Bilingualism: Language and Cognition 17 (1), 2014, 89–117 © Cambridge University Press 2013 doi:10.1017/S1366728913000084

Individual differences in inhibitory control relate to bilingual spoken word processing*

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(Received: August 20, 2012; final revision received: February 4, 2013; accepted: February 5, 2013; first published online 4 April 2013)

We investigated whether individual differences in inhibitory control relate to bilingual spoken word recognition. While their eye movements were monitored, native English and native French English–French bilinguals listened to English words (e.g., field*) and looked at pictures corresponding to the target, a within-language competitor (*feet*), a French cross-language competitor (*fille *"girl"), or both, and unrelated filler pictures. We derived cognitive and oculomotor inhibitory control measures from a battery of inhibitory control tasks. Increased cognitive inhibitory control was linked to less within-language competition for all bilinguals, and less cross-language competition for native French low-English-exposure bilinguals. Increased oculomotor inhibitory control was linked to less within-language competition for all native French bilinguals, and less cross-language competition for native French low-English-exposure bilinguals. The results extend previous findings (Blumenfeld & Marian, 2011), and suggest that individual differences in inhibitory control relate to bilingual spoken word processing.*

Keywords: spoken word recognition, bilingualism, inhibitory control, individual differences, visual world

Spoken language processing requires that people map a temporally unfolding and noisy acoustic signal onto stored knowledge about words in memory. This process is hindered by word-onset competition (Luce & Pisoni, 1998; Marlsen-Wilson & Welsh, 1978; McClelland & Elman, 1986; McQueen & Cutler, 2001; Norris, 1994), in that listeners must inhibit partially activated word-onset (and other) competitors while simultaneously enhancing activation of an intended word. Spoken word processing is thus computationally challenging when people comprehend spoken words in their first language (L1). It is likely to be even more challenging for bilinguals, who must inhibit word candidates arising from their knowledge of multiple languages, particularly when they are listening to speech in a second language (L2) context and L1 competitors must be inhibited. In this paper, we investigate the link, among bilinguals, between individual differences in inhibitory control and spoken word processing, in terms of both within- and cross-language competition.

Several lines of evidence suggest a link between individual differences in inhibitory control and within- and cross-language competition in bilinguals. First, bilingual spoken language processing involves the simultaneous activation of two languages (e.g., Blumenfeld & Marian, 2007; Canseco-Gonzalez, Brehm, Brick, Brown-Schmidt, Fischer & Wagner, 2010; Marian & Spivey, 2003a, b; Marian, Spivey & Hirsch, 2003), especially if the target language is the L2 (e.g., Canseco-Gonzalez et al., 2010; Cutler, Weber & Otake, 2006; Weber & Cutler, 2004). Such increased lexical competition slows word recognition (e.g., Norris, McQueen & Cutler, 1995), and creates a need to efficiently control both within- and cross-language lexical activation (e.g., Dijkstra, Van Jaarsveld & Ten Brinke, 1998; Green, 1998). Second, recognizing spoken words requires that phonemes be distinguished from one another, and L2 phonemic categories can be extremely hard to acquire (Best, 1995), especially when they differ from those of the L1 (e.g., Broersma & Cutler, 2011; Cutler et al., 2006; Weber & Cutler, 2004). Thus, L2 phoneme perception is often inaccurate (Strange, 1995), and words that would not normally become lexical candidates in L1 may be transiently activated during L2 word recognition

* This research was supported by an NSERC Discovery Award (Titone). 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, Françoise Brosseau-Lapré, Stéphane Coulombe Bisson, Matthieu Couturier, Dr. Corinne Haigh, Emily Quinan, and Karen Jarboe Singletary. Grateful thanks to anonymous reviewers who helped revise a previous version of the manuscript.

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(e.g., Broersma & Cutler, 2011 Cutler et al., 2006; Weber & Cutler, 2004).

Another reason to expect a link between bilingual spoken language processing and inhibitory control is work suggesting that bilinguals are advantaged relative to monolinguals in non-linguistic cognitive control (Bialystok, Craik, Green & Gollan, 2009; Bialystok, Craik & Luk, 2008; Bialystok, Craik & Ryan, 2006; Costa, Hernández & Sebastián-Gallés, 2008). These benefits have been reported over the life-span during normal aging (Bialystok et al., 2008; but see Kousaie & Phillips, 2012) and pathological aging (Bialystok, Craik & Freedman, 2007, Craik, Bialystok & Freedman, 2010; Schweizer, Ware, Fischer, Craik & Bialystok, 2012 but see Chertkow, Whitehead, Phillips, Wolfson, Atherton & Bergman, 2010; Gollan, Salmon, Montoya & Galasko, 2011). They are thought to arise from the routine need to use inhibitory control to suppress language-irrelevant material (Green, 1998; but see Bialystok, Craik & Luk, 2012, for a view that extends beyond inhibitory control). Thus, bilingual cognitive advantages, where reported, presumably emerge from the very demands that bilinguals face during language processing, such as inhibiting within- and cross-language competition during spoken language processing (e.g., Bialystok, 2005, Chapter 20; Kroll, 2008; see Hervais-Adelman, Moser-Mercer, & Golestani, 2011, for a review of neuroimaging and neuropsychology examining the role of cognitive control in the bilingual brain; but see also Hilchey & Klein, 2011).

Here, we investigated within- and cross-language competition during spoken bilingual word processing using the visual world method (e.g., Canseco-Gonzalez et al., 2010; Cutler et al., 2006; Ju & Luce, 2004; Marian & Spivey, 2003a, b; Spivey & Marian, 1999; Weber & Cutler, 2004). The visual world method allows one to track the "activation" (averaged across trials) of an intended lexical item relative to one or several competitors, with millisecond precision using a relatively natural task (Allopenna, Magnuson & Tanenhaus, 1998; Cooper, 1974; Dahan, Magnuson & Tanenhaus, 2001; Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995; see Huettig, Rommers & Meyer, 2011, for a review and critical evaluation). For example, Spivey and Marian (1999) presented Russian–English bilinguals with an array of objects including the target (an object called *marker* in English), a phonologically similar cross-language competitor (*marka*, "stamp" in Russian), and two phonologically and semantically unrelated distracters, while following the spoken instruction to move an object (marker). Cross-language competitor objects were fixated significantly more than unrelated objects. Subsequent studies have shown that within- and cross-language competition varies with a number of factors, including whether the task is in the L1 or L2 (i.e., Marian & Spivey, 2003a, b), age of acquisition and proficiency of the non-target language (Blumenfeld & Marian, 2007; Canseco-Gonzalez et al., 2010), cross-language phonemic confusability (Cutler et al., 2006; Weber & Cutler, 2004), and language mode (Canseco-Gonzalez et al., 2010; Grosjean, 1998, 2001).

Of relevance here, Blumenfeld and Marian (2011) investigated the link between inhibitory control and bilingual spoken language processing by comparing the size of within-language competition across monolinguals and bilinguals performing the task in their native language. Although monolinguals and bilinguals displayed similar levels of within-language competition, individual differences in inhibitory control (measured by a non-verbal Stroop task) related to the size of within-language competition in bilinguals (measured as the difference in fixation proportions between the within-language competitor and control pictures). They did not, however, investigate whether such relation also held for cross-language competition, and whether the relation between within-language competition and inhibitory control held in an L2 context.

Thus, we investigated how individual differences in inhibitory control modulated within- and cross-language competition among bilinguals whose L2 abilities varied, which in our sample was best captured by the percentage of daily English exposure (see also Whitford & Titone, 2012). We also explored another critical dimension affecting spoken lexical competition, the amount of phonological overlap existing between a target and within- and cross-language competitor words. Work investigating monolingual spoken word processing using the phonological priming paradigm suggests that lexical competition depends on the length of the phonological match between the prime and the target (Dufour & Peereman, 2003; Slowiaczek & Hamburger, 1992). Consequently, both within- and cross-language competition should be greater when targets and competitors had high vs. low phonological overlap. Moreover, the recruitment of inhibitory control should become greater as phonological overlap increases.

To accomplish these goals, we used a relatively simple version of the visual world task (Allopenna et al., 1998), which allowed us to separately assess within- and cross-language competition. Participants listened to instructions ("Click on the field") while they viewed picture arrays that included pictures of the target word (*field*), within-language competitor (*feet*), cross-language competitor (*fille,* "girl" in French), or both, and one or two unrelated words (i.e., *car* and *church*) depending on whether the display contained one or both competitor pictures.

The first dependent variable of interest was the speed with which bilinguals correctly clicked on target pictures as a function of whether they heard a target vs. control word. In the case where they heard the target word, we expected longer response latency reflecting

https://doi.org/10.1017/S1366728913000084 Published online by Cambridge University Press

the cost associated with having to rule out the lexical competitor picture(s) as a viable alternative within the display, compared to when they heard the control word. The second dependent variable of interest was how bilinguals fixated the competitor images in the display as a function of whether they heard the target word vs. the control word. Again, in the case where they heard the target word, we expected a greater proportion of looks to the competitor pictures compared to when they heard the control word. Participants also performed several inhibitory control tasks to assess domain-general inhibitory control similar to prior work (e.g., Bialystok, Craik, Klein & Viswanathan, 2004; Bialystok et al., 2006; Blumenfeld & Marian, 2011).

We predicted that all bilinguals would show comparable within-language competition as a function of phonological overlap but that native French bilinguals (who performed the task in their L2) would show more cross-language competition as a function of their daily exposure to the task language (English). In terms of the link between spoken word processing and inhibitory control, we predicted that bilinguals with greater inhibitory control would show less within- and cross-language competition, again, as a function of phonological overlap and English exposure. Specifically, we expected that the role of inhibitory control would be greater for items that had a high degree of phonological overlap. The relation between inhibitory control capacity and within- vs. cross-language competition should be greater for native French bilinguals performing the task in their L2, potentially as a function of daily English exposure.

Methods

Participants

Seventy English–French bilinguals participated for course credit or monetary compensation ($10/hr). Twenty-four had English as their native and dominant language ($M = 23.8$ years, $SD = 4.3$ years, 17 women, 7 men) and 46 French ($M = 23.9$ years, $SD = 3.7$ years, 32 women, 14 men). Of the latter, 23 had daily English exposure of 30% or above ($M = 55\%$, $SD = 20\%$) and were assigned to the high-English-exposure subgroup, and 23 had daily English exposure of 25% or less ($M = 15\%$, $SD = 7\%$) and were assigned to a low-English-exposure subgroup. In comparison, native English bilinguals were exposed to English 34% of the time or above ($M = 66\%$, $SD = 12\%$). All participants were between 18 and 35 years old, reported normal or corrected-to-normal vision, and had no speech or hearing disorders.

Materials

Materials consisted of 20 item sets that included a spoken target word and six pictures (target, within- and cross-language competitors, and three distracter controls, one of them named in the control conditions; see Appendix A for the entire stimulus set). Pictures were colour photos (Google Image Search, 2008). Within- and cross-language target-competitor pairs overlapped by an average of 2.05 phonemes ($SD = 0.22$), which did not significantly differ across conditions ($p > .05$). Targets were comparable in word frequency ($M = 20.40$, $SD = 31.26$) to within-language ($M = 30.20$, $SD = 63.35$, $p > .05$) and cross-language ($M = 20.50$, $SD = 60.71$, $p > .05$) competitors, based on Celex (Baayen, Piepenbrock & van Rijn, 1995).

There were eight trial types for each of the 20 stimulus sets arising from two possible spoken words and four display types. The two spoken stimulus types were the target (*field*) and control (*car*) words, which were preceded by instructions directing participants to click on the named picture (“Click on the field”). The four display types were the within-language English competitor display (e.g., *feet*; abbreviated EC because it included an English competitor), the cross-language French competitor display (e.g., *fille*; abbreviated FC because it included a French competitor), the combined within- and cross-language competitors (abbreviated EFC because it included both an English and a French competitor), and the control display (with no competitor; see Appendix B). Thus, for each of the 20-stimulus sets, there were four display types, each heard in two spoken word conditions, for a total of 160 trials, 62.5% of which were without lexical competitors in the display. The control trials were presented to minimize the likelihood of participants noticing the competitors (Tanenhaus, 2007).

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^2. 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 in each half of the task (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 (see Figure 2 for timing details). There were no differences in length (in milliseconds) between targets ($M = 728.20$, $SD = 101.98$) and control words ($M = 749.95$, $SD = 118.62$, $p = .53$). We determined the amount of phonological overlap between the target and competitor words of each type (i.e., within- and

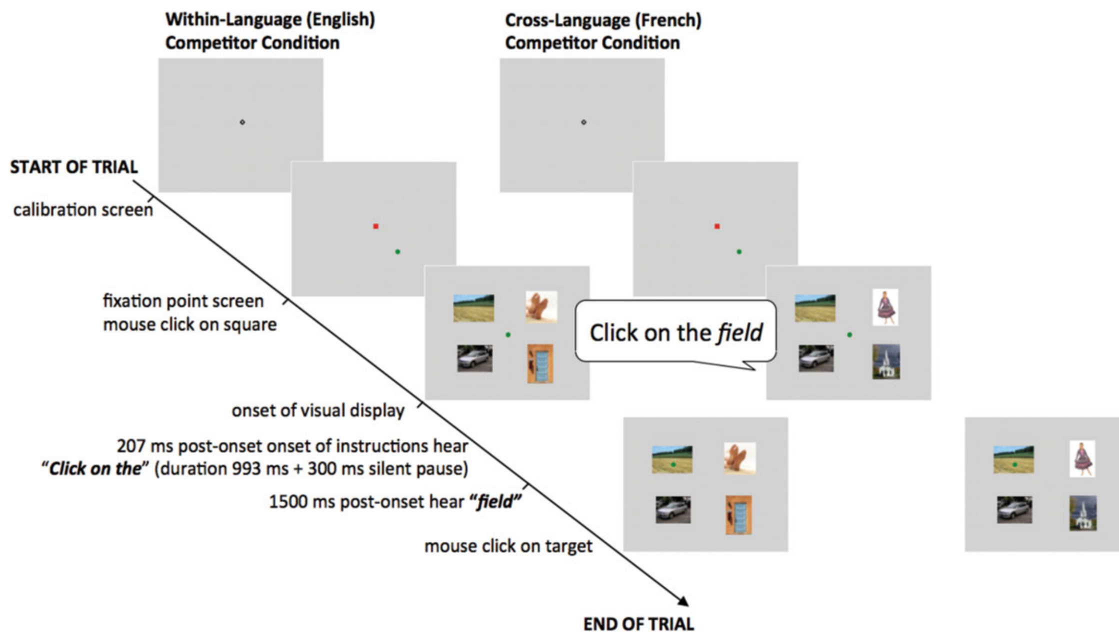

Figure 1. (Colour online) Example of EC and FC trials on the visual world task. EFC trials (not shown) contain pictures of both the within- and cross-language competitors, together with one control distracter (car). The green circle on the second and third displays is the cursor participants moved to the picture they chose as corresponding to the target word.

cross-language) for each stimulus set individually, using a gating procedure (e.g., Grosjean, 1980). Specifically, coders (one English–French bilingual and one French–English bilingual) listened to incrementally longer sections of target word files using Sony Sound Forge 8.0, and determined the point in time when the target stimuli no longer sounded like within- and cross-language competitors (reliability across raters was $r = 0.88$). Each item was reviewed individually, and in the cases of discrepant values, a consensus was reached. The mean duration of word-initial overlap between targets and within-language competitors was 298.85 ms; that between targets and cross-language competitors 290.40 ms.

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 five-point grid. The stimuli were presented on a 21-inch (50.8-cm) ViewSonic CRT monitor with a refresh rate of 60 Hz located 71 cm away from participants.

Procedure

Most participants were recruited through the departmental participant pool, which required them to answer a variety of screening questions from several laboratories. Some were recruited through advertisements specifying eligibility criteria. Once participants arrived at the lab, their bilingual status was not emphasized until the end of the experiment. The experiment was carried out exclusively in English by non-Francophone experimenters, and language measures (vocabulary task, speeded lexical judgment task, language questionnaire) were administered last to reduce the probability of inadvertently activating the non-target language (French) and thus altering the baseline activation levels of English and French.

Visual World Task

Each trial began with a central calibration point, which participants were asked to fixate (see Figure 1), followed by a red square. Participants clicked on this red square to trigger the appearance of a picture display and the beginning of the recorded instructions. The cursor (green circle) appeared centrally to ensure participants would fixate there at the beginning of each trial. Participants were asked to naturally scan the pictures and click on the appropriate one after hearing the instructions. The array disappeared following a click on any picture, and the calibration circle reappeared, signaling a new trial.

Individual difference measures

These included an L1 vocabulary task (WASI; Wechsler, 1999), a language experience questionnaire (Marian, Blumenfeld & Kaushanskaya, 2007), a speeded animacy

https://doi.org/10.1017/S1366728913000084 Published online by Cambridge University Press

Table 1. *Means and standard deviations of measures from which composite inhibitory control measures were derived.*

	Native English (n = 24)		Native French: High English exposure (n = 23)		Native French: Low English exposure (n = 23)	
	Mean	SD	Mean	SD	Mean	SD
Cognitive Inhibition Measures (ms)						
Non-Verbal Simon						
Congruent	477	62	445	49	503	82
Incongruent	512	63	496	51	552	69
Proportion Cost	0.08	0.09	0.12	0.11	0.11	0.13
Non-Verbal Stroop						
Congruent	486	66	447	83	495	62
Incongruent	500	64	461	80	522	74
Proportion Cost	0.03	0.07	0.03	0.06	0.05	0.06
Non-Verbal Number Stroop						
Congruent	580	84	591	86	652	95
Incongruent	643	96	645	86	709	97
Proportion Cost	0.11	0.07	0.09	0.06	0.09	0.06
Oculomotor Inhibition Measures (%)						
Pure Antisaccade						
Pro	97	5	98	4	98	4
Anti	80	17	85	14	84	16
Proportion Cost	0.18	0.16	0.14	0.15	0.14	0.16
Mixed Antisaccade						
Pro	95	5	93	8	95	4
Anti	78	19	85	14	83	14
Proportion Cost	0.18	0.19	0.08	0.13	0.13	0.15
Computed Composite Inhibitory Scores						
Cognitive Inhibition Cost	–0.06	0.67	0.04	0.67	0.03	0.65
Oculomotor Inhibition Cost	0.23	1.02	–0.20	0.82	–0.05	0.89

Note: Proportion cost measures were obtained by subtracting the congruent/pro responses from the incongruent/anti responses, and dividing the results by the congruent/pro responses. The pure antisaccade measure was derived from the pure pro- and anti-saccade blocks of the antisaccade task. The mixed antisaccade measure was derived from the mixed pro- and anti-saccade block. The three groups were comparable across proportion cost and composite inhibitory measures according to one-way ANOVAs.

judgment task performed in the L1 and L2 (Segalowitz & Frenkiel-Fishman, 2005), and several non-verbal measures of inhibitory control. The inhibitory control measures included the Simon task (Simon & Ruddell, 1967; non-verbal version developed by Blumenfeld & Marian, 2007), two Stroop tasks (Stroop, 1935; one using arrows adapted from Liu, Banich, Jacobson & Tanabe, 2004; one using numbers), and an anti-saccade task (Hallet, 1978; see details below and Table 1 for mean results). Of those, the anti-saccade task was always administered first. Presentation order for inhibitory control tasks was counterbalanced across participants. See Table 2 (next page) for mean results on language measures.

Anti-saccade task

This task requires the suppression of a prepotent tendency to look at a peripherally presented target in order to make an eye movement in the opposite direction as quickly as possible. It contained three blocks, always administered in order (pro-saccade, anti-saccade, and mixed pro- and anti-saccade), each with 48 experimental trials.

In the PRO-SACCADE BLOCK, participants fixated a green central fixation square until it disappeared, and then looked at the peripheral target. In the ANTI-SACCADE BLOCK, participants fixated a red central fixation square until it disappeared, and then looked at the opposite side of the peripheral target, at approximately the same distance

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Table 2. *Self-assessed L2 proficiency ratings, language history and use, speeded animacy judgment performance, and objective English (task language) proficiency scores.*

	Native English (n = 24)		Native French: High English exposure (n = 23)		Native French: Low English exposure (n = 23)		Nature of difference (post-hoc tests)
	Mean	SD	Mean	SD	Mean	SD	
General language abilities (L1)							
WASI vocabulary	14	2	14	2	14	2	
Self-rated L2 proficiency							
Listening comprehension**	8	1	9	1	7	2	LE < HE, native English
Speaking***	8	1	9	1	7	1	LE < HE, native English
Reading	8	2	8	2	7	1	
Writing**	7	2	8	2	6	1	LE < HE, native English
Translating	7	2	8	2	6	2	
Pronunciation***	8	1	8	2	6	2	LE < HE
Fluency***	8	2	8	2	6	2	LE < HE, native English
Vocabulary**	8	1	7	2	6	2	LE < HE, native English
Grammatical ability	7	2	7	2	6	2	
Overall competence**	8	1	8	1	7	2	LE < HE, native English
Age of L2 acquisition**	6	4	7	4	10	4	LE > HE, native English
Daily exposure to language L1 and L2							
L1***	66	12	41	19	81	9	LE > HE, native English
L2***	34	11	54	20	15	6	LE < HE, native English
Speeded Lexical Judgment Task							
Reaction time							
L1	682	108	671	96	701	85	
L2	758	170	664	96	739	130	
Accuracy							
L1	97	2	96	3	96	4	
L2	95	4	96	3	96	3	
Objective proficiency in English (target language)							
Ratio of English-to-French reaction Time***	0.92	0.12	1.01	0.07	1.05	0.11	LE, HE > native English

Note: The three groups were compared on all measures with one-way ANOVAs (* $p < .05$, ** $p < .01$, *** $p < .001$). No significant correlation was found between the following measures of proficiency and composite measures of inhibitory function (see Table 1; all *ps* < .05): self-reported overall L2 competence, daily exposure to L2, and age of L2 acquisition.

away from the center of the screen. In the MIXED PRO- AND ANTI-SACCADE BLOCK, participants were asked to pay close attention to the colour of the central fixation square. If the central fixation square was green, they made a saccade to the peripheral target (i.e., pro-saccade). If the central fixation square was red, they made a saccade in the opposite direction from to the peripheral target (i.e., anti-saccade). The mixed anti-saccade trials (24 pro-, 24 anti-) were presented in a random fashion (see Figure 2).

Non-verbal Simon and Stroop tasks

Both tasks assess the tendency for motor responses to be made more quickly and accurately when the left/right spatial location of stimulus presentation corresponds to the left/right spatial location of a response. The Stroop task additionally assesses interference arising when the semantic meaning of a stimulus conflicts with its spatial location.

Both tasks presented arrows on the left or right side of the screen. Participants made a left/right response

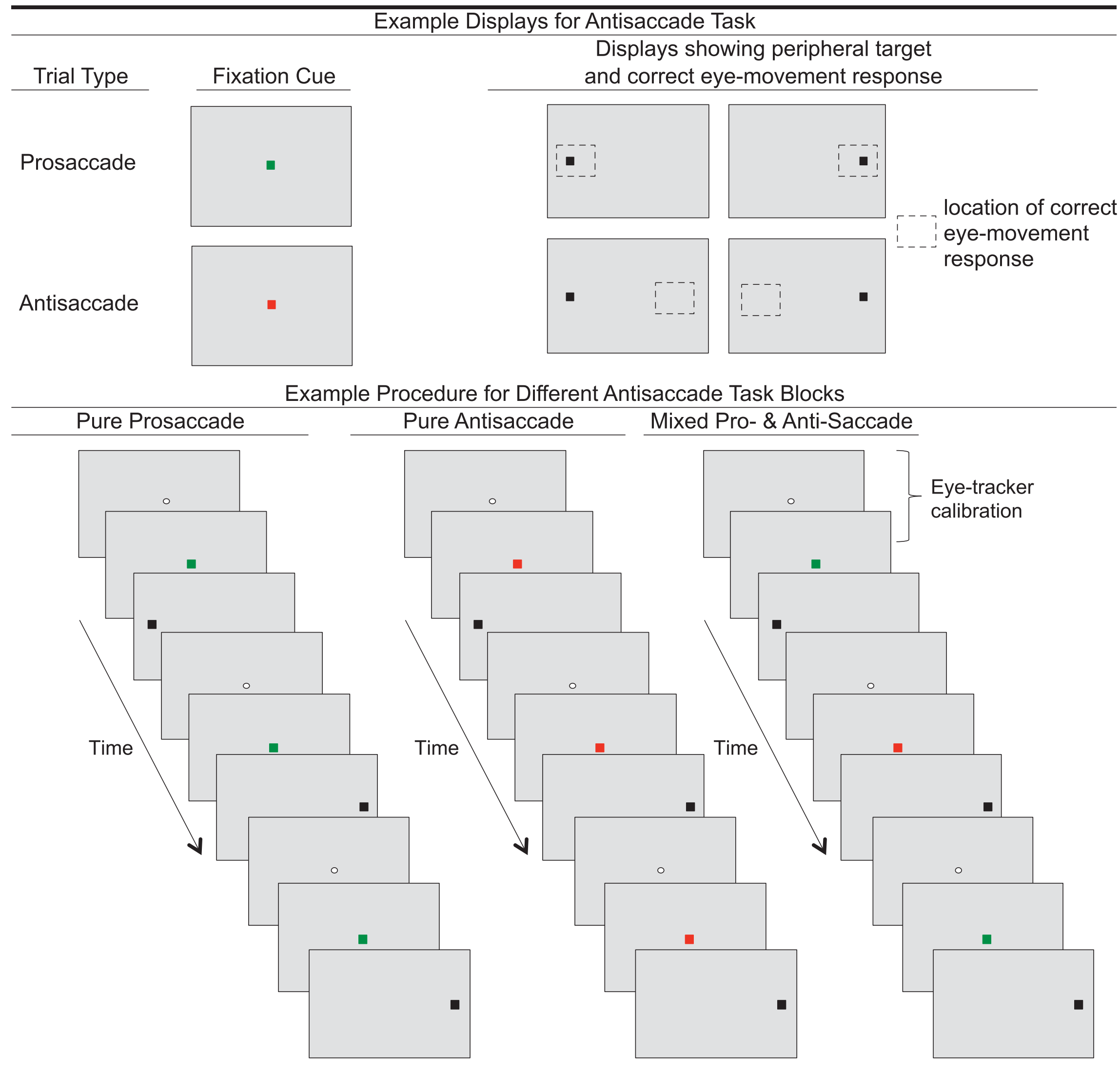

Figure 2. (Colour online) Example of displays and procedures for the antisaccade task. The pure pro-, anti-, and mixed pro- and anti-saccade blocks were always administered in order.

indicating the direction of the arrow as quickly and accurately as possible. In the Simon task, arrows were pointed up or down to be semantically neutral with respect to the response. Trials with an arrow presented on the same side of the screen as the required response were congruent; trials with an arrow presented on the opposite side of the response were incongruent. In the Stroop task, arrows were pointed left or right to be semantically congruent/incongruent with respect to the location on the screen. Trials with an arrow presented on the same side of the screen as the arrow direction were congruent; trials with an arrow presented on the opposite side as the arrow direction were incongruent. Each task included 40 trials of each type, randomly distributed between the left and the right sides of the display (see Figure 3, next page).

Number Stroop task

This task assesses the interference arising when the semantic meaning of a stimulus conflicts with a required response. The task was implemented by presenting digits in the center of the screen and asking participants to use one of the first four fingers of their dominant hand to indicate the number of presented digits (i.e., 1, 2, 3 or 4) as quickly and accurately as possible. The numbers composing the digits were either semantically congruent (e.g., 4444, 333) or incongruent (e.g., 2222, 44) with the required response. The task included 48 congruent and 48 incongruent trials, evenly distributed across all four fingers (see Figure 3).

Principal component analyses revealed that two component factors derived from the inhibitory control

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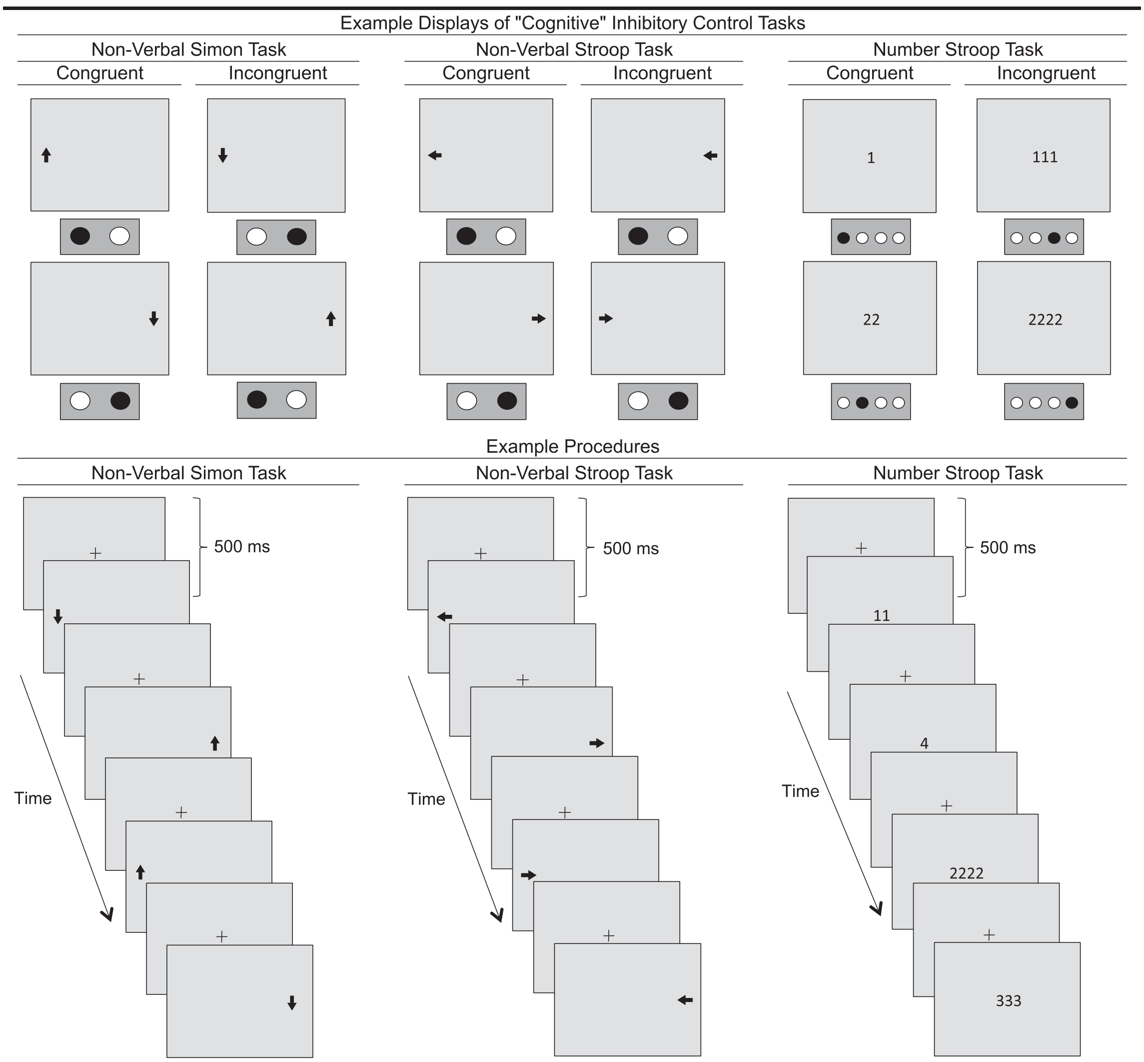

Figure 3. Example of displays and procedures for the non-verbal Simon, non-verbal Stroop, and number Stroop tasks. Filled circles represent correct key responses.

measures accounted for 62.91% of the variance contained in the data (see Table 3 below). To provide more stable measures of the underlying abilities captured by these measures, we created composite measures based on these factors by computing standardized scores for each variable, and then averaging the standardized scores for each participant and composite measure separately. This resulted in two composite inhibitory scores per participant (see Table 1 above for mean scores).

The first composite measure, a COGNITIVE INHIBITION COST SCORE, was based on non-verbal Simon, Stroop, and number Stroop proportion cost measures. These tasks all measured response suppression with key presses and thus required symbolic mapping between stimuli and keys. The two Stroop tasks additionally assessed interference elicited by the semantic mismatch between the meaning of the stimulus and the required response. The second composite measure, OCULOMOTOR INHIBITION COST SCORE, was based on the two measures from the antisaccade task (i.e., pure antisaccade, mixed antisaccade). While the mixed antisaccade block required some symbolic mapping between colour and trial type (e.g., pro- or anti-), the kind of suppression required here was generally less symbolic in that it involved directly suppressing a reflexive pro-saccade motor response (Bialystok et al., 2006).

Results

Data were analyzed using linear mixed effects (LME) models within the lme4 package of R (version 2.14.0 for Mac OS X; Baayen, Davidson & Bates, 2008; Bates, 2007; R Development Core Team, 2011). We created separate models for each dependent variable and type of lexical

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Table 3. *Principal component analysis for inhibitory control measures. The numbers in bold indicate the component on which measures loaded most heavily.*

	Rotated Component Matrix	
	Component 1	Component 2
Non-Verbal Simon Proportion Cost	–0.12	**0.81**
Non-Verbal Stroop Proportion Cost	0.33	**0.72**
Non-Verbal Number Stroop Proportion Cost	–0.23	**0.36**
Pure Antisaccade Proportion Cost	**0.88**	–0.22
Mixed Antisaccade Proportion Cost	**0.92**	0.14

competition (i.e., within- and cross-language). Dependent variables included the latency of response (i.e., the mouse click to the target picture) and the proportion of fixations to lexical competitors (within- or cross-language) as a function of the spoken word heard. 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 (4% of the data). Accuracy was above 90% (see Table 4 for details).

Across models, we first examined whether within-language competition varied as a function of phonological overlap between target and competitor words across all participants and displays that contained within-language competitor pictures (within-language competitor display and combined within- and cross-language competitors display, respectively abbreviated EC and EFC), for each kind of dependent variable separately (i.e., correct

Table 4. *Mean accuracy and correct latency on visual world task.*

		Native English (n = 24)		Native French: High English Exposure (n = 23)		Native French: Low English Exposure (n = 23)	
		Mean	SD	Mean	SD	Mean	SD
Accuracy							
Target word heard							
	Within-Language Competitor Display	99	2	97	4	92	7
	Cross-Language Competitor Display	99	2	97	3	92	6
	Within- & Cross-Language Competitor Display	100	0	97	4	93	6
	Control Display	100	0	97	3	93	7
Control word heard							
	Within-Language Competitor Display	100	1	99	4	96	6
	Cross-Language Competitor Display	100	1	100	1	95	6
	Within- & Cross-Language Competitor Display	100	1	99	2	96	5
	Control Display	100	1	99	2	98	4
Response Latency							
Target word heard							
	Within-Language Competitor Display	820	202	894	242	1229	386
	Cross-Language Competitor Display	827	218	855	221	1201	471
	Within- & Cross-Language Competitor Display	773	187	907	269	1205	337
	Control Display	787	220	849	220	1258	345
Control word heard							
	Within-Language Competitor Display	771	177	849	209	1116	260
	Cross-Language Competitor Display	788	192	891	257	1125	277
	Within- & Cross-Language Competitor Display	766	201	831	259	1076	279
	Control Display	759	222	825	241	1100	268

Note: Incorrect trials were discarded from subsequent analyses.

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response latency and proportion of fixations to the competitor picture). We then examined whether the findings held in models that separately examined native English and native French bilinguals, and EC and EFC displays. To further examine fixation patterns, we then examined whether the time course of within-language competition varied across groups. The same analytic procedure was used to examine cross-language competition. Finally, following specification of the basic pattern of within- and cross-language effects, we examined whether individual differences in inhibitory control played a modulatory role.

The main models included the following fixed effects: word heard (target vs. control word, baseline: control), the proportion of target/competitor phonological overlap (continuous), and trial order (continuous) to account for any change in strategic expectations over the course of the experiment.[1] In models involving all participants, language background was also a fixed effect (treatment coded: native English vs. native French high-English-exposure vs. native French low-English-exposure, native English = baseline).[2]

To reduce collinearity, continuous variables were standardized and centered. Across all models, participants and items were random factors (random intercepts only), and Markov chain Monte Carlo (MCMC) sampling tests (n = 10000) were used to obtain *p*-values for all fixed factors. The correlation among predictor fixed effects across all models was < .41.

Within-language competition

Correct response latency of mouse clicks for within-language competition trials

Here, we examined whether mouse-clicks to target pictures in displays that contained within-language competitor pictures were slower when people heard the target word vs. the unrelated control word. Table 5 presents the results of models that examined within-language competition with three-way interactions among word heard, phonological overlap, and group in terms of correct response latency (left panel). There was a three-way interaction involving word heard, phonological overlap, and group ($b = 965.83$, $SE = 349.94$, $p_{MCMC} = .004$) when combining displays that contained a within-language competitor picture (i.e., EC and EFC displays). As shown in Figure 4 (upper panel), native French low-English-exposure bilinguals (right panel) showed greater within-language competition as phonological overlap increased compared to native English bilinguals (left panel). In contrast, native French high-English-exposure bilinguals (central panel) did not significantly differ from native English bilinguals. This result held for EC displays alone ($b = 949.90$, $SE = 474.68$, $p_{MCMC} = .04$), but was borderline for EFC displays alone ($b = 981.43$, $SE = 517.51$, $p_{MCMC} = .06$). Additional models that had native French high-English-exposure bilinguals as the baseline also confirmed that native French low-English-exposure bilinguals (right panel) showed greater within-language competition as phonological overlap increased, compared to native French high-English-exposure bilinguals (central panel; $b = 715.61$, $SE = 355.81$, $p_{MCMC} = .05$). This result was borderline for EC displays alone ($b = 844.61$, $SE = 484.61$, $p_{MCMC} = .08$), but did not hold for EFC displays alone.

To further understand the group interactions described above, we computed separate models for native English and native French bilinguals alone. Native English bilinguals were slower to make a mouse-click on the target picture when they heard the target vs. control word, and this interference effect increased as phonological overlap increased ($b = 364.51$, $SE = 110.14$, $p_{MCMC} = .001$). The interaction of word heard and phonological overlap was significant for EFC displays alone ($b = 479.23$, $SE = 157.27$, $p_{MCMC} = .002$), but borderline for EC displays alone ($b = 254.59$, $SE = 154.71$, $p_{MCMC} = .10$).

Native French bilinguals also showed greater within-language interference in mouse-clicks to the target picture as phonological overlap of targets and competitors increased ($b = 1481.63$, $SE = 367.19$, $p_{MCMC} < .001$). The amount of English exposure (tested here as a continuous rather than group variable) did not significantly modulate this relationship. When examining display conditions separately, the effect was similar across EC ($b = 1313.41$, $SE = 498.18$, $p_{MCMC} = .009$) and EFC displays ($b = 1650.51$, $SE = 542.96$, $p_{MCMC} = .003$).

To summarize, all participants took more time to make a mouse-click response to target pictures when there was a within-language competitor in the display and when the amount of phonological overlap between target and competitor words was high. However, there

[1] We ran separate models that also included several additional control predictors to investigate whether accounting for the variance introduced by differences in the material, including the length of target and control words (continuous), and naming agreement for target and lexical competitor (within- or cross-language, depending on the model) pictures (continuous) would alter the results. We also included vocabulary scaled scores (continuous) to account for variance related to individual differences in participants' language abilities in L1 and verbal intelligence. None of these variables altered the results, which led us to keep the most parsimonious models excluding these variables. We also examined whether percentage of L2 (French) exposure and objective L2/L1 proficiency altered the cross-language competition effects in native English participants, and found that they did not interact with the size of cross-language competition as phonological overlap increased, which also led us to keep the models excluding these variables.

[2] To clarify whether significant differences existed between native French high and low-English-exposure bilinguals, we ran separate models using native French high-English-exposure bilinguals as the baseline group (i.e., language background was treatment coded: native English vs. native French high-English-exposure vs. native French low-English-exposure, native French low-English-exposure = baseline).

Table 5. *Individual differences in inhibitory control relate to bilingual spoken word processing.*

Fixed effects	Response latency (ms)			Within-language competitor fixation proportions		
	b	*SE*	p_{MCMC}	*b*	*SE*	p_{MCMC}
Word heard (Target/Control)[a]	–106.35	104.26	.3020	–0.02	0.03	.6064
Proportion of target/competitor phonological overlap	70.61	277.96	.8200	–0.04	0.07	.5210
Language Group[b] – Native French High English exposure	232.09	125.66	.0646	0.01	0.03	.6528
– Native French Low English exposure	589.93	125.66	.0001***	0.06	0.03	.0572
Word Heard × Proportion of Phonological Overlap	367.93	244.10	.1270	0.19	0.07	.0064**
Word Heard × Language Group (Native French High English exposure)	–145.88	149.90	.3384	–0.01	0.04	.9174
Word Heard × Language Group (Native French Low English exposure)	–342.58	149.67	.0206*	–0.03	0.04	.4058
Phonological overlap × Language Group (Native French High English exposure)	–339.95	248.37	.1864	0.02	0.07	.7764
Phonological overlap × Language Group (Native French Low English exposure)	–584.16	246.74	.0186*	–0.04	0.07	.5656
Word Heard × Proportion of Phonological Overlap × Language Group (High English exposure)	250.22	351.21	.4842	0.00	0.10	.9870
Word Heard × Proportion of Phonological Overlap × Language Group (Low English exposure)	965.83	349.94	.0038**	0.03	0.10	.7778
Control predictors	*b*	*SE*	p_{MCMC}	*b*	*SE*	p_{MCMC}
Trial presentation order	–2.56	0.17	.0001***	–0.00	0.00	.0001***
(Intercept)	967.28	128.58	.0001***	0.14	0.03	.0001***
Random effects		Variance			Variance	
Participant		5352			0.0007	
Item		11477			0.0005	
Residual		338650			0.0298	

*$p_{MCMC} < .05$; ** $p_{MCMC} < .01$; *** $p_{MCMC} < .001$
[a]Contrasts were treatment coded; model assumes control word as a baseline.
[b]Contrasts were treatment coded; model assumes native English as a baseline.

was evidence that native French low-English-exposure bilinguals experienced more within-language competition than the other groups, in that response interference occurred for all items, not just the items that had a high amount of phonological overlap between target and competitor words.

Fixation proportions to within-language competitor pictures

Here, we examined whether participants made more fixations to within-language competitor pictures when they heard a target word vs. an unrelated control word. We computed the average proportion of fixations to each picture 200 to 1000 ms after target-word onset for the within- and combined within- and cross-language competitor displays (see Figure 5). We chose 200 ms as a lower bound for the analysis based on the visual examination of the fixations over time, taking into consideration the time needed to program and launch a saccade (e.g., Altmann & Kamide, 2004; Fischer, 1992; Hallet, 1978; Matin, Shao & Boff, 1993; Saslow, 1967), and following other visual world studies (e.g., Dahan et al., 2001; Magnuson, Dixon, Tanenhaus & Aslin, 2007; Salverda, Dahan, Tanenhaus, Crosswhite, Masharov & McDonough, 2007; Yee, Blumstein & Sedivy, 2008; but see Altmann, 2011, for saccade programming estimate of approximately 100 ms). The 1000-ms upper boundary was chosen based on both inspection of the data, and previous visual world studies showing that fixations to targets typically reach an asymptote at this time (e.g., Allopenna et al., 1998).

Table 5 above presents the results of models that included three-way interactions among word heard, phonological overlap, and group with respect to fixation

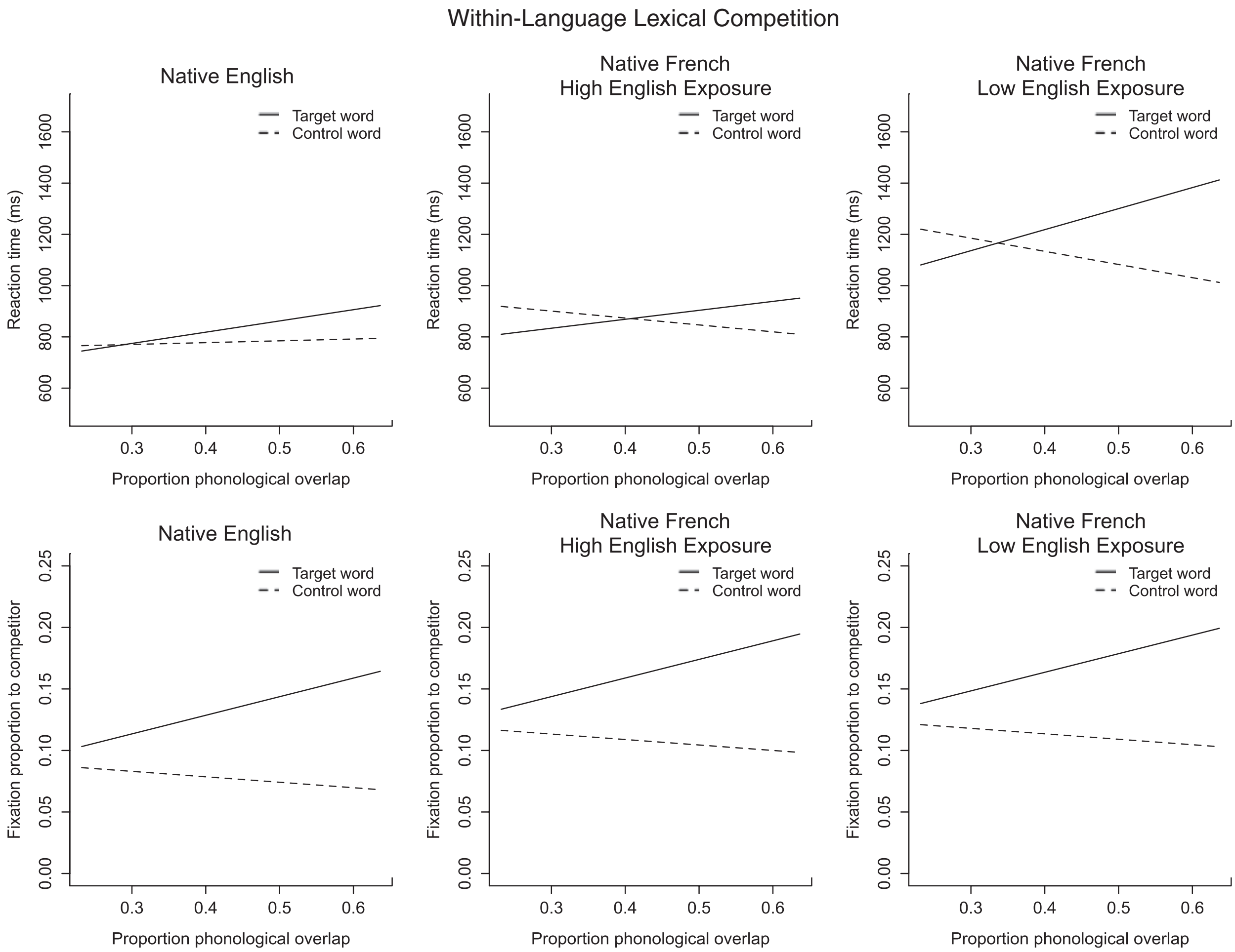

Figure 4. Within-language competition effects (EC and EFC displays combined). In the upper panel, a three-way interaction between word heard (target vs. control), proportion of phonological overlap and group (native English vs. native French high-English-exposure vs. native French low-English-exposure) for the latency of response selecting the target picture during the visual world task. Native French low-English-exposure participants show significantly greater growth in lexical competition as phonological overlap increased compared to native English and native French high-English-exposure bilinguals. In the lower panel, a significant interaction between word heard (target vs. control) and proportion of phonological overlap for the proportion of fixations made to the within-language competitor across all groups.

proportions to the within-language competitor (right panel). There was a significant interaction involving word heard and phonological overlap ($b = 0.19$, $SE = 0.07$, $p_{\text{MCMC}} = .006$) for combined EC and EFC displays. This did not interact with group (see lower panel of Figure 4 and Table 5). Near significant trends were found for EC ($b = 0.19$, $SE = 0.10$, $p_{\text{MCMC}} = .06$) and EFC ($b = 0.19$, $SE = 0.10$, $p_{\text{MCMC}} = .06$) displays alone. These findings suggest that all groups experienced comparable levels of within-language competition as phonological overlap between target and competitor words increased.

To examine if within-language competition changed over time, we computed models that included interactions among word heard, group, and time bin for each display alone (EC, EFC). Time bin was a fixed categorical factor (200–400, 400–600, 600–800, and 800–1000 ms, baseline: 200–400 ms). We found three-way interactions among word heard, group, and time bin for the 600–800 ms bin ($b = 0.08$, $SE = 0.04$, $p_{\text{MCMC}} = .021$) and the 800–1000 ms bin ($b = 0.08$, $SE = 0.04$, $p_{\text{MCMC}} = .018$), both indicating that native French low-English-exposure bilinguals performed differently from native English bilinguals when presented with the EFC display. Using native French high-English-exposure participants as the baseline, we similarly found three-way interactions among word heard, group, and time bin for the 600–800 ms bin ($b = 0.08$, $SE = 0.04$, $p_{\text{MCMC}} = .039$), and the 800–1000 ms bin ($b = 0.08$, $SE = 0.04$, $p_{\text{MCMC}} = .022$). This indicated that native French low-English-exposure

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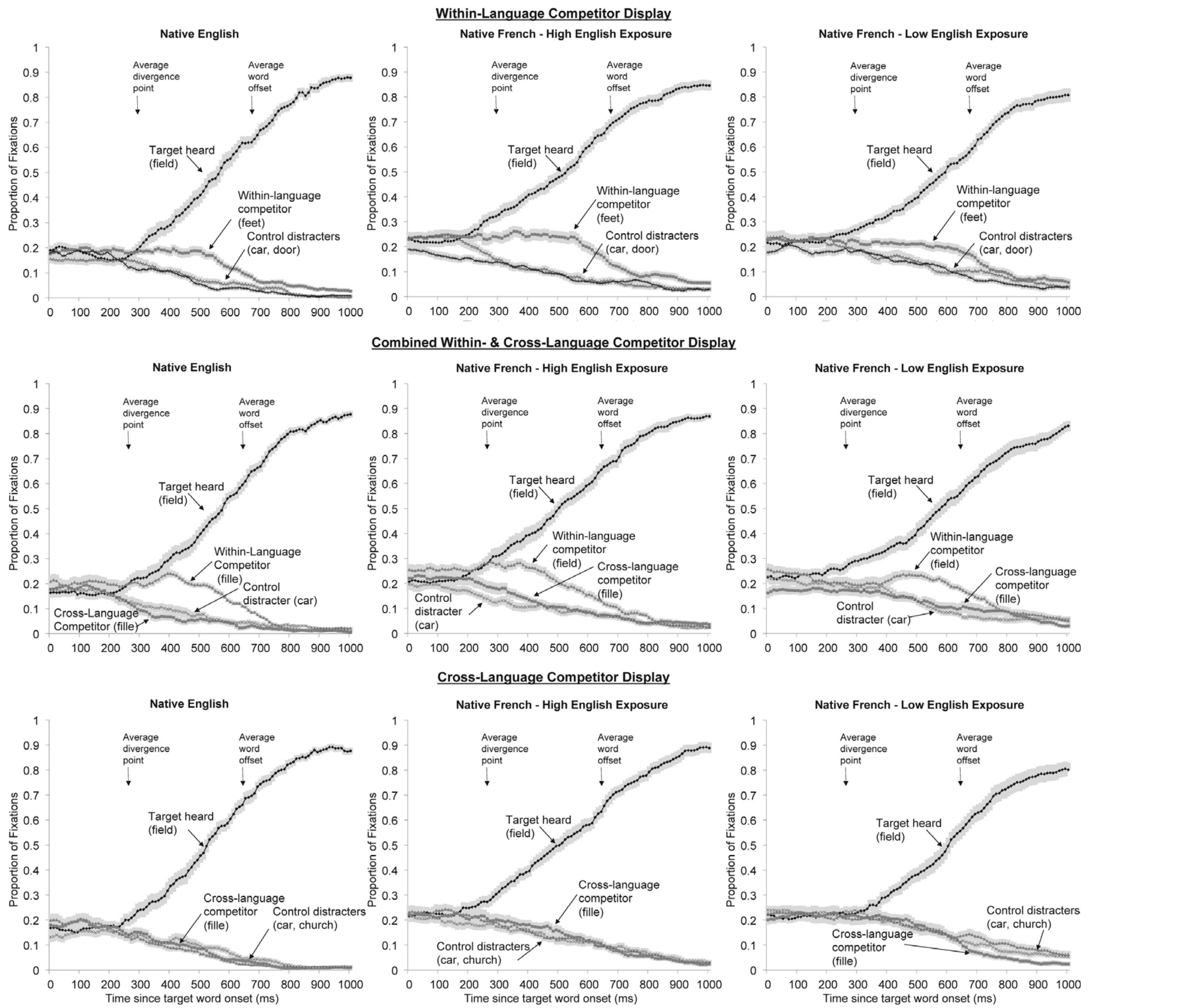

Figure 5. EC (top panel), EFC (central panel), and FC (bottom panel) displays. Probability of fixating the target, relevant lexical competitor(s) and distracter (control) pictures upon hearing the target word (native English vs. native French high-English-exposure vs. native French low-English-exposure; left vs. middle vs. right columns). Only trials where the target picture was correctly identified were included. The grey error border reflects the standard error of the mean.

performed differently from native French high-English-exposure when presented with the EFC display.

However, these effects seemed driven by the pattern of fixation proportions across groups for the 200–400 ms time bin. To confirm this, we computed models to examine the interaction between word heard and group for each time bin separately. Significant interactions between word heard and group were found for the 200–400 ms bin for the EFC display, whether using native English bilinguals ($b = -0.08$, $SE = 0.03$, $p_{MCMC} = .016$) or native French high-English-exposure bilinguals as baseline ($b = -0.07$, $SE = 0.03$, $p_{MCMC} = .047$). These interactions both suggested that native French low-English-exposure bilinguals experienced a delayed onset of within-language competition compared to the other groups, as can be seen in Figure 5. No other significant interaction in the detailed time analyses was found.

Summary of within-language competition effects

Across both mouse-click and eye fixation response measures, all bilinguals experienced greater within-language competition as phonological overlap increased. However, native French low-English-exposure bilinguals showed a delayed fixation response to within-language

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competitors presented in EFC displays, and were especially sensitive to within-language competition in terms of response latency.

Cross-language competition

Correct response latency of mouse clicks on cross-language competition trials

Here, we examined whether mouse-clicks to target pictures in displays that contained cross-language competitor pictures were slower when people heard the target vs. an unrelated control word. Table 6 presents the results of models that examined cross-language competition with three-way interactions among word heard, phonological overlap, and group in terms of correct response latency (left panel). There was a three-way interaction involving word heard, phonological overlap, and group ($b = 1623.90$, $SE = 390.20$, $p_{MCMC} < .001$) for all displays that contained a cross-language competitor (cross-language competitor display and combined within- and cross-language competitors display, respectively abbreviated FC and EFC). As shown in the upper panel of Figure 6, native French low-English-exposure bilinguals (right panel) showed greater cross-language competition as phonological overlap increased, compared to native English (left panel) bilinguals. This result held for FC ($b = 1380.25$, $SE = 472.71$, $p_{MCMC} = .003$) and EFC ($b = 1860.36$, $SE = 619.38$, $p_{MCMC} = .002$) displays alone. As well, native French low-English-exposure

Table 6. *Effect sizes (b), standard errors (SE), and* p_{MCMC} *values for LME models examining cross-language competition.*

	Response latency (ms)			Cross-language competitor fixation proportions		
Fixed effects	*b*	*SE*	p_{MCMC}	*b*	*SE*	p_{MCMC}
Word Heard (Target/Control)[a]	–265.87	111.02	.0178*	–0.06	0.03	.0454*
Proportion of target/competitor phonological overlap	–205.14	315.39	.5356	–0.05	0.06	.4390
Language Group[b] – Native French High English exposure	183.67	131.21	.1532	0.07	0.03	.0466
– Native French Low English exposure	527.89	130.97	.0001***	0.09	0.03	.0082**
Word Heard × Proportion of Phonological Overlap	721.43	271.43	.0082**	0.12	0.07	.1166
Word Heard × Language Group (Native French High English exposure)	–258.06	159.91	.1056	–0.07	0.04	.0928
Word Heard × Language Group (Native French Low English exposure)	552.45	159.75	.0008***	–0.04	0.04	.4028
Phonological Overlap × Language Group (Native French High English exposure)	–249.09	275.13	.3710	–0.10	0.08	.1936
Phonological Overlap × Language Group (Native French Low English exposure)	–520.22	274.08	.0586	–0.12	0.08	.1126
Word Heard × Proportion of Phonological Overlap × Language Group (High English exposure)	652.02	390.75	.0924	0.22	0.11	.0386*
Word Heard × Proportion of Phonological Overlap × Language Group (Low English exposure)	1623.90	390.20	.0001***	0.13	0.11	.2332
Control predictors	*b*	*SE*	p_{MCMC}	*b*	*SE*	p_{MCMC}
Trial presentation order	–2.28	0.16	.0001***	–0.00	0.00	.0028**
(Intercept)	1052.03	138.12	.0001***	0.13	0.03	.0001***
Random effects		Variance			Variance	
Participant		53034			0.0007	
Item		10485			0.0002	
Residual		290068			0.0221	

* $p_{MCMC} < .05$; ** $p_{MCMC} < .01$; *** $p_{MCMC} < .001$
[a] Contrasts were treatment coded; model assumes control word as a baseline.
[b] Contrasts were treatment coded; model assumes native English as a baseline.

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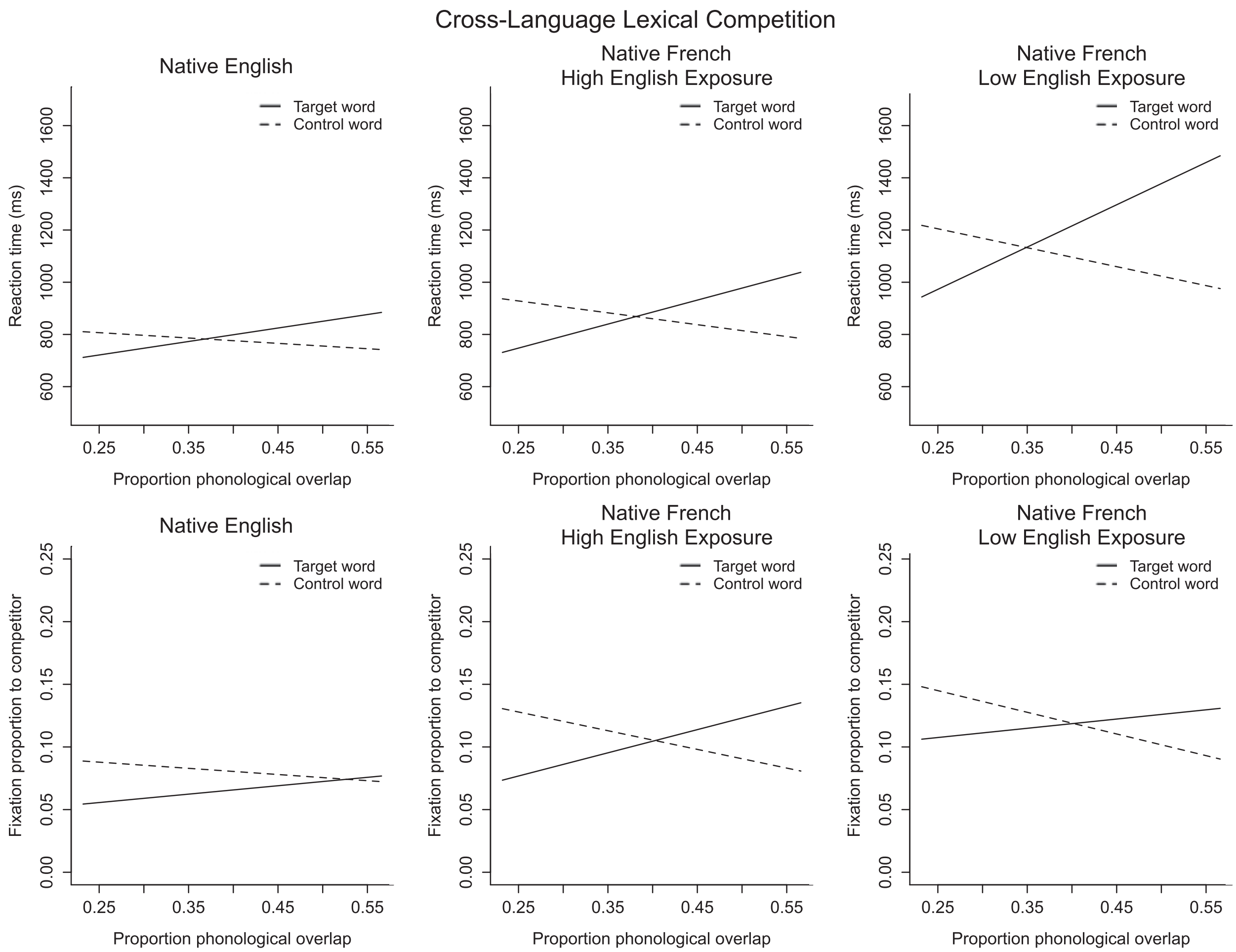

Figure 6. Cross-language competition effects (FC and EFC displays combined). A three-way interaction between word heard (target vs. control), proportion of phonological overlap and group (native English vs. native French high-English-exposure vs. native French low-English-exposure) for the latency of response selecting the target picture during the visual world task (upper panel) and proportion of fixations made to the cross-language competitor across all groups (lower panel). For the latency of response, native French low-English-exposure bilinguals showed greater cross-language competition as phonological overlap increased, compared to both native English bilinguals and native French high-English exposure participants. For the fixations to the cross-language competitor, only high-English-exposure bilinguals showed a significant word heard by phonological overlap interaction.

bilinguals (right panel) also showed greater cross-language competition as phonological overlap increased, compared to native French high-English-exposure (central panel) bilinguals ($b = 971.88$, $SE = 397.44$, $p_{\mathrm{MCMC}} = .015$). This result, however, was borderline for FC ($b = 1125.93$, $SE = 629.45$, $p_{\mathrm{MCMC}} = .08$) and EFC ($b = 814.18$, $SE = 482.92$, $p_{\mathrm{MCMC}} = .09$) displays alone.

To further understand the group interactions described above, we computed separate models for each group alone. Native English bilinguals were slower when they heard the target vs. control word, and this interference effect grew larger as phonological overlap increased ($b = 721.24$, $SE = 121.64$, $p_{\mathrm{MCMC}} < .001$). This effect held for FC ($b = 596.58$, $SE = 151.88$, $p_{\mathrm{MCMC}} < .001$) and EFC ($b = 847.78$, $SE = 187.13$, $p_{\mathrm{MCMC}} < .001$) displays alone. Native French bilinguals also showed greater cross-language competition as phonological overlap increased ($b = 2518.97$, $SE = 410.35$, $p_{\mathrm{MCMC}} < .001$), irrespective of percentage of English exposure (examined here as a continuous factor). This cross-language competition effect was similar for FC displays ($b = 1960.88$, $SE = 495.77$, $p_{\mathrm{MCMC}} < .001$) and EFC displays ($b = 3064.85$, $SE = 653.01$, $p_{\mathrm{MCMC}} < .001$) alone. Thus, group differences were more pronounced between native French low-English-exposure bilinguals and native English bilinguals, than between native French low- and high-exposure bilinguals.

To summarize, all participants took longer to make mouse-click responses to target pictures when there was a cross-language competitor in the display, and when

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phonological overlap between targets and cross-language competitor words was high. However, native French bilinguals showed some evidence of experiencing greater cross-language competition than native-English bilinguals.

Eye fixations to cross-language competitor pictures

Here, we examined whether participants made more fixations to cross-language competitor pictures when they heard a target word vs. a control word. We computed the average proportion of fixations to each picture 200 to 1000 ms after the target word onset in the cross-language competitor display (see Figure 5). Table 6 above presents the results of models that examined cross-language competition with three-way interactions among word heard, phonological overlap, and group (right panel). There was a three-way interaction involving word heard, phonological overlap, and group ($b = 0.22$, $SE = 0.11$, $p_{MCMC} = .039$) for combined FC and EFC displays. As shown in the lower panel of Figure 6, native French high-English-exposure bilinguals (central panel) showed more cross-language competition as phonological overlap increased compared to native English (left panel), but not compared to native French low-English-exposure bilinguals. This three-way interaction was borderline for FC displays alone ($b = 0.28$, $SE = 0.16$, $p_{MCMC} = .07$), and not significant for EFC displays alone. However, EFC displays alone showed a trend towards a three-way interaction of word heard, phonological overlap, and group ($b = 0.27$, $SE = 0.15$, $p_{MCMC} = .07$), suggesting that native French low-English-exposure bilinguals showed more cross-language competition as phonological overlap increased compared to native English bilinguals.

To further understand these group interactions, we computed separate models for each group alone. For FC displays alone, only native French bilinguals showed a three-way interaction involving word heard, phonological overlap, and percentage English exposure (here assessed continuously) ($b = 0.01$, $SE = 0.00$, $p_{MCMC} = .039$). To better understand this group interaction, we then examined the native French high- and low-English-exposure groups separately. Only native French high-English-exposure bilinguals looked more at cross-language competitors as phonological overlap increased ($b = 0.45$, $SE = 0.11$, $p_{MCMC} < .001$).

Unlike what we had seen previously for within-language competition, models that examined cross-language competition across time-bins for the groups resulted in no significant effect. Thus, the amount of cross-language competition as measured in fixation responses was relatively uniform over the whole time window across all groups.

Summary of cross-language competition effects

With respect to the amount of time taken to make a mouse-click on the target picture, all bilingual groups were slower when they heard the target vs. the control word, and when phonological overlap between targets and cross-language competitors was high. However, this effect was greater for native French bilinguals. Interestingly, only native French bilinguals showed any evidence of cross-language competition in terms of fixations to cross-language competitor pictures. Specifically, native French high-English-exposure bilinguals experienced cross-language competition for FC displays only, whereas native French low-English-exposure bilinguals experienced cross-language competition for EFC displays only (though the latter effect was more subtle).

Inhibitory control analyses

To summarize the basic pattern of effects thus far, within-language competition was robust across both comprehension measures and all bilingual groups, whereas cross-language competition was only robust for mouse-click responses for all bilinguals, and fixation responses for native French bilinguals only. In this section, we now examine whether individual differences in inhibitory control modulated these basic effects. To accomplish this goal, we created new models that separately assessed whether there was an interaction of inhibitory cost, word heard and phonological overlap across all bilinguals, and also for native English and native French bilinguals alone. For models involving native French bilinguals alone, we also included percentage of English exposure (measured continuously) to these higher-order interactions.

With respect to within-language competition seen during mouse-click responses, the only significant effect involving inhibitory control was a three-way interaction involving word heard, phonological overlap, and oculomotor inhibition cost for native French bilinguals ($b = 2121.71$, $SE = 681.78$, $p_{MCMC} = .001$) for EFC displays alone. As seen in the upper panel of Figure 7, native French bilinguals with poor oculomotor inhibitory control (central and right panels) show the greatest amount of within-language competition as phonological overlap increased compared to those with good oculomotor inhibitory control (left panel), who showed virtually no evidence of within-language competition.

With respect to within-language competition seen for eye fixations to within-language competitor pictures, the only modulatory effect of inhibitory control was a three-way interaction involving word heard, phonological overlap, and cognitive inhibition cost ($b = -0.16$, $SE = 0.07$, $p_{MCMC} = .017$) across all bilinguals and displays that contained a within-language competitor (i.e., EC and EFC displays). As seen in the lower panel of Figure 7, within-language competition for bilinguals with poor cognitive inhibitory control was less dependent on phonological overlap (right panel), compared to

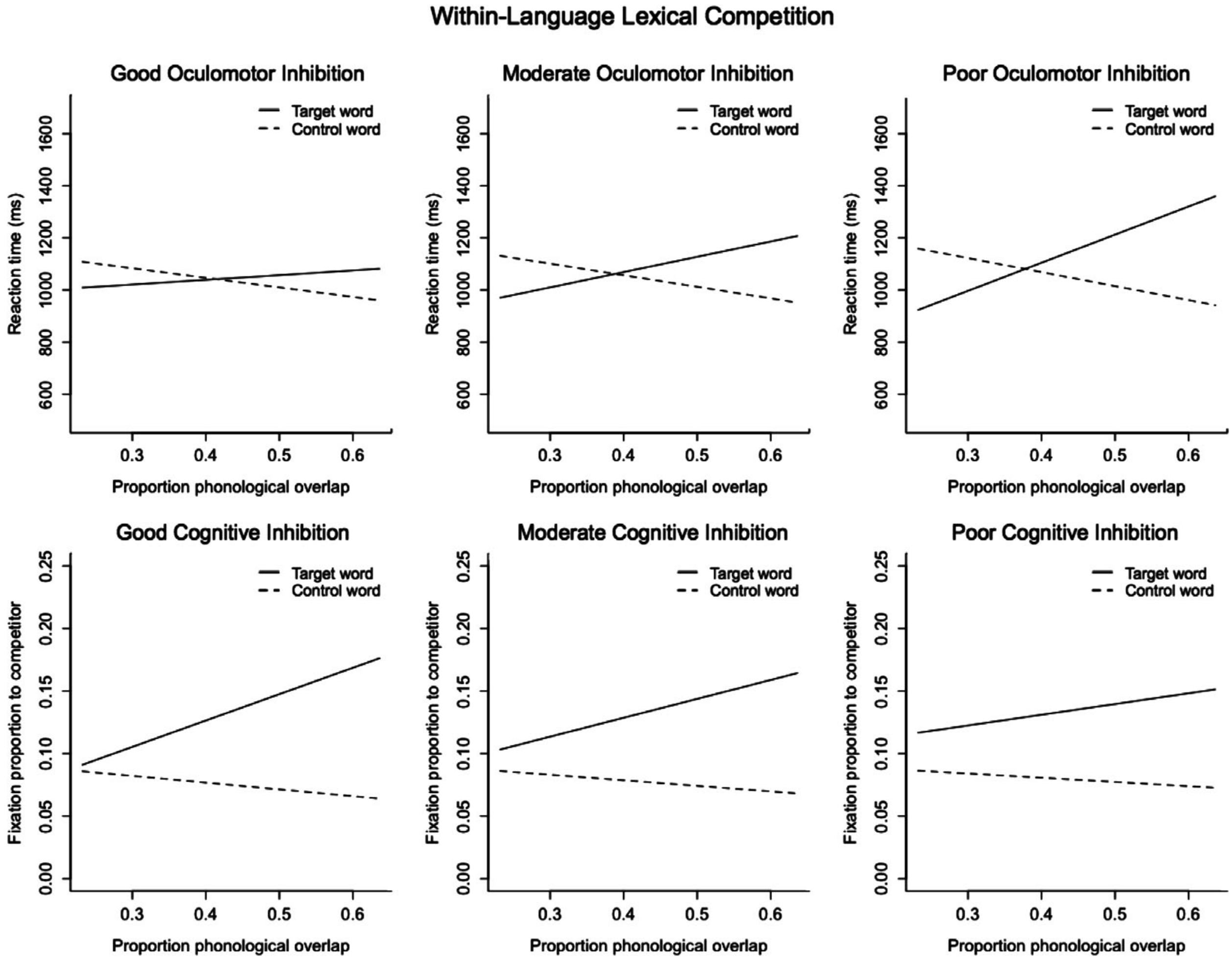

Figure 7. Inhibitory control interactions for within-language competition effects. In the upper panel, a three-way interaction between word heard (target vs. control), proportion of phonological overlap and oculomotor inhibition cost for the latency of response selecting the target picture during the visual world task for native French bilinguals (EFC display). In the lower panel, a three-way interaction between word heard (target vs. control), proportion of phonological overlap and cognitive inhibition cost for the proportion of fixations made to the within-language competitor for all bilinguals (EC and EFC displays).

that for bilinguals with good cognitive inhibitory control (left panel), who only showed within-language competition when phonological overlap between targets and competitors was high. Thus, when phonological overlap was low, bilinguals with good cognitive inhibitory control appeared to completely suppress within-language competition.

With respect to cross-language competition seen for mouse-click responses, there was a significant three-way interaction involving word heard, phonological overlap, and oculomotor inhibition cost ($b = 439.51$, $SE = 183.46$, $p_{\text{MCMC}} = .018$) across all bilinguals, when FC and EFC displays were combined. When examining each group individually, however, the only inhibitory control interaction was for native French bilinguals, who showed a four-way interaction involving word heard, phonological overlap, oculomotor inhibition cost, and percentage English exposure (measured continuously) for the FC ($b = –42.98$, $SE = 18.94$, $p_{\text{MCMC}} = .027$) and EFC ($b = –67.65$, $SE = 24.71$, $p_{\text{MCMC}} = .006$) displays. To better understand this interaction, we examined native French high and low-English-exposure bilinguals separately for each display alone. The only significant effect was a three-way interaction involving word heard, phonological overlap and oculomotor inhibition cost in low-English-exposure bilinguals for EFC displays ($b = 3004.01$, $SE = 787.32$, $p_{\text{MCMC}} < .001$). As seen in the upper panel of Figure 8, native French low-English-exposure bilinguals with poor oculomotor inhibitory control (right panel) show the greatest increase in cross-language competition as phonological overlap increased when presented with EFC displays.

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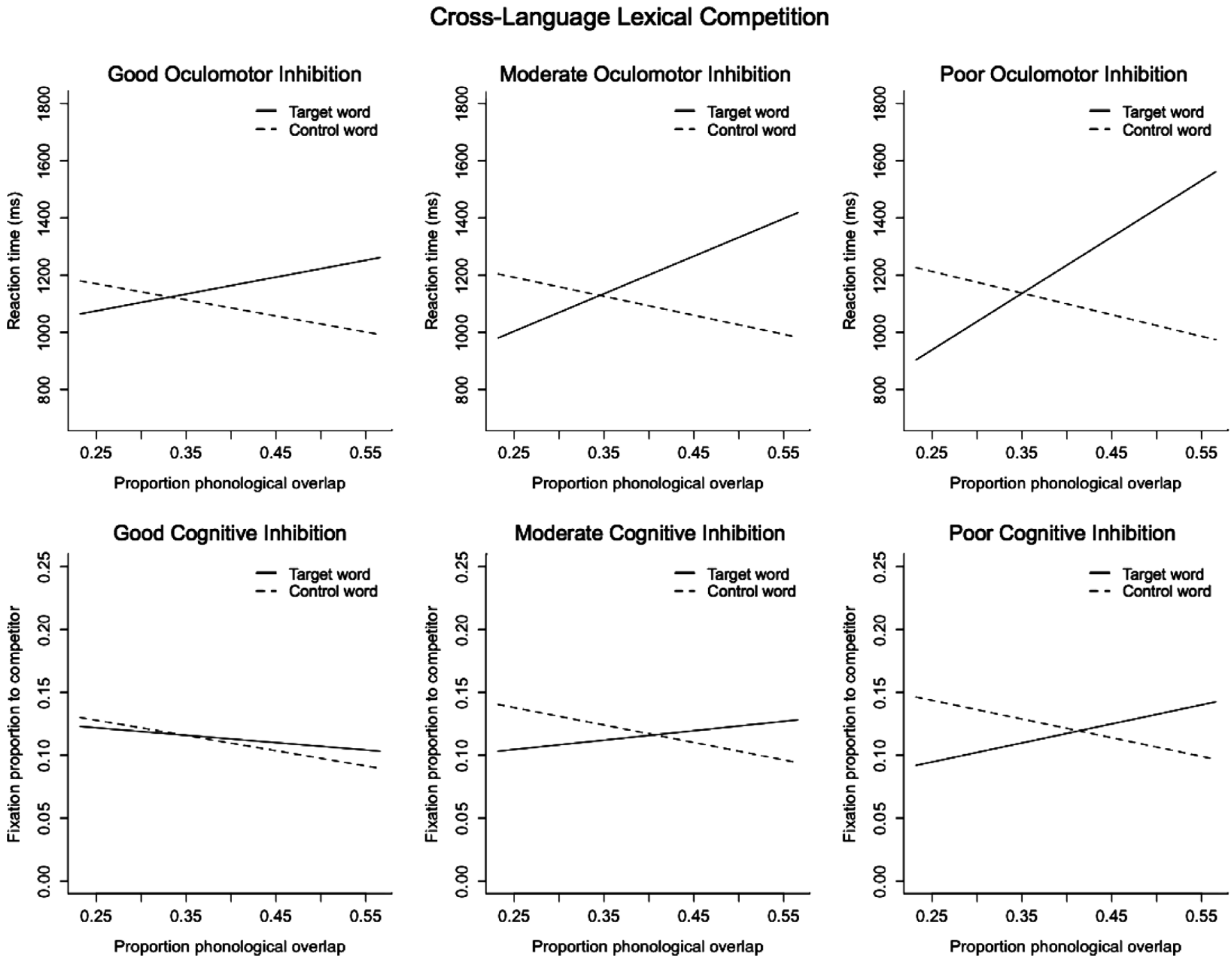

Figure 8. Inhibitory control interactions for cross-language competition effects (EFC display). In the upper panel, a three-way interaction between word heard (target vs. control), proportion of phonological overlap and oculomotor inhibition cost for the latency of response selecting the target picture during the visual world task in native French low-English-exposure bilinguals. In the lower panel, a trend towards a three-way interaction between word heard (target vs. control), proportion of phonological overlap and cognitive inhibition cost for the proportion of fixations made to the cross-language competitor in the native French low-English-exposure bilinguals.

With respect to cross-language competition seen for eye fixations to cross-language competitor pictures, the only modulatory effect of inhibitory control was for native French bilinguals and combined FC and EFC display trials. Here, there was a four-way interaction involving word heard, phonological overlap, cognitive inhibition cost, and percentage English exposure ($b = -0.01$, $SE = 0.07$, $p_{MCMC} = .006$), and a four-way interaction involving word heard, phonological overlap, oculomotor inhibition cost, and percentage English exposure ($b = -0.01$, $SE = 0.07$, $p_{MCMC} = .010$). To further understand these interactions, we examined the native French high and low-English-exposure groups separately. Interactions with inhibitory control only occurred in low-English-exposure bilinguals. We found a borderline three-way interaction involving word heard, phonological overlap, and cognitive inhibition cost ($b = 0.25$, $SE = 0.13$, $p_{MCMC} = .063$) and a three-way interaction involving word heard, phonological overlap, and oculomotor inhibition cost ($b = 0.27$, $SE = 0.09$, $p_{MCMC} = .006$). The lower panel of Figure 8 shows that low-English-exposure bilinguals with poor cognitive (right panel) show the greatest increase in competition as phonological overlap increases (a similar relation with oculomotor inhibitory control was visually similar, and thus is not displayed). These results held for the EFC (cognitive inhibition cost: $b = 0.38$, $SE = 0.19$, $p_{MCMC} = .040$; oculomotor inhibition cost: $b = 0.46$, $SE = 0.14$, $p_{MCMC} = .001$) but not FC displays.

Summary of inhibitory control effects

Taken together, the results suggest that individual differences in inhibitory control modulate both within- and cross-language competition, however, this link depends on the relative amount of competition and difficulty of the task. A modulatory role for cognitive inhibitory control was only found in terms of fixation proportions to the competitor pictures, thus, early in the time-course of word recognition. Here, cognitive inhibitory control modulated the size of within-language competition for all bilinguals, regardless of their language background. In contrast, cognitive inhibition only modulated cross-language competition in native French bilinguals presented with EFC displays, who faced the need to suppress fixations to both within- and cross-language competitors.

The role of oculomotor inhibitory control seemed more closely linked to specific task demands, in that it modulated the size of lexical competition only in EFC displays, which required the suppression of fixations to simultaneously presented within- and cross-language competitors. Also, its recruitment was restricted to native French bilinguals, who experienced the most lexical competition overall. More specifically, oculomotor inhibitory control modulated the size of within-language competition in terms of mouse-click responses across native French bilinguals, and the size of cross-language competition in terms of both mouse-click and eye fixation response measures for native French low-English exposure, for whom the task was most difficult.

Discussion

We investigated whether individual differences in inhibitory control relate to the amount of within- and cross-language competition during bilingual spoken language processing. Table 7 summarizes the overall pattern of within- and cross-language competition effects across bilingual groups. Table 8 summarizes the general set of findings regarding the modulatory role of inhibitory capacity.

In line with studies conducted during L1 (e.g., Allopenna et al., 1998; Blumenfeld & Marian, 2011; Dahan & Gaskell, 2007; Yee & Sedivy, 2006) and L2 spoken language processing (e.g., Canseco-Gonzalez et al., 2010; Marian & Spivey, 2003a, b), all bilinguals showed the typical within-language competitor effect, regardless of whether they performed the task in their L1 or L2. Those performing the task in L2 also showed this effect regardless of their degree of exposure to the task language (English), which was a proxy measure of L2 proficiency (i.e., the two were significantly

Table 7. *Summary of interactions between lexical competition and phonological overlap.*

	Dependent variable	
Type of lexical competition	Response latency	Proportion of fixations to competitor
Within-language competition	All participants show effect, but greater in native French low-English-exposure bilinguals	All participants show effect, but delayed in native French low-English-exposure bilinguals in EFC displays
Cross-language competition	All participants show effect, but greater in native French low-English-exposure bilinguals	Only native French bilinguals show effect, high-English-exposure show more in FC displays, low-English-exposure more in EFC displays

Table 8. *Summary of interactions between lexical competition, phonological overlap, and inhibitory control.*

	Within-language competition		Cross-language competition	
Type of inhibition	Response latency	Fixation proportions	Response latency	Fixation proportions
Cognitive inhibitory control	–	All bilinguals (across displays)	–	Only in native French low-English-exposure bilinguals (EFC displays only)
Oculomotor inhibitory control	Only in native French bilinguals (EFC displays only)	–	Only in native French low-English-exposure bilinguals (EFC displays only)	Only in native French low-English-exposure bilinguals (EFC displays only)

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correlated). Upon hearing target words (e.g., *field*), all bilinguals looked at within-language competitors (e.g., *feet*) more than unrelated distracters early in the word recognition process for both EC and EFC displays. Of note, all bilinguals experienced greater within-language competition as phonological overlap increased, both in terms of response latency and fixation proportions to the within-language competitor picture. When examining fixation proportions as words unfolded, native French bilinguals, especially those less exposed to English, less efficiently recognized English words. They showed a delayed within-language competitor effect compared to both native English and native French high-English-exposure bilinguals when presented with the EFC displays (see Figure 3), and were especially slowed down by within-language competition.

In contrast, evidence for cross-language competition as a function of phonological overlap was less pervasive. All bilingual groups showed greater cross-language competition as phonological overlap increased in terms of response latency to FC displays, although native French bilinguals less exposed to English showed the greatest effect. In contrast, cross-language competition as measured by fixation proportions was greater in high vs. low-English-exposure bilinguals. Additional analyses, however, revealed that this finding did not result from greater automatic activation of cross-language candidates in native French high-English-exposure bilinguals.[3] Instead, it appears that native French bilinguals who had high levels of L2 exposure looked more at cross-language competitor pictures as the experiment progressed.

The relatively weak evidence for cross-language activation found in terms of fixations, even in native French bilinguals with limited exposure to the task language, contrasts with prior findings by Marian and Spivey (Marian & Spivey, 2003a, b; Marian et al., 2003; Spivey & Marian, 1999). They found that native Russian speakers who were relatively late learners of English (L2) activated cross-language competitors whether tested in their L1 or L2, even when the context was made to be as monolingual as possible. Our results are more in line with those who have found more modest evidence for cross-language competition in the L1 and L2 (Canseco-Gonzalez et al., 2010) or no evidence of cross-language competition in an L1 context unless acoustic cues were such that L1 words sounded like they were L2 accented (Ju & Luce, 2004).[4] Several factors may have influenced Marian and Spivey's bilingual participants' baseline level of L1 relative to L2 lexical activation, and contributed to an increased likelihood of observing cross-language competition even in the L1. Their participants were all highly proficient in the L2, their daily L1 use was limited, most preferred using the L2 over the L1, and the language of the task (L1) differed from the broader language context in which participants were normally immersed (L2).

Generally speaking, cross-language activation and interference may vary based on communication demands, being greatest when bilinguals need to inhibit top–down semantic activation of all but the target language during production (e.g., Green, 1998; reviewed in Kroll & Gollan, in press), intermediate when bilinguals read words whose meanings conflict across languages (i.e., interlingual homographs; e.g., Titone, Libben, Mercier, Whitford & Pivneva, 2011; Van Assche, Duyck & Hartsuiker, 2012; Whitford & Titone, 2012), and most limited during spoken comprehension, where salient acoustic-phonetic cues may help constrain lexical activation to a specific target language (e.g., Canseco-Gonzalez et al., 2010; Ju & Luce, 2004).

Several other factors specific to the visual world task may also have contributed to different patterns of findings across studies (Huettig et al., 2011). First, the names of only a subset of the pictures were heard during this study (i.e., target and named control), which may have boosted the relative degree of lexical activation of these words, thus reducing the likelihood of pictures depicting other words to be fixated. Indeed, the learning that takes place over the course of an experiment through repetitions can have a sizable impact on participants' fixation patterns (Salverda, Brown & Tanenhaus, 2011; note, however, that we statistically accounted for repetition effects in our analyses by including trial presentation order as a control variable).

Second, participants only manipulated named pictures in the present study (i.e., via mouse click), which may have further increased participants' likelihood of looking

[3] We hypothesized that the task may be have been easier for native French high-English-exposure bilinguals than low-English-exposure bilinguals, and that they may have thus had more resources available to notice the manipulation and use this knowledge to modify their performance of the task. We reasoned that if this was the case, the tendency for high-English-exposure bilinguals to show more cross-language competition should grow as the experiment progressed. To investigate this possibility, we ran additional analyses examining whether the interaction between word heard and phonological overlap was modulated by the variable trial presentation order. For native French bilinguals overall, there were three-way interactions between word heard, phonological overlap and trial presentation order ($b = 0.01$, $SE = 0.00$, $p_{MCMC} = .009$), and between word heard, phonological overlap, and English exposure ($b = 0.02$, $SE = 0.01$, $p_{MCMC} = .016$). These three-way interactions, together with a borderline four-way interaction between word heard, phonological overlap, trial presentation order and English exposure ($p_{MCMC} = .12$) suggest that native French high-English-exposure bilinguals paid increasing attention to the cross-language lexical competitors as the experiment progressed.

[4] Canseco-Gonzalez et al. (2010) tested participants in one of three language mode conditions: monolingual, mixed, or bilingual. Relevant comparisons between our study and theirs were only done with the results of participants tested in the monolingual mode, which most resembled the context of our study.

at the named vs. unnamed pictures (e.g., Irwin, 2004; Land, Mennie & Rusted, 1999). Moreover, previous visual world studies showing comparatively stronger cross-language competition (e.g., Marian & Spivey, 2003a, b; Marian et al., 2003; Spivey & Marian, 1999) had spoken word repetitions, but also required the manipulation of physically presented objects that existed in the real world rather than on a computer screen.[5] These factors, combined with the more reliable cross-language competition effects in terms of latency than fixations, suggest that participants may have activated cross-language candidates, but that relatively lower levels of activation resulted in presaccadic shifts in covert attention (e.g., Henderson, 1992; Henderson, Pollatsek & Rayner, 1989), but no saccadic motor plans leading to fixations (Altmann, 2011).

The monolingual nature of the testing setting, combined with the fact the non-target language (i.e., French) was never heard or alluded to during the experiment, might have also limited the observation of cross-language activation.[6] Indeed, even if some participants were aware of the importance of their bilingual status prior to the experiment, the modest magnitude of cross-language effects renders improbable that they operated under a bilingual mode of processing. While some work reports cross-language activation despite efforts to control language mode (e.g., Blumenfeld & Marian, 2007; Canseco-Gonzalez et al., 2010; Marian & Spivey, 2003a, b; Van Hell & Dijkstra, 2002), others show it to vary as a function of language intermixing (de Groot, Delmaar & Lupker, 2000; Dijkstra et al., 1998; Titone et al., 2011). Still, several models propose that factors such as recency of use and contextual relevance can alter the activation threshold of words from the non-target language (Dijkstra & Van Heuven, 2002; Grosjean, 2008; Paradis, 2001). By and large, cross-language activation and interference during spoken language comprehension may be especially hard to observe in the context of relatively stereotyped, and thus less demanding, utterances and task demands presented in a monolingual vs. multilingual context (i.e., less attentional need; Krizman, Marian, Shook, Skoe & Kraus, 2012) presenting limited verbal and non-verbal distractions (e.g., competing voices, background noise).

Our key finding, however, is that individuals with better inhibitory control showed an enhanced ability to suppress lexical competitors. We now discuss the results for each type of inhibitory control, cognitive and oculomotor, in turn. First, increased cognitive inhibitory control was linked to less within-language competition for all bilinguals in terms of fixations patterns. In native French bilinguals with low English exposure, however, it was also linked to less cross-language competition in terms of fixations. Thus, the group most likely to experience cross-language effects was also most likely to show a modulation of cross-language competition based on cognitive inhibition. Therefore, cognitive inhibition appears important to the resolution of lexical competition to the extent that it is strong enough to affect comprehension.

The pattern of results obtained for oculomotor inhibitory control was less straightforward. Increased oculomotor inhibitory control was linked to less within-language competition for all native French bilinguals in terms of response latency. However, this was only observed for EFC displays. Increased oculomotor inhibitory control was also linked to less cross-language competition for native French bilinguals with low English exposure in terms of response latency and fixations, again only for EFC displays. We believe that oculomotor inhibition was particularly relevant for performance on EFC displays because participants could entertain both within- and cross-language competitors as viable candidates, and thus have their visual attention captured by both picture types. As a result, participants probably had to exert more control over their eye movements to redirect their attention to the pictures whose name they heard. The results suggest that this more effortful lexical disambiguation process prolonged the word recognition process, and thus slowed participants' selection of the appropriate picture.

This leads to interesting speculations on the role of cognitive and oculomotor inhibitory control in the context of the visual world task. Both inhibitory control measures probably reflected something about domain-general cognitive control (see also Bialystok, Craik & Ryan, 2006), and indeed, oculomotor inhibition tasks (e.g., antisaccade) recruit brain regions in the prefrontal areas that overlap with other kinds of non-oculomotor control tasks (Egner, 2011; Melcher & Gruber, 2009; Munoz & Everling, 2004). Cognitive inhibitory control, however, may more closely relate to the need to internally inhibit transiently activated competitors as spoken word recognition unfolds over time. Conversely, oculomotor inhibitory control may closely relate to the need to exert control over the tendency to look at pictures corresponding to competitors temporarily matching the presented spoken word. Indeed, the visual world task requires that the listener, following the disambiguation of the auditory signal, redirects his or her attention away from partially activated competitors and towards the picture whose name

5 Naming agreements for cross- vs. within-language competitors were comparable in the present study (see Appendix C for supplementary details), and the number of target/competitor overlapping phonemes across studies in the literature have also been similar. These factors are thus unlikely to have undermined our ability to measure a cross-language competition effect.

6 The vocabulary task (performed in L1), language questionnaire, and speeded lexical judgment task, which included blocks of trials in L1 and L2, were always administered last, after the main experiment.

https://doi.org/10.1017/S1366728913000084 Published online by Cambridge University Press

matches the target (e.g., by suppressing fixations and redirecting his or her gaze) so that an accurate response can be made.

This suggests that oculomotor inhibitory control may be related to lexical competition here partly because of a superficial similarity with the visual world task, which, by nature, relies on the measurement of eye movements to related and unrelated pictures. The pattern of results we obtained, however, suggests a more complicated picture. Given that associations between oculomotor inhibitory control and lexical competition was mostly observed in less proficient bilinguals for whom the task was most challenging, one possibility is that oculomotor inhibitory control is more engaged to the extent that cognitive inhibitory control is insufficient to efficiently disengage visual attention from competitors. For native English bilinguals, for whom the task, performed in L1, was easier, "internally" suppressing competitors may have been sufficient to redirect their attention onto the targets.

In contrast, native French bilinguals may have had insufficient cognitive inhibitory control resources available to "internally" suppress competitors, and thus been more visually distracted by the competitor pictures, especially if less exposed or proficient in the task language (their L2). This would have made them more likely to recruit oculomotor inhibitory control to disengage their visual attention from competitors, especially in EFC displays, which is where we found the association between oculomotor inhibitory control and lexical competition. This raises the possibility that in more cognitively demanding situations or in populations whose inhibitory capacities are compromised, different levels of inhibitory control may be recruited based on the specific task demands. Additional research will be needed to better understand the role of distinct kinds of inhibition under different language processing situations.

The results are consistent with work showing that cognitive abilities relate to an ability to disregard irrelevant word meanings (e.g., homonyms) during reading (e.g., Gadsby, Arnott & Copland, 2008; Gernsbacher & Faust, 1991; Gunter, Wagner & Friederici, 2003; Miyake, Just & Carpenter, 1994; Wagner & Gunter, 2004), and the amount of lexical competition during spoken word recognition in both special populations (e.g., Sommers & Danielson, 1999; Titone & Levy, 2004; Yee et al., 2008) and healthy individuals (Prabhakaran, Blumstein, Myers, Hutchison & Britton, 2006; Righi, Blumstein, Mertus & Worden, 2010). The results are also consistent with recent findings that individual differences in inhibitory control modulate bilingual cross-language activation during reading (Pivneva, Mercier & Titone, 2013) and speech production (Pivneva, Palmer & Titone, 2012). Finally, the results complement those of Blumenfeld and Marian (2011), who showed that individual differences in inhibitory control are related to the resolution of within-language competition during L1 spoken comprehension in bilinguals but not monolinguals, but did not examine if individual differences in inhibitory control had a similar impact on cross-language competition.

Recent research suggests that speech processing is more demanding in L2 (by virtue of being non-selective and less precise; e.g., Broersma & Cutler, 2011; Cutler et al., 2006; Weber & Cutler, 2004), that more widespread brain activation is associated with phonological processing in L2 than L1 (Marian et al., 2003), and that more efficient inhibitory mechanisms are associated with an enhanced ability to cope with lexical competition (e.g., Blumenfeld & Marian, 2011), which together point to the recruitment of non-verbal inhibitory processes during language processing as the mechanisms behind the development of non-verbal cognitive advantages in bilinguals reported in the literature (e.g., Bialystok et al., 2009; Bialystok et al., 2004; Bialystok et al., 2008; Costa et al., 2008; Luk, De Sa & Bialystok, 2011).

Although the present study was not designed to directly test the "bilingual advantage" view, we examined the relation between L2 proficiency and inhibitory control. We found no evidence that bilinguals with more vs. less L2 exposure/proficiency had greater inhibitory control (cognitive inhibition cost: $r = -0.14$, $p = .26$; oculomotor inhibition cost: $r = 0.09$, $p = .47$; this absence of correlation held if examining performance on individual inhibitory control tasks; but see Mercier, Sudarshan, Pivneva, Baum & Titone, 2013; Pivneva & Titone, 2013, for moderate correlations). These studies, however, were not designed to test this hypothesis and had limited sample sizes, and thus potentially restricted ranges in L2 ability or other ways bilinguals may differ that bear on this hypothesized relationship (language learning history, current language usage patterns, etc.). This hypothesis will be better addressed in a methodologically more compelling way by future studies using larger sample sizes and better control of the many important ways bilinguals differ (Green, 2011; Wu & Thierry, 2010).

One possible explanation for the absence of relation between L2 exposure/proficiency and inhibitory control is that young adult participants perform inhibitory control tasks at ceiling, and that such relation is only observable when cognitive abilities are compromised. The bilingual advantage has most consistently been observed in more demanding tasks and in older adults whose cognitive control is known to be declining (e.g., Bialystok et al., 2008; Bialystok et al., 2004; Costa, Hernández, Costa-Faidella & Sebastián-Gallés, 2009; but see Hilchey & Kline, 2011). For instance, we recently used the same material as in the present study in older bilinguals, and found a relation between increased L2 proficiency and better inhibitory control (Mercier et al., 2013).

An additional and not mutually exclusive hypothesis proposed by Luk and colleagues (Luk, Anderson, Craik, Bialystok & Grady, 2010) is that, as proficiency increases, different and/or more widespread neural processes become engaged during language processing in young adults, but that behavioural measures lack the required sensitivity to capture these differences.

Finally, the results of this study suggest that inhibitory control mechanisms modulate the time-course of spoken language comprehension in a way that is not acknowledged in current models of spoken word recognition. Indeed, current models do not include a role for top–down, domain-general cognitive processes in the inhibition of transiently activated lexical competitors (Bilingual Interactive Activation Model Plus, or BIA+, in Dijkstra & Van Heuven, 2002; Bilingual Interactive Model of Lexical Access, or BIMOLA, in Grosjean, 2008; Bilingual Language Interaction Network for Comprehension of Speech model, or BLINCS, in Shook & Marian, published online September 5, 2012).[7] Our results suggest that more complete accounts of speech processing will be reached when the role of individual differences in both domain-general inhibition and language-specific mechanisms are considered.

In conclusion, our findings suggest that bilingual spoken word recognition is not exempt from non-linguistic influences and that domain-general inhibitory control plays a role regardless of whether it takes place in a first or second language. Individual differences in different types of inhibition predict the size of within- and cross-language competition, especially in participants least exposed to L2, for whom language comprehension is more demanding. Although we did not find direct evidence for an association between increased L2 proficiency and enhanced inhibitory control, it appears reasonable that, over time, the regular recruitment of domain-general inhibitory mechanisms by bilinguals to cope with the demand of managing their two languages lead to a strengthening of these same mechanisms. Investigating language processing in more cognitively demanding situations or in populations whose inhibitory capacities are compromised such as older bilinguals should help shed more light on this hypothesis.

[7] The BIA+ model was developed for visual word recognition, but its authors suggest it is applicable to spoken word recognition.

Appendix A. Stimulus sets for the visual world task

The target and control words were heard in the instructions (*). Overlapping phonemes are shown in bold.

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**t͂ɔ/	magnet /mægnɛt/	hunter /həntər/	lobster /lɑbstər/
2	beans /**bi**nz/	beak /**bi**k/	bidon /**bi**d͂ɔ/	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**mj͂ɔ/	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/
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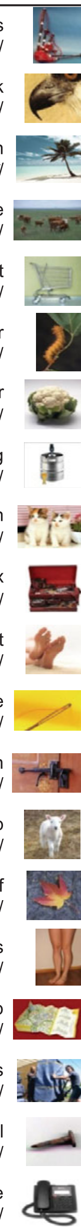
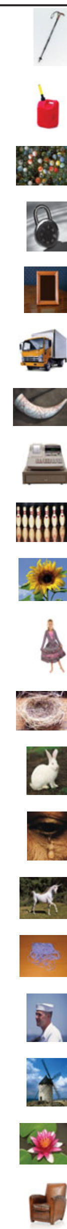
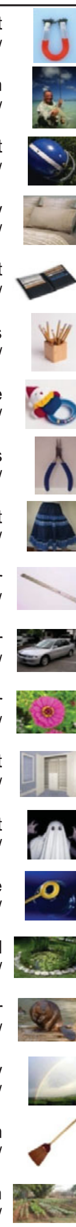
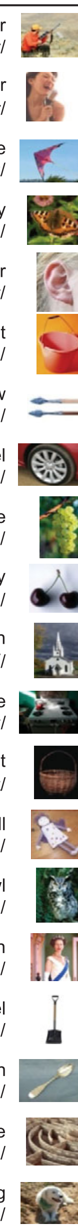
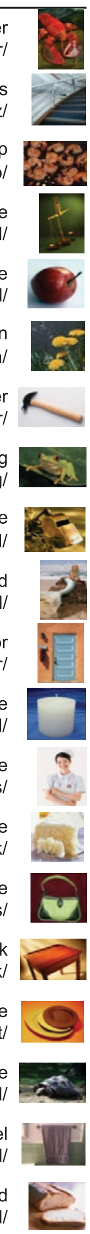

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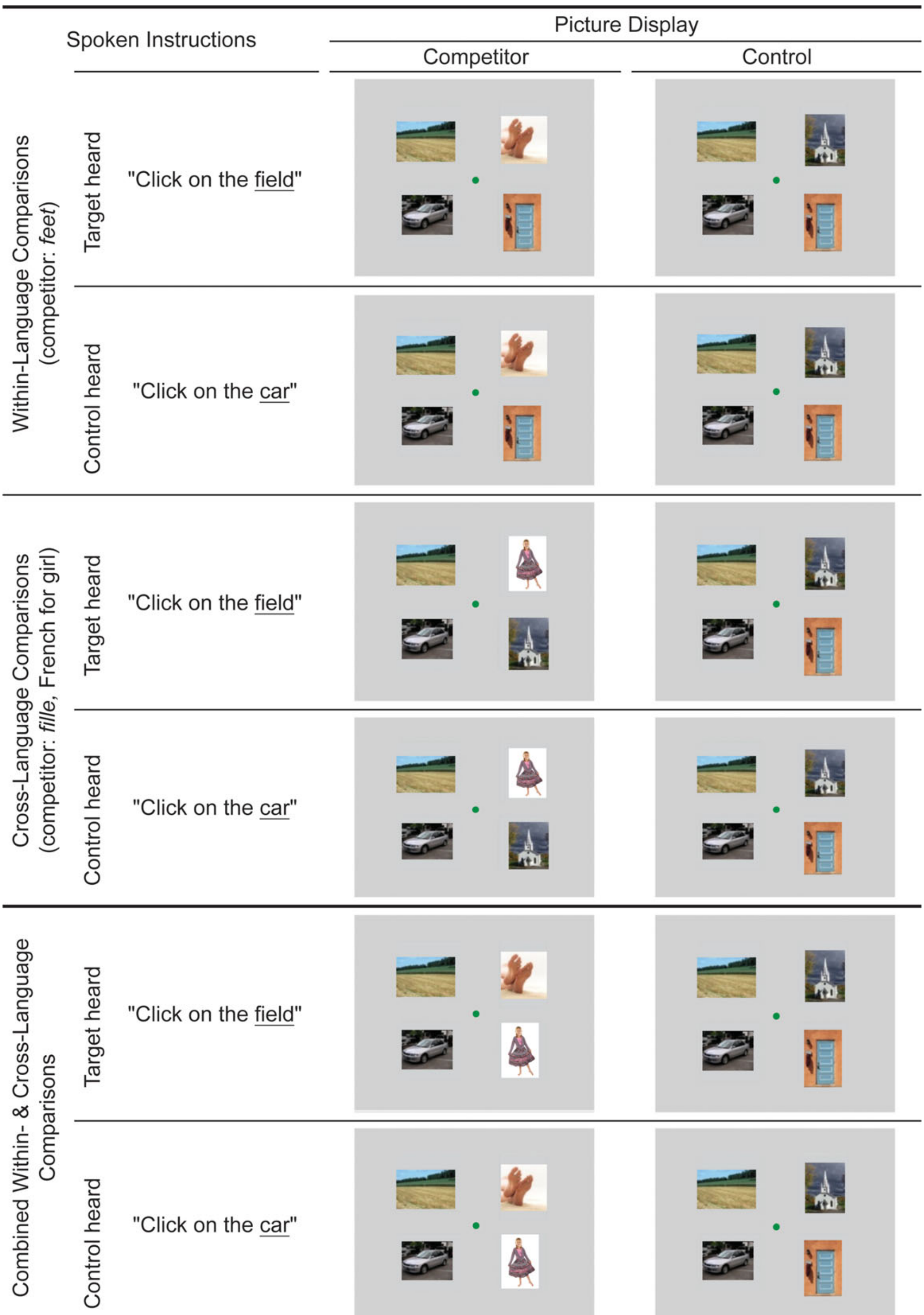
Appendix B. Example of displays viewed and words heard in the visual world task

Examples of within-language English competitors (EC), cross-language French competitors (FC), combined within- and cross-language competitors (EFC), 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.



https://doi.org/10.1017/S1366728913000084 Published online by Cambridge University Press

Appendix C. Supplementary information on materials

At the end of the study, native French participants provided names for all pictures, and answers were coded to reflect whether the given labels corresponded to the intended names (1 or 0). The naming agreements for the different pictures significantly differed ($F(4,95) = 7.38$, $p < .01$), and differences were assessed with pair-wise comparisons. The naming agreement obtained for the within-language word-onset competitor ($M = 0.59$, $SD = 0.26$) was significantly lower than that for the cross-language lexical competitor ($M = 0.77$, $SD = 0.21$, $p = .03$), control distracter ($M = 0.77$, $SD = 0.14$, $p = 0.02$), and not surprisingly given they had been heard in the course of the study, named control ($M = 0.89$, $SD = 0.14$, $p < .01$), and target ($M = 0.85$, $SD = 0.18, p < .01$) pictures. No other differences reached significance. The majority of names given that did not correspond to the intended names fell in the same semantic category. The same participants then rated the match between each picture and its intended label (1 = poor match and 5 = excellent match). Overall, pictures and their intended labels were judged as highly matching ($M = 4.74$, $SD = .28$) but significant differences were found between the pictures ($F(4,95) = 3.99$, $p < .01$), which were again assessed with pair-wise comparisons. The ratings obtained for within-language word-onset competitors ($M = 4.61$, $SD = .40$) were significantly lower than that for the named controls ($M = 4.85$, $SD = 0.20$, $p < .01$). No other differences reached significance.

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