (n = 48)	
	Mean	SD	Mean	SD
Age (years)	23.8	3.8	66.0	6.2
Gender	34 women, 14 men		31 women, 17 men	
Education (years)	15.7	1.1	15.6	4.4
General Language Abilities (L1)				
WASI Vocabulary*	14	2	13	3
Self-Rated L2 Proficiency				
ListeningComprehension	8	2	8	2
Speaking	8	1	7	2
Reading	8	1	8	2
Writing	7	2	7	2
Translating	7	2	7	2
Pronunciation	7	2	8	2
Fluency	7	2	8	2
Vocabulary**	7	2	8	2
Grammatical Ability	7	2	7	2
Overall Competence	7	1	8	2
Age of L2 Acquisition	8	4	8	5
Daily Percentage of Exposure to Language				
L1	66	19	72	22
L2	32	19	28	22
Objective Proficiency (Speeded Animacy Judgment Task)				
Reaction Time				
L1***	687	89	826	148
L2***	740	152	875	164
Accuracy				
L1	96	3	96	2
L2	95	4	96	3
Objective Proficiency in English (Target Language)				
Ratio of English-to-French Reaction Time	0.99	0.13	0.96	0.13

Note. The two groups were compared on all measures with independent t-tests (* $p < .05$, ** $p < .01$, *** $p < .001$). Daily percentages of exposure to L1 and L2 do not add up to 100% in bilingual younger adults because some participants were exposed to a third language.

Figure 1. Timing details of the visual world task. Example of within- and cross-language competitor trials where the target word was presented (the same displays were presented with the control word).

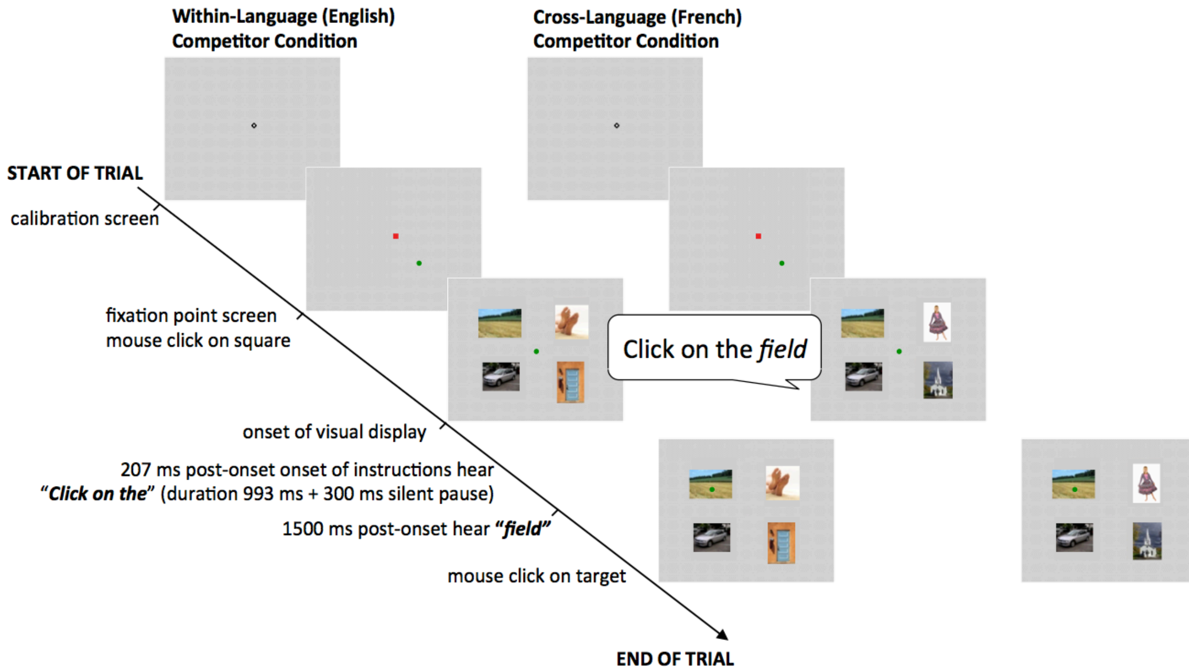


Figure 2. Within-language competition for younger and older adults (left panel and right panel, respectively). Only trials where the target picture was correctly identified were included. The grey border reflects the standard error of the mean. The red lines reflect looks to the target images when the target word was heard and a within-language competitor image was present in the display; the blue lines reflect looks to the target images when the target word was heard and there was no competitor image in the display; the orange line reflects looks to the within-language competitor images when the target word was heard; the green lines reflect looks to the within-language competitor images when an unrelated control word was heard.

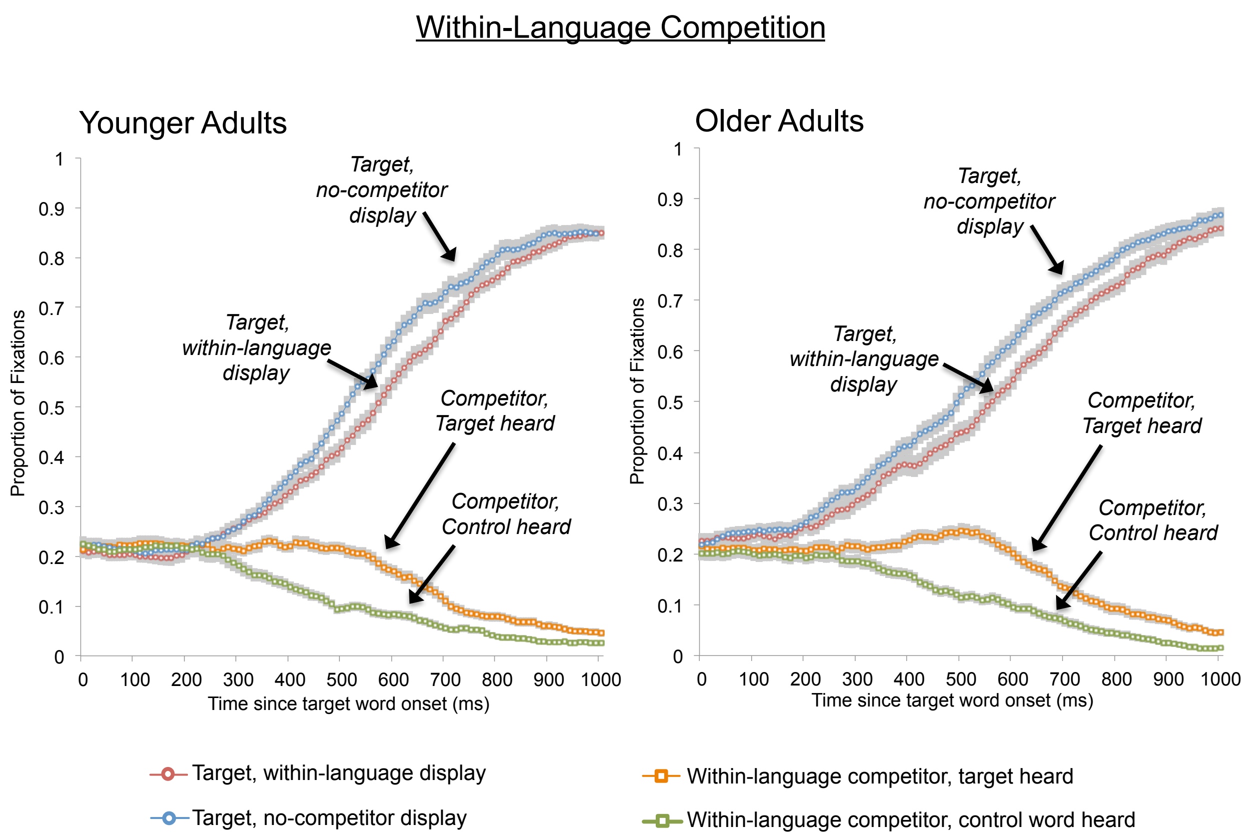


Figure 3. Within-language competition effects for younger and older adults (left panel and right panel, respectively) for 600 – 1000 ms window as a function of phonological overlap. Only trials where the target picture was correctly identified were included. Confidence bands depict 1 SEM.

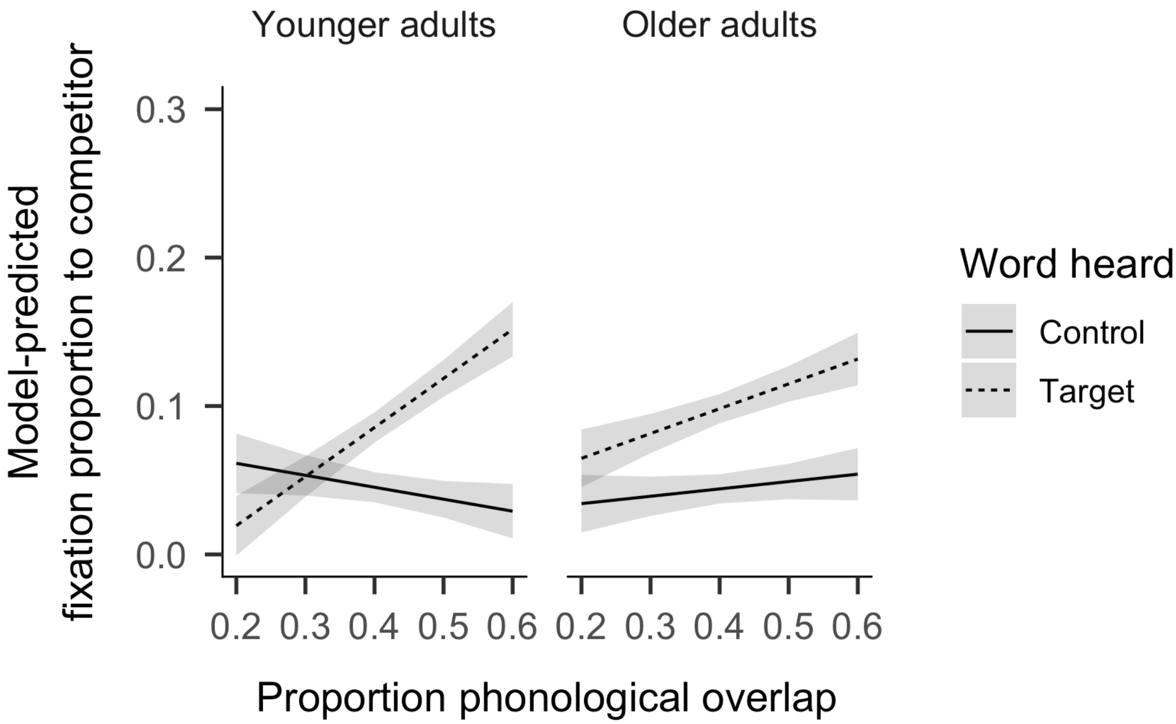


Figure 4. Cross-language competition effects for younger and older adults (left panel and right panel, respectively). Only trials where the target picture was correctly identified were included. The grey border reflects the standard error of the mean. The red lines reflect looks to the target images when the target word was heard and a cross-language competitor image was present in the display; the blue lines reflect looks to the target images when the target word was heard and there was no competitor image in the display; the orange line reflects looks to the cross-language competitor images when the target word was heard; the green lines reflect looks to the cross-language competitor images when an unrelated control word was heard.

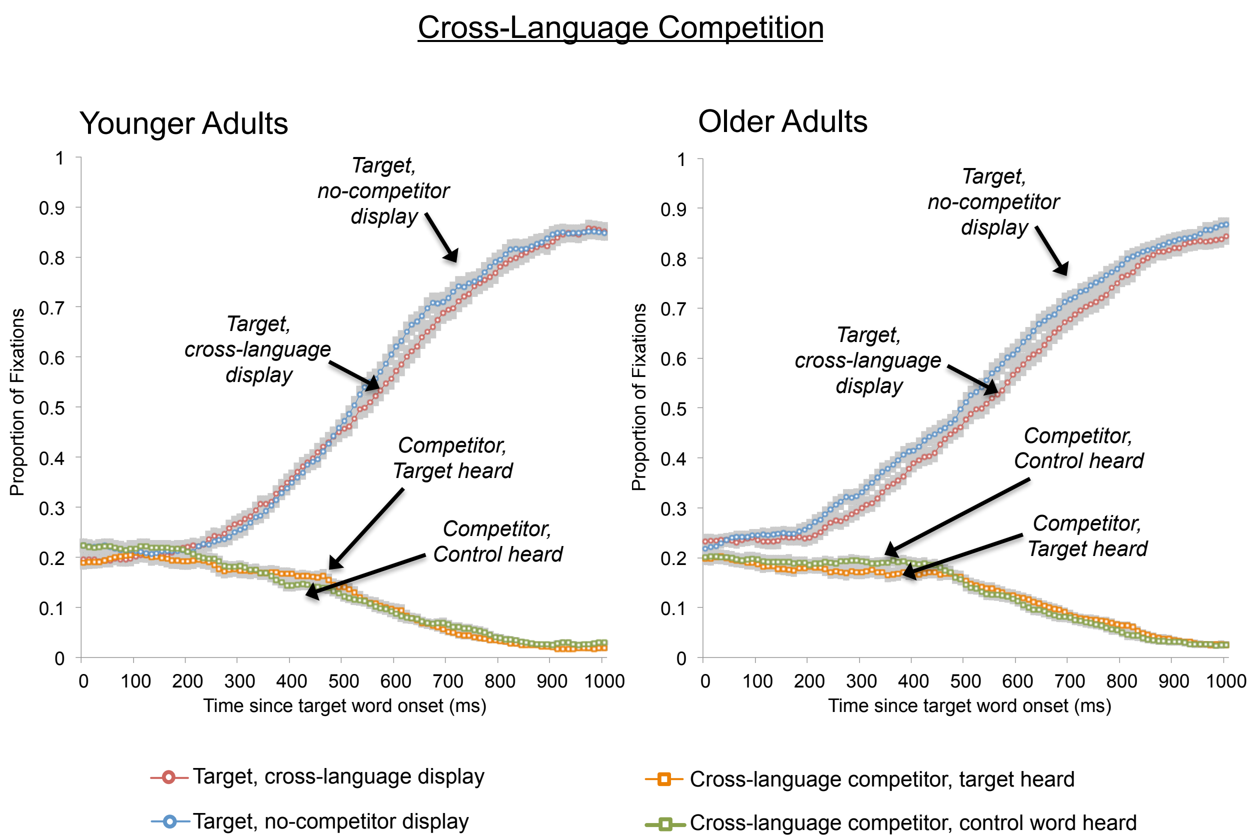


Figure 5. Cross-language competition effects for younger and older adults (left panel and right panel, respectively) for 600 – 1000 ms window as a function of phonological overlap. Only trials where the target picture was correctly identified were included. Confidence bands depict 1 SEM.

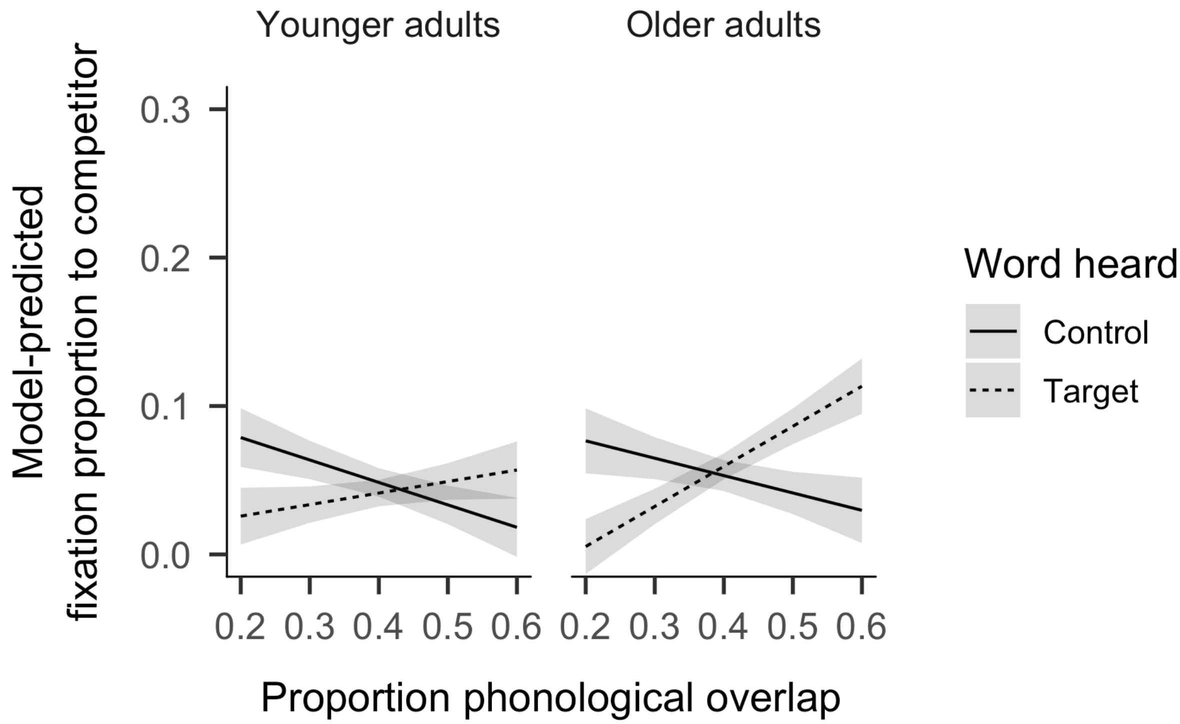
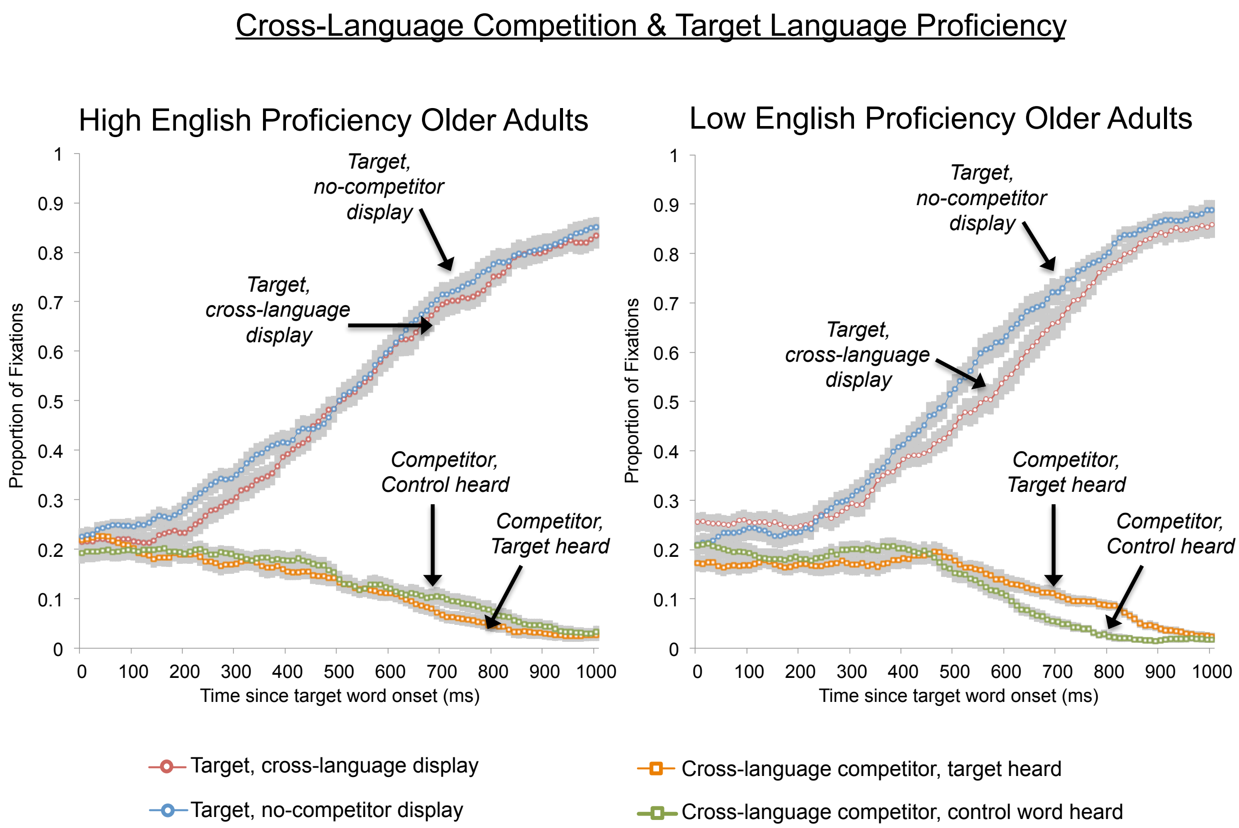


Figure 6. Cross-language competition effects for older adults with higher (n = 24) and lower (n = 24) English proficiency, based on a median split of a the ratio of English-to-French latency on a speeded animacy judgment task (left panel and right panel, respectively). Only trials where the target picture was correctly identified were included. The grey border reflects the standard error of the mean. The red lines reflect looks to the target images when the target word was heard and a cross-language competitor image was present in the display; the blue lines reflect looks to the target images when the target word was heard and there was no competitor image in the display; the orange line reflects looks to the cross-language competitor images when the target word was heard; the green lines reflect looks to the cross-language competitor images when an unrelated control word was heard.

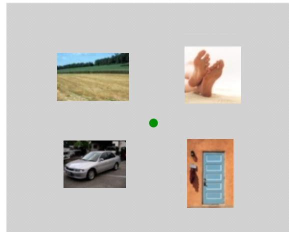
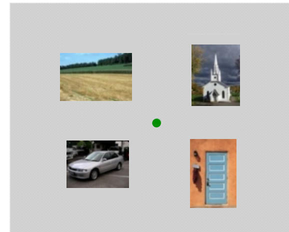
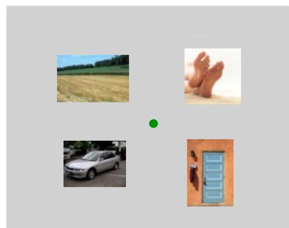
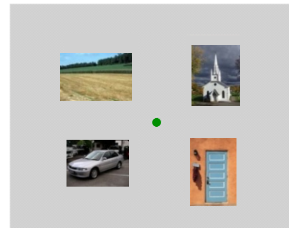
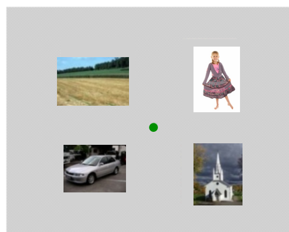
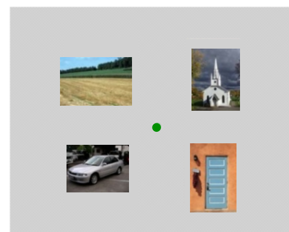
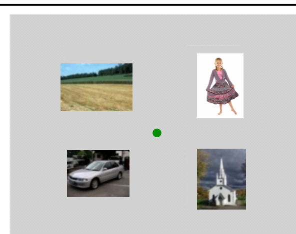
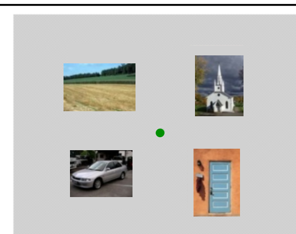


Appendix A

Set	Target*	Within-Language (English) Lexical Competitor	Cross-Language (French) Lexical Competitor	Distracter Control*	Within-Language Lexical Competitor Control	Cross-Language Lexical Competitor Control
1	bathtub /**bæ**θtəb/	bagpipes /**bæ**gpɑjps/	bâton /**ba**t̃ɔ/	magnet /mægnɛt/	hunter /həntər/	lobster /lɑbstər/
2	beans /**bi**nz/	beak /**bi**k/	bidon /**bi**d̃ɔ/	fisherman /fɪʃɚmən/	singer /sɪŋər/	stairs /stɛrz/
3	beehive /**bi**hɑjv/	beach /**bi**tʃ/	billes /**bi**j/	helmet /hɛlmɛt/	kite /kajt/	shrimp /ʃrɪmp/
4	cabbage /**kæ**bədʒ/	cattle /**kæ**t'l/	cadenas /**kæ**dnɑ/	pillow /pɪlo/	butterfly /bətərflɑj/	scale /skel/
5	camel /**kæ**məl/	cart /**ka**rt/	cadre /**kæ**dʀ/	wallet /wɒlɛt/	ear /ɪr/	apple /æp'l/
6	castle /**kæ**səl	caterpillar /**kæ**təpɪlər/	camion /**ka**mj̃ɔ/	pencils /pɛnsəlz/	bucket /bəkət/	dandelion /dændəlɑjən/
7	coffin /**ka**fɪn/	cauliflower /**ka**liflawɚ/	corne /**ka**ʀn/	rattle /ræt'l/	arrow /æro/	hammer /hæmər/
8	kettle /**kɛ**təl/	keg /**kɛ**g/	caisse /**kɛ**s/	pliers /plajərz/	wheel /wil/	frog /frɑg/
9	kiss /**kɪ**s/	kitten /**kɪ**ʔ'n/	quilles /**ki**j/	skirt /skərt/	grape /grep/	whistle /wɪsəl/
10	toothbrush /**tu**θbrəʃ/	toolbox /**tu**:lbɒks/	tournesol /**tu**ʀnəsɔl/	ruler /rulər/	cherry /tʃɛri/	mermaid /mərmed/
11	field /**fi**ld/	feet /**fi**t/	fille /**fi**j/	car /kɑr/	church /tʃərtʃ/	door /dɔr/
12	knees /**ni**z/	needle /**ni**jd'l/	nid /**ni**/	flower /flawər/	stove /stov/	candle /kændəl/
13	ladder /**læ**dər/	latch /**læ**tʃ/	lapin /**la**pɛ̃/	closet /klɑzɛt/	basket /bæskɛt/	nurse /nərs/
14	lap /**læ**p/	lamb /**læ**m/	larme /**la**ʀm/	ghost /gost/	doll /dɑl/	cake /kek/
15	leash /**li**ʃ/	leaf /**li**f/	licorne /**li**kɔʀn/	bubble /bəb'l/	owl /awl/	purse /pərs/
16	lemon /**lɛ**mən/	legs /**lɛ**gz/	laine /**lɛ**n/	pond /pɑnd/	queen /kwin/	desk /dɛsk/
17	matchbook /**mæ**tʃbʊk/	map /**mæ**p/	matelot /**ma**tlo/	beaver /bivər/	shovel /ʃəvəl/	plate /plet/
18	movie /**mu**vi/	movers /**mu**vərz/	moulin /**mu**lɛ̃/	rainbow /renbo/	spoon /spun/	turtle /tərt'l/
19	navel /**ne**vəl/	nail /**ne**l/	nénuphar /**ne**nyfaʀ/	broom /brum/	maze /mez/	towel /tawəl/
20	fold /**fo**ld/	phone /**fo**n/	fauteuil /**fo**tœj/	garden /gɑrdən/	dog /dɒg/	bread /brɛd/

Note. Stimulus sets for the visual world task. The target and control words were heard in the instructions (*). Overlapping phonemes are shown in bold.

Appendix B

		Spoken Instructions	Picture Display: Competitor	Picture Display: Control
Within-Language Comparisons (competitor: *feet*)	Target heard	"Click on the <u>field</u>"		
	Control heard	"Click on the <u>car</u>"		
Cross-Language Comparisons (competitor: *fille*, French for girl)	Target heard	"Click on the <u>field</u>"		
	Control heard	"Click on the <u>car</u>"		

Note. Examples of within- and cross-language competitor displays and control displays with experimental (*Click on the "target"*) and control (*Click on the "control"*) instructions. The central green circle represents the cursor, which always appeared in the middle of the screen at the beginning of a trial.

References

Albinet, C. T., Boucard, G., Bouquet, C. A., & Audiffren, M. (2012). Processing speed and executive functions in cognitive aging: How to disentangle their mutual relationship? *Brain and Cognition, 79*(1), 1-11. doi: 10.1016/j.bandc.2012.02.001

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38*(4), 419-439. doi: 10.1006/jmla.1997.2558

Altmann, G. T. M. (2011). Language can mediate eye movement control within 100 milliseconds, regardless of whether there is anything to move the eyes to. *Acta Psychologica, 137*(2), 190-200. doi: 10.1016/j.actpsy.2010.09.009

Altmann, G. T. M., & Kamide, Y. (1999). Incremental interpretation at verbs: restricting the domain of subsequent reference. *Cognition, 73*(3), 247-264. doi: S0010027799000591 [pii]

Altmann, G. T. M., & Kamide, Y. (2004). Now you see it, now you don't: Mediating the mapping between language and the visual world. In J. M. Henderson & F. Ferreira (Eds.), *The interface of language, vision, and action: Eye movements and the visual world* (pp. 347–386). New York: Psychology Press.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*, 390-412.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*(3), 255-278. doi: 10.1016/j.jml.2012.11.001

Bates, D. M. (2007). Linear mixed model implementation in lme4. *Unplished manuscript, University of Wisconsin, Madison*.

Bates, D. M., Kliegl, R., Vasishth, S., & Baayen, H. (2015). Parsimonious mixed models http://arxiv.org/abs/1506.04967v1 *stat.ME*.

Baum, S., & Titone, D. (2014). Moving toward a neuroplasticity view of bilingualism, executive control, and aging. *Applied Psycholinguistics, 35*(5), 857-894. doi: 10.1017/s0142716414000174

Ben-David, B. M., Chambers, C. G., Daneman, M., Pichora-Fuller, M. K., Reingold, E. M., & Schneider, B. A. (2011). Effects of aging and noise on real-time spoken word recognition: Evidence from eye movements. *Journal of Speech Language and Hearing Research, 54*(1), 243-262. ()

Benichov, J., Cox, L. C., Tun, P. A., & Wingfield, A. (2012). Word recognition within a linguistic context: Effects of age, hearing acuity, verbal ability, and cognitive function. *Ear and Hearing, 33*(2), 262-268. doi: 10.1097/AUD.0b013e31822f680f

Best, C. (1995). A direct realist view of cross-language speech perception: Standing at the crossroads. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research.* (pp. 171-204). Baltimore: York Press.

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology-Learning Memory and Cognition, 34*(4), 859-873. doi: 10.1037/0278-7393.34.4.859

Blumenfeld, H. K., & Marian, V. (2007). Constraints on parallel activation in bilingual spoken language processing: Examining proficiency and lexical status using eye-tracking. *Language and Cognitive Processes, 22*, 633-660. doi: 10.1080/01690960601000746

Blumenfeld, H. K., & Marian, V. (2011). Bilingualism influences inhibitory control in auditory comprehension. *Cognition, 118*(2), 245-257. doi: 10.1016/j.cognition.2010.10.012

Braver, T. S., & Barch, D. A. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience and Biobehavioral Reviews, 26*(7), 809-817. doi: 10.1016/s0149-7634(02)00067-2

Broersma, M., & Cutler, A. (2011). Competition dynamics of second-language listening. *Quarterly Journal of Experimental Psychology, 64*(1), 74-95. doi: 10.1080/17470218.2010.499174

Canseco-Gonzalez, E., Brehm, L., Brick, C. A., Brown-Schmidt, S., Fischer, K., & Wagner, K. (2010). Carpet or Carcel: The effect of age of acquisition and language mode on bilingual lexical access. [Article]. *Language and Cognitive Processes, 25*(5), 669-705. doi: 10.1080/01690960903474912

Cooper, R. M. (1974). Control of eye fixation by meaning of spoken language - new methodology for real-time investigation of speech perception, memory, and language processing. *Cognitive Psychology, 6*(1), 84-107. doi: 10.1016/0010-0285(74)90005-x

Cutler, A., Weber, A., & Otake, T. (2006). Asymmetric mapping from phonetic to lexical representations in second-language listening. *Journal of Phonetics, 34*(2), 269-284. doi: 10.1016/j.wocn.2005.06.002

Dahan, D., & Gaskell, G. M. (2007). The temporal dynamics of ambiguity resolution: Evidence from spoken-word recognition. *J Mem Lang, 57*(4), 483-501. doi: 10.1016/j.jml.2007.01.001

Dahan, D., Magnuson, J. S., & Tanenhaus, M. K. (2001). Time course of frequency effects in spoken-word recognition: Evidence from eye movements. *Cognitive Psychology, 42*(4), 317-367. doi: 10.1006/cogp.2001.0750

Dijkstra, T., Van Jaarsveld, H., & Ten Birken, S. (1998). Interlingual homograph recognition: Effects of task demands and language intermixing. *Bilingualism-Language and Cognition, 1*. doi: 10.1017/S1366728998000121

Dufour, S., & Peereman, R. (2003). Lexical competition in phonological priming: Assessing the role of phonological match and mismatch lengths between primes and targets. *Memory & Cognition, 31*(8), 1271-1283. doi: 10.3758/bf03195810

Fischer, B. (1992). Saccadic reaction time: Implications for reading, dyslexia and visual cognition. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading*. New York: Springer-Verlag.

Gollan, T. H., Montoya, R. I., Cera, C., & Sandoval, T. C. (2008). More use almost always means a smaller frequency effect: Aging, bilingualism, and the weaker links hypothesis. *Journal of Memory and Language, 58*(3), 787-814. doi: 10.1016/j.jml.2007.07.001

Gollan, T. H., Salmon, D. P., Montoya, R. I., & Galasko, D. R. (2011). Degree of bilingualism predicts age of diagnosis of Alzheimer's disease in low-education but not in highly educated Hispanics. *Neuropsychologia, 49*(14), 3826-3830. doi: 10.1016/j.neuropsychologia.2011.09.041

Gollan, T. H., Slattery, T. J., Goldenberg, D., Van Assche, E., Duyck, W., & Rayner, K. (2011). Frequency drives lexical access in reading but not in speaking: The frequency-lag hypothesis. *Journal of Experimental Psychology-General, 140*(2), 186-209. doi: 10.1037/a0022256

Green, D. (1998). Mental control of the bilingual lexico-semantic system *Bilingualism-Language and Cognition, 1*, 67-81.

Grosjean, F. (1980). Spoken word recognition processes and the gating paradigm. *Perception and Psychophysics, 28*, 267–283. doi: 10.3758/BF03204386
Hallett, P. E. (1978). Primaty and secondary saccades to goals defined by instructions. *Vision Research, 18*(10), 1279-1296. doi: 10.1016/0042-6989(78)90218-3
Hasher, L., Lustig, C., & Zacks, R. (2007). Inhibitory mechanisms and the control of attention. In A. Conway, C. Jarrold, M. Kane, A. Miyake & J. Towse (Eds.), *Variation in working memory* New York: Oxford University Press.
Hedden, T., & Gabrieli, J. D. E. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience, 5*(2), 87-U12. doi: 10.1038/nrn1323
Huettig, F., Rommers, J., & Meyer, A. S. (2011). Using the visual world paradigm to study language processing: A review and critical evaluation. *Acta Psychologica, 137*(2), 151-171. doi: 10.1016/j.actpsy.2010.11.003
Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2016). *lmerTest: Tests in linear mixed effects models*.

Lash, A., Rogers, C. S., Zoller, A., & Wingfield, A. (2013). Expectation and entropy in spoken word recognition: Effects of age and hearing acuity. *Experimental Aging Research, 39*(3), 235-253. doi: 10.1080/0361073x.2013.779175

Libben, M. R., & Titone, D. A. (2009). Bilingual Lexical Access in Context: Evidence From Eye Movements During Reading. *Journal of Experimental Psychology-Learning Memory and Cognition, 35*(2), 381-390.
Liu, X., Banich, M. T., Jacobson, B. L., & Tanabe, J. L. (2004). Common and distinct neural substrates of attentional control in an integrated Simon and spatial Stroop task as assessed by event-related fMRI. *Neuroimage, 22*, 1097-1106.
Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing, 19*(1), 1-36. doi: 10.1097/00003446-199802000-00001
Magnuson, J. S., Dixon, J. A., Tanenhaus, M. K., & Aslin, R. N. (2007). The dynamics of lexical competition during spoken wrd recognition. *Cognitive Science, 31*, 1-24.
Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The language experience and proficiency questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech Language and Hearing Research, 50*, 940-967.
Marian, V., & Spivey, M. (2003a). Bilingual and monolingual processing of competing lexical items. *Applied Psycholinguistics, 24*(2), 173-193. doi: 10.1017/s0142716403000092
Marian, V., & Spivey, M. (2003b). Competing activation in bilingual language processing: Within- and between-language competition. *Bilingualism: Language and Cognition, .6*(2), pp.
Marian, V., Spivey, M., & Hirsch, J. (2003). Shared and separate systems in bilingual language processing: converging evidence from eyetracking and brain imaging. *Brain and Language, 86*(1), 70-82. doi: S0093934X02005357 [pii]
Marslen-Wilson, W. D., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology, 10*(1), 29-63. doi: 10.1016/0010-0285(78)90018-x
Matin, E., Shao, K. C., & Boff, K. R. (1993). Saccadic overhead - information-processing time with and without saccades. *Perception & Psychophysics, 53*(4), 372-380. doi: 10.3758/bf03206780

McClelland, J. L., & Elman, J. L. (1986). The TRACE model of speech-perception. *Cognitive Psychology, 18*(1), 1-86. doi: 10.1016/0010-0285(86)90015-0
McQueen, J. M., & Cutler, A. (2001). Spoken word access processes: An introduction. *Language and Cognitive Processes, 16*(5-6), 469-490.
Mercier, J., Pivneva, I., & Titone, D. (2014). Individual differences in inhibitory control relate to bilingual spoken word processing. *Bilingualism-Language and Cognition, 17*(1), 89-117. doi: 10.1017/s1366728913000084
Nasreddine, Z., Phillips, N. A., Bedrian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment (MoCA): A brief screening tool for mild cognitive impairment. *Journal of the American Geriatric Society, 53*, 695–699.
Norris, D. (1994). Shortlist - a connectionist model of continuous speech recognition. *Cognition, 52*(3), 189-234. doi: 10.1016/0010-0277(94)90043-4
Pichora-Fuller, M. K. (2003). Cognitive aging and auditory information processing. *International Journal of Audiology, 42*, S26-S32.
Pivneva, I., Mercier, J., & Titone, D. (2014). Executive control modulates cross-language lexical activation during L2 reading: Evidence from eye movements. *Journal of Experimental Psychology-Learning Memory and Cognition, 40*(3), 787-796. doi: 10.1037/a0035583
Pivneva, I., Palmer, C., & Titone, D. (2012). Inhibitory control and L2 proficiency modulate bilingual language production: evidence from spontaneous monologue and dialogue speech. *Frontiers in Psychology, 3*. doi: 10.3389/fpsyg.2012.00057
R Development Core Team. (2012). R: A language and environment for statistical computing. *Foundation for Statistical Computing, Vienna, Austria*. doi: http://www.R-project.org/
Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional finding. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 1-90). Mahwah, NJ: Erlbaum.
Revill, K. P., & Spieler, D. H. (2012). The effect of lexical frequency on spoken word recognition in young and older listeners. *Psychology and Aging, 27*(1), 80-87. doi: 10.1037/a0024113
Rogers, C. L., Lister, J. J., Febo, D. M., Besing, J. M., & Abrams, H. B. (2006). Effects of bilingualism, noise, and reverberation on speech perception by listeners with normal hearing. *Applied Psycholinguistics, 27*(3), 465-485. doi: 10.1017/s014271640606036x
Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*(3), 403-428. doi: 10.1037/0033-295x.103.3.403
Salverda, A. P., Dahan, D., Tanenhaus, M. K., Crosswhite, K., Masharov, M., & McDonough, J. (2007). Effects of prosodically modulated sub-phonetic variation on lexical competition. *Cognition, 105*(2), 466-476. doi: 10.1016/j.cognition.2006.10.008
Saslow, M. G. (1967). Latency for saccdic eye movement. *Journal of the Optical Society of America, 57*(8), 1030-&. doi: 10.1364/josa.57.001030
Segalowitz, N., & Frenkiel-Fishman, S. (2005). Attention control and ability level in a complex cognitive skill: Attention shifting and second-language proficiency. *Memory & Cognition, 33*(4), 644-653. doi: 10.3758/bf03195331
Shook, A., & Marian, V. (2012). Bimodal bilinguals co-activate both languages during spoken comprehension. *Cognition, 124*(3), 314-324. doi: 10.1016/j.cognition.2012.05.014
Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: the effect of an irrelevant cue on information processing. *Journal of Applied Psycolinguistics, 51*, 300-304.

Slowiaczek, L. M., & Hamburger, M. (1992). Prelexical facilitation and lexical interference in auditory word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 1239-1250. doi: 10.1037/0278-7393.18.6.1239

Sommers, M. S. (1996). The structural organization of the mental lexicon and its contribution to age-related declines in spoken-word recognition. *Psychology and Aging, 11*(2), 333-341. doi: 10.1037/0882-7974.11.2.333

Sommers, M. S., & Danielson, S. M. (1999). Inhibitory processes and spoken word recognition in young and older adults: The interaction of lexical competition and semantic context. *Psychology and Aging, 14*(3), 458-472. doi: 10.1037/0882-7974.14.3.458

Spivey, M. J., & Marian, V. (1999). Cross talk between native and second languages: Partial activation of an irrelevant lexicon. *Psychological Science, 10*(3), 281-284. doi: 10.1111/1467-9280.00151

Strange, W. (1995). Cross-language studies of speech perception: A historical review. In W. Strange (Ed.), *Speech perception and linguistic experience* (pp. 3–48). Baltimore: York Press.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662. doi: 10.1037/h0054651

Taler, V., Aaron, G. P., Steinmetz, L. G., & Pisoni, D. B. (2010). Lexical neighborhood density effects on spoken word recognition and production in healthy aging. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences, 65*(5), 551-560. doi: 10.1093/geronb/gbq039

Tanenhaus, M. K. (2007). Spoken language comprehension: insights from eye movements. In G. Gaskell (Ed.), *Oxford Handbook of Psycholinguistics* (pp. 309–326). Oxford: Oxford University Press.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science, 268*(5217), 1632-1634.

Titone, D., Libben, M., Mercier, J., Whitford, V., & Pivneva, I. (2011). Bilingual lexical access during L1 sentence reading: The effects of L2 knowledge, semantic constraint, and L1-L2 intermixing. *Journal of Experimental Psychology-Learning Memory and Cognition, 37*(6), 1412-1431. doi: 10.1037/a0024492

Titone, D., Gullifer, J., Subramaniapillai, S., Rajah, N., & Baum, S. (2017). History-inspired reflections on the Bilingual Advantages Hypothesis. Growing Old with Two Languages: Effects of Bilingualism on Cognitive Aging, 53, 265.

Weber, A., & Cutler, A. (2004). Lexical competition in non-native spoken-word recognition. *Journal of Memory and Language, 50*(1), 1-25.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence*. San Antonio, TX: The Psychological Corporation.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120*(2), 272-292. doi: 10.1037/0033-2909.120.2.272

Whitford, V., & Titone, D. (2012). Second-language experience modulates first- and second-language word frequency effects: Evidence from eye movement measures of natural paragraph reading. *Psychonomic Bulletin & Review, 19*(1), 73-80. doi: 10.3758/s13423-011-0179-5

Whitford, V., & Titone, D. (2014). Second-Language experience modulates eye movements during first- and second-language sentence reading: Evidence from the moving window paradigm *Journal of Experimental Psychology-Learning Memory and Cognition, 41*, 1118-1129.

Whitford, V., & Titone, D. (2016). Eye movements and the perceptual span during first-and second-language sentence reading in bilingual older adults. Psychology and Aging, 31(1), 58.

Whitford, V., & Titone, D. (2017). The effects of word frequency and word predictability during first-and second-language paragraph reading in bilingual older and younger adults. Psychology and aging, 32(2), 158.

Wingfield, A., Aberdeen, J. S., & Stine, E. A. L. (1991). Word onset gating and linguistic context in spoken word recognition by young and elderly adults. *Journals of Gerontology, 46*(3), P127-P129.

Yee, E., Blumstein, S. E., & Sedivy, J. C. (2008). Lexical-semantic activation in Broca's and Wernicke's Aphasia: Evidence from eye movements. *Journal of Cognitive Neuroscience, 20*(4), 592-612. doi: 10.1162/jocn.2008.20056