Cross-language and cross-modal activation in hearing bimodal bilinguals

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Highlights

Activation of sign language while bimodal bilinguals heard spoken words.

Non-selective cross modality language activation in native and late signers.

Parallel activation of the non-dominant language while using the dominant language.

Abstract

This study investigates cross-language and cross-modal activation in bimodal bilinguals. Two groups of hearing bimodal bilinguals, natives (Experiment 1) and late learners (Experiment 2), for whom spoken Spanish is their dominant language and Spanish Sign Language (LSE) their non-dominant language, performed a monolingual semantic decision task with word pairs heard in Spanish. Half of the word pairs had phonologically related signed translations in LSE. The results showed that bimodal bilinguals were faster at judging semantically related words when the equivalent signed translations were phonologically related while they were slower judging semantically unrelated word pairs when the LSE translations were phonologically related. In contrast, monolingual controls with no knowledge of LSE did not show any of these effects. The results indicate cross-language and cross-modal activation of the non-dominant language in hearing bimodal bilinguals, irrespective of the age of acquisition of the signed language.

Keywords

Cross-language activation; cross-modal activation; bimodal bilingualism; sign language.

Introduction

A central question in bilingualism is whether the processing of one language necessarily involves activating the other, or whether the two languages are accessed independently. Some neuroimaging studies have revealed overlapping activation of the same brain regions for both languages (e.g., Chee, Tan, & Thiel, 1999; Illes et al., 1999; Klein, Milner, Zatorre, Meyer, & Evans, 1995), suggesting that the languages share the same neural circuitry. Furthermore, there is growing evidence for cross-language activation even when bilinguals are using just one of their languages when reading words (e.g., Schwartz, Kroll, & Diaz, 2007; Thierry & Wu, 2007) or sentences (e.g., Libben & Titone, 2009), when hearing words (e.g., Marian & Spivey, 2003; Spivey & Marian, 1999), or while naming pictures (e.g., Costa, Caramazza, & Sebastian-Galles, 2000), even when both languages use different written scripts (e.g., Hoshino & Kroll, 2008). In contrast, claims have been made for language independence in monolingual contexts given the strong inhibition of one language (Rodriguez-Fornells, Rotte, Heinze, Nösselt, & Münte, 2002).

The present study investigates whether cross-language activation is present in hearing bimodal bilinguals by asking whether there is activation of their second language (L2), Spanish Sign Language, LSE (*lengua de signos española*), when performing a task in their first language (L1), spoken Spanish. Thus, we will be testing cross-language and *cross-modal* activation, where modality refers to the perceptual channels employed by the language (oral-auditory and gestural-visual). To that end, we adapted the semantic relatedness paradigm used in a within modality setting by Thierry and Wu (2007; see also Wu & Thierry, 2010), who showed that bilinguals in two spoken languages activated their L1 (Chinese) while dealing with their L2 (English).

A very small number of studies focusing on bimodal bilingualism in deaf individuals have examined whether non-selective access can also be found across languages that do not overlap in modality. The activation of L1 when dealing with L2 occurs in deaf balanced bilinguals (Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011). Deaf native signers of American Sign Language (ASL) read pairs of words in English and judged their semantic relatedness. The results showed cross-language activation since the presence of a phonological relation between the ASL equivalents of the English words influenced the reaction times for the semantic judgement. Thus, on one hand, in the context of a semantic relation, a (unseen L1) phonological relation produced a facilitation effect. Conversely, when the items were not semantically related, the (unseen L1) phonological relation gave rise to an inhibitory effect. A similar experiment was run in a subsequent study with two groups of unbalanced ASL/English bilinguals: a group of deaf ASL-dominant/English and a group of hearing English-dominant/ASL signers (Morford, Kroll, Piñar, & Wilkinson, 2014). Deaf bilinguals showed the same inhibitory and facilitatory effects reported previously. However, the hearing English-dominant signers, for whom ASL was their L2, showed only the inhibitory effect. Importantly, the deaf bilinguals were performing the task in their L2, while the hearing bilinguals performed the experiment in the written form of their L1. In addition, deaf native signers normally associate English word forms with ASL signs when they learn to read, while the hearing group would have linked the English orthography with the spoken English phonological forms. A very similar experiment using the same procedure was carried out in proficient deaf bilinguals in German Sign Language, DGS (*Deutsche Gebärdensprache*), and written German (Kubus, Villwock, Morford, & Rathmann, 2015). Kubus et al. (2015) found the inhibitory effect described by Morford et al. (2011) but not the facilitatory effect for the 'hidden' phonological relation (in the context of a semantic relationship). The authors linked this difference in the results to two reasons: differences in the experimental stimuli and in the languages involved.

Therefore, there is evidence for a cross-modal print-sign parallel activation when the languages are of a different modality in deaf and hearing bimodal bilinguals. However, there are two important considerations. Firstly, the spoken language was presented in its written form, a secondary code that provides a visual representation of an auditory signal. This involves looking for links between the representation of the static written form of the spoken language and the representation of the dynamic signal of the sign language. Additionally, this means that the explicit and the implicit codes are both visual, the experimental task is performed in the same (visual) modality as the language for which implicit activation is sought. Secondly, most of the participants in these studies were deaf bimodal bilinguals. These individuals are sign-print bilinguals due to their limited or indirect access to the acoustic form of the spoken language. More critically, these two factors interact since many deaf individuals learn to read by associating the signs of the signed language with the written forms of the spoken language. This raises the issue of the type of representation that deaf individuals have (of the written form) of the spoken language and how that may come to bear on the question of cross-linguistic and cross-modal activation.

In the present study we focus on the modality of the dynamic *primary* signal for a given language, namely, oral-auditory for spoken language, and visual-gestural for signed language. Examining these effects in hearing bimodal bilinguals, who acquire the dynamic primary signal of each language directly, would provide a clearer picture of cross-modal and cross-language activation. To our best knowledge, there are only two studies (Giezen, Blumenfeld, Shook, Marian, & Emmorey, 2015; Shook & Marian,

2012) that have looked directly at cross-language activation in hearing bimodal bilinguals with spoken language as stimuli using a very different procedure: the visual world paradigm. Participants heard a word and had to select one of four images on a screen. In addition to the target, there were two unrelated distractors and a phonological competitor of the target in the ‘hidden’ language (ASL) that shared three phonological parameters. Bimodal bilinguals looked more often and longer at the competitor rather than the distractors. Consequently, co-activation does not seem to be dependent on the modality of the languages in bimodal bilinguals. Thus, these two studies showed parallel activation of the sign language (the non-explicit language: ASL) during comprehension of spoken English in highly proficient hearing bimodal bilinguals. However, the participants were looking at images while hearing words, so the task offered visual stimuli in order to activate the signed language. In addition, the paradigm prompted explicitly a representation through the picture that activated the sign language competitor. Both the explicit trigger and the hidden target shared the visual modality. Furthermore, these stimuli were not controlled for iconicity of the signs. The form of iconic signs bears some resemblance to the meaning and iconicity has been found to play a role in the activation of signs from word stimuli in deaf bilingual children (Ormel, Hermans, Knoors, & Verhoeven, 2012). Thus, some of the picture stimuli from the experiment may have resembled the corresponding sign forms and have triggered the activation of signs. A task without any visual cues would be a stronger test to find out whether the cross-language activation is actually set off by the language input. Finally, none of these studies investigated whether these putative effects are modulated by age of acquisition (AoA); that is, whether the effect is present both in native bimodal bilinguals and late learners of the signed language.

When the signed language has been learnt impacts how the mental lexicon is organized, how the sublexical parameters are processed (Carreiras, Gutiérrez-Sigut, Baquero, & Corina, 2008; Corina & Hildebrandt, 2002; Emmorey & Corina, 1990; Emmorey, Corina, & Bellugi, 1995; Mayberry & Eichen, 1991) and it might also impact on the link with the spoken language. Hearing native bimodal bilinguals normally have deaf parents who use the signed language. The milestones of language learning in these babies are the same as those of children that acquire two spoken languages, and very similar to those of children that acquire only one language, whether signed or spoken (Petitto et al., 2001). Hearing late learners of a signed language have the spoken language as L1. Late learners, compared to natives, rely more on iconicity (Campbell, Martin, & White, 1992) and associations with their spoken language in order to learn the signed language. Furthermore, there is robust neurological evidence of AoA differences in hearing bimodal bilinguals when processing signed and spoken languages (Neville et al., 1997; Newman, Bavelier, Corin, Jezzard, & Neville, 2002; Zachau et al., 2014). Therefore, given the previous differences between native signers and late learners, in the present study we will investigate whether hearing bimodal bilinguals who have acquired a signed language at different ages activate signs (L2) when hearing words (L1).

For the current experiments, we used the semantic relatedness paradigm from Thierry and Wu (2007) that Morford el al. (2011) adapted to deaf signers. In our case, we modified the implicit priming for hearing bimodal bilinguals in spoken Spanish and LSE and we ran the experiment in spoken Spanish (the dominant language) to see if LSE (the non-dominant language) was activated. Previous cross-language and cross-modal experiments using this semantic relatedness paradigm with implicit priming have been run with the written form of the spoken language. This study, however, uses the spoken language in its primary manifestation as the input in order to assess whether there is selective or non-selective access from one primary code to another. In this sense, the paradigm in this study is also a cross-modal paradigm: participants hear spoken words and we check whether or not they prime visual signs. This will allow us to make solid interpretations concerning activation when the two languages involved do not share modality. This is a crucial difference with respect to the paradigm of the previous studies that have demonstrated cross-modal activation: the paradigm was unimodal in the sense that the visual form of the language was used to prime a visual signed language.

We studied two groups of hearing bimodal bilinguals: native (Experiment 1) and late learners (Experiment 2). For hearing bimodal bilinguals the spoken language was the dominant language according to self-ratings provided by the participants in this study (see Methods section below). Both experiments were also run with hearing participants with no knowledge of LSE as the control groups.

Given that sign language can be activated when hearing spoken language we expect the highly proficient native bimodal bilinguals in Experiment 1 to show strong evidence of cross-language cross-modal activation. Specifically, we expect that: (1) In the presence of a semantic relation, native bimodal bilinguals should show shorter reaction times (RTs) and/or lower error rates when there is an implicit phonological relation (2) In the absence of a semantic relation, native bimodal bilinguals should show longer RTs and/or higher error rates when there is an implicit phonological relation. In Experiment 2 we expect either similar results or, in line with the results found by Morford et al., (2014), less evidence of cross-language and cross-modal activation, limited to inhibitory effects on the semantically unrelated pairs since this appears to be a more robust effect.

Experiment 1. Hearing native bimodal bilinguals (CODAs) and hearing monolinguals

Methods

Participants. We recruited 20 children of deaf adults (CODAs) highly proficient in both languages (LSE and Spanish) for the experimental group, and 20 hearing monolinguals in Spanish as controls. In order to make sure that the CODAs were using LSE and Spanish on an everyday basis, we selected subjects who were sign language interpreters at the time of the study and who had been working as such for at least the previous two years. The bimodal bilingual group and the control group were matched in age and education level. A small group of bimodal bilinguals had knowledge of other (spoken) languages, such as regional Spanish languages (e.g. Galician, Basque) or English. Participants' characteristics are shown in Table 1. The experiment was run in the different locations where participants were recruited (Bilbao, Burgos, León, Madrid, Palencia, Pamplona, San Sebastián and Valladolid).

Table 1
Experiment 1. Participants' Characteristics

Group	Number of participants	Mean Age	Gender	Years of experience as sign language interpreters	Self-rated LSE competence (from 1 to 7)
Native Bimodal Bilinguals	20	39.6	15 women 5 men	17.7 (mean)	6.6 (mean)
Hearing Monolinguals	20	39.2	12 women 8 men		

Materials. 64 pairs of words in Spanish were selected (Appendix A). Thirty two of the word pairs were semantically related and the other thirty two unrelated. Different semantic relations between primes and target words were included, such as antonyms, synonyms, hypernyms and hyponyms, coordinate terms and associative relations. Within each semantic condition, half of the pairs had associated LSE signs that were phonologically related, and the other half had no phonological relation in LSE. An example of each condition appears in Figure 1. Sixteen additional word pairs were fillers.

	Semantic relation		No semantic relation	
Phonologic relation	*suegra* (mother-in-law) 	*madre* (mother) 	*criada* (maid) 	*golfo* (scoundrel) 
No phonologic relation	*hija* (daughter) 	*madre* (mother) 	*suerte* (luck) 	*golfo* (scoundrel) 

Figure 1. Examples of stimuli. Participants only heard words in Spanish, the explicit language. Photographs show the translation in LSE, the implicit language, for illustrative purposes. English translations appear within parentheses.

Pairs of signs with phonological relation shared at least two formational parameters: handshape, orientation, movement and location (Appendix B). The focus of this study was covert activation of LSE. Although it has been shown that these different parameters are not processed identically (Carreiras et al., 2008) we were not aiming to disentangle the influence of each parameter individually in the present study. Within each semantic condition, the second word (the target word) appeared in pairs with and without phonological relationship. This way, participants were responding to the same words in the two critical conditions of interest.

Within each semantic condition, for every phonologically related word pair a parallel word pair was created with the same target word and a phonologically unrelated prime in LSE. A group of 20 native Spanish speakers (with no knowledge of LSE, and who did not participate in the main experiment) judged the semantic relatedness of each word pair on a scale from 1 (no semantic relation) to 7 (strong semantic relation). Only pairs with scores below 3 or above 5 were considered.

As a further check on the semantic relatedness of the selected word pairs, we obtained automatic text-based values of first-order and second-order semantic similarity using DISCO (*extracting DIstributionally related words using CO-occurrences*, Kolb, 2008, 2009) on a large, 232 million (word) token corpus of Spanish texts.[1] Both words in each pair were members of the same grammatical class. We also controlled for log frequency and number of phonemes according to the values from EsPal, the Spanish Lexical Database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013), using the Written and Web Tokens database (2012-11-06) and Castilian Spanish phonology. The properties of the final word lists are shown in Tables 2 (semantically related) and 3 (semantically unrelated).

[1] The corpus consisted of the entire Spanish Wikipedia from July 2008, a collection of Parliamentary debates and works of literature from the 19th and 20th centuries. More details (and the corpus itself) are available at http://www.linguatools.de/disco/disco-languagedatapackets_en.html#esgeneral.

Table 2
Characteristics of Semantically Related Words (means and standard deviations in brackets)

	Phonologically			
	Related primes	Unrelated primes	p-value of t-test primes	Targets
Log frequency	1.48 (0.57)	1.68 (0.65)	0.37	1.80 (0.51)
Number of phonemes	5.69 (0.87)	5.81 (1.38)	0.68	5.25 (1.12)
Duration (ms)	789 (84)	773 (101)	0.63	754 (116)
DISCO semantic similarity[2]	0.37 (0.27)	0.41 (0.27)	0.52	
Human rating of semantic relationship between primes and targets	6.34 (0.41)	6.24 (0.42)	0.48	

Table 3
Characteristics of Semantically Unrelated Words (means and standard deviations in brackets)

	Phonologically			
	Related primes	Unrelated primes	p-value of t-test primes	Targets
Log frequency	1.33 (0.81)	1.20 (0.70)	0.63	1.24 (0.65)
Number of phonemes	5.56 (1.75)	5.25 (0.77)	0.38	5.13 (1.26)
Duration (ms)	778 (123)	766 (85)	0.76	744 (103)
DISCO semantic similarity	0.04 (0.04)	0.04 (0.05)	0.86	
Human rating of semantic relationship between primes and targets	1.53 (0.50)	1.41 (0.49)	0.5	

The words were recorded using Goldwave audio software in an audio recording booth, spoken by a male native Spanish speaker with an unmarked accent. The audio

[2] For both semantically related and unrelated word pairs only DISCO values for second-order semantic similarity are reported as first-order values were also matched with no significant differences. First and second order refers to different matrices in size concerning the amount of words taken into consideration to compute the semantic similarity values. Second-order values show a reasonable correlation with human-based values (Kolb, 2008).

files were edited, de-noised and equalized using Praat (Boersma & Weenink, 2014). A time span of 100 ms of silence before the voice onset of each word was set, visualising the waveforms of each recording and matching them when necessary in order to make sure that all the onsets were identical. For the analysis, this silent span was subtracted from the RTs of each response, so the RT reflected the latency from the onset of the word, not from the beginning of the audio recording.

Procedure. The experiment was presented using the SR Research Experiment Builder software (V.10.1025) on a Toshiba laptop with Intel® Pentium® M processor (1.73 GHz) with a Realtek AC97 Audio sound device and headphones (Beyerdynamic DT 770 Pro 250 ohm) for the audio. The headphones provided soundproofing from any environmental noise and delivered words at a volume of 60 dB (checked with a sound level meter). For each word pair, participants listened to the two words in succession and had to decide whether or not their meanings were related. Participants responded as soon as they could after hearing the second word of the pair. Right-handed participants pressed the right key ('L' on a qwerty keyboard) for semantic relation and the left key ('A' on the keyboard) for lack of semantic relation. Left-handed participants pressed 'A' for semantic relation and 'L' for lack of semantic relation. In this way, all participants responded positively with their dominant hand.

The participants read the instructions for the experiment in Spanish, which included various illustrative examples of the types of semantic relations that appeared in the experimental items (i.e. synonyms, antonyms, coordinate terms). The participants were instructed to respond as quickly and as accurately as possible. This was followed by a practice task consisting of eight trials in which the computer provided feedback (correct/incorrect) to help in understanding the task. The presentation of the experimental trials was counterbalanced and pseudorandomized. There were at least five trials (i.e. ten different words) separating both appearances of the same word. We used two different lists so that half of the participants were presented with one list and the other half with the other list.

Reaction times were measured after the onset of the second word of each pair. Each trial started with a fixation cross in the centre of the screen (500 ms), then the first word was presented, followed by 200 ms of silence before the second word was played. After the participant's response, before the next trial began, there were 1500 ms of silence.

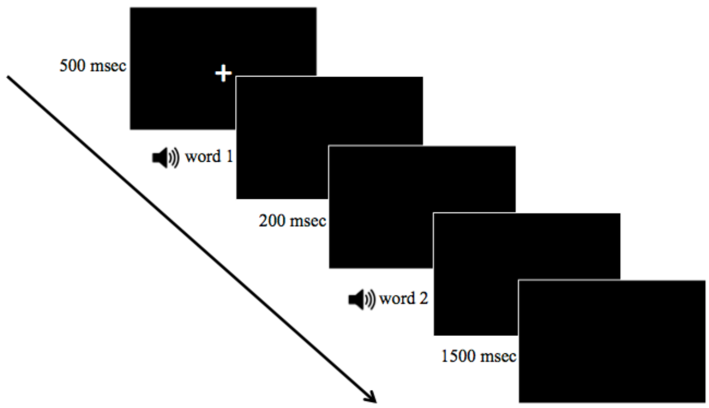

Figure 2. Trial sequence.

After the experiment, the bimodal bilinguals had to translate into LSE all words presented during the experiment to ensure that they associated the target sign (and not some dialectal variant) with that word. As we had bimodal bilinguals from various locations, for each participant, items whose sign translation did not match the expected translation were eliminated (4.99% of responses were removed for this reason).

Inaccurate responses were also discarded for the reaction time analysis (2.93% of responses). Reaction times more than 2.5 standard deviations from the mean by subject and condition were considered outliers and discarded (1.73% of responses).

Participants also completed a questionnaire about their language profile (history and use) after finishing the experiment.

Results. Table 4 shows the mean RTs and probability of errors of both groups. The 2 (Group; CODAs vs. control) x 2 (list; A vs. B) x 2 (Semantic relation; yes vs. no) x 2 (Phonologic relation; yes vs. no) repeated measures across subjects (F1) and across items (F2) ANOVAs on accuracy did not show any interactions and only a main effect of group was revealed in the analysis by items. Bimodal bilinguals were more accurate than controls, $F1(1,38)=2.98$, $p=.09$, $F2(1,60)=5.48$, $p<.05$. In any case, due to the high rate of correct responses, the data are not normally distributed (confirmed by the Shapiro-Wilk test) and there is also a ceiling effect, as most of the results for accuracy are nearly 100%.

The ANOVA on reaction time showed a main effect of semantic relatedness. Participants were faster to answer to semantically related than unrelated pairs of words, $F1(1,36)=55.55$, $p<.001$, $F2(1,60)=38.37$, $p<.001$. The interaction of semantics and phonology was significant in the analysis by subjects, $F1(1,36)=32.03$, $p<.001$, $F2(1,60)=2.92$, $p=.093$. Importantly, the triple interaction of semantics and phonology and group was significant $F1(1,36)=21.65$, $p<.001$, $F2(1,60)=8.45$, $p<.01$.

Table 4
Experiment 1. Participants. Mean Reaction Times and Mean Probability Error (standard deviations in brackets)

		Semantically related		Semantically unrelated	
		Phonologically		Phonologically	
		related	unrelated	related	unrelated
Mean Reaction Times (ms)	Native bimodal bilinguals	886.67 (181.94)	938.45 (196.83)	1151.05 (213.12)	1041.43 (175.75)
	Hearing monolinguals	815.67 (188.51)	821.64 (204.88)	996.92 (214.26)	984.93 (217.01)
Mean Probability Error	Native bimodal bilinguals	.006 (.019)	.003 (.017)	.003 (.017)	.003 (.014)
	Hearing monolinguals	.012 (.032)	.006 (.027)	.012 (.025)	.012 (.025)

Native bimodal bilinguals. The 2 (Semantic relation) x 2 (Phonologic relation) ANOVA run for the native bimodal bilinguals revealed a significant main effect of semantics, $F1(1,19)=23.09$, $p<001$, $F2(1,60)=26.18$, $p<001$, and an interaction of semantics and phonology, $F1(1,19)=33.28$, $p<.001$, $F2(1,60)=5.63$, $p<.05$. Follow-up comparisons revealed that native bimodal bilinguals were quicker to respond to semantically related words with phonologically related than unrelated LSE translations $t(19)=-3.11$, $p<.01$. In addition, participants were slower to respond to semantically unrelated words with phonologically related signed translations than with phonologically unrelated translations, $t(19)=4.24$, $p<.001$ (see Figure 3).

Hearing L1 Spanish controls with no knowledge of LSE. The same 2x2 ANOVA run for the controls only showed a main effect of semantic relatedness, $F1(1,19)=35.42$, $p<001$, $F2(1,69)=44.81$, $p<.001$. No significant interaction of semantics and phonology was revealed, $F1(1,19)=1.83$, $p=.19$, $F2(1,60)=.19$, $p=.67$.

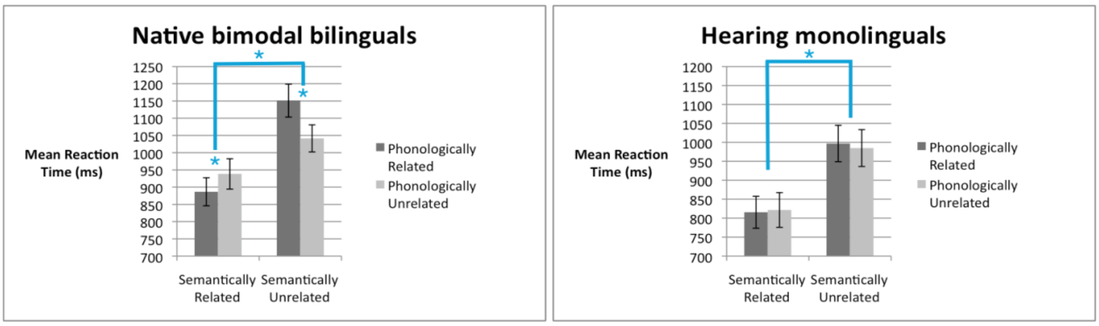

Figure 3. Mean reaction times (in ms) for native bimodal bilinguals (left) and hearing monolinguals with no knowledge of LSE (right). Error bars show the standard error of the mean (from the F1).

Experiment 1 widens the results of previous studies using the same semantic relatedness paradigm (Morford et al., 2011; Morford et al., 2014; Kubus et al., 2015) to hearing native signers whose dominant language is spoken Spanish. Crucially, in the current study, cross-language and cross-modal activation of the non-dominant code was primed by exclusive use of the dominant language in the natural spoken modality (dynamic signal). This parallel activation is highly robust, as shown by the appearance of both effects: facilitation and inhibition.

Experiment 2. Hearing late bimodal bilinguals and hearing monolinguals

The results of Experiment 1 provide clear evidence of cross-language and cross-modal activation in native hearing bimodal bilinguals. This effect could be linked to the native status of the language for the experimental group, who learned LSE from birth. Therefore, the next question was whether this parallel activation would also occur in late bimodal bilinguals, who learned LSE late in life. And if so, would this take place in the same terms as the native bimodal bilinguals (facilitation and inhibition) or would it be different. Thus, differences or similarities in the results of the two groups of bimodal bilinguals would supply valuable data for inferences concerning the AoA of the signed language.

Methods

Participants. Forty highly proficient bimodal bilinguals who were late learners of LSE and 40 hearing Spanish speakers monolinguals were recruited. As in experiment 1, in order to assure that the late learners were highly competent in both languages, we chose bimodal bilinguals who were sign language interpreters at the time of the study and who had been working as such for at least the previous two years. They started learning sign language after the age of 18. Participants’ characteristics are shown in Table 5.

Table 5
Experiment 2. Participants' Characteristics

Group	Number of participants	Mean Age	Gender	Years of experience as sign language interpreters	Self-rated LSE competence (from 1 to 7)
Late Bimodal Bilinguals	40	34.35	31 women 9 men	10.02 (mean)	6.01 (mean)
Hearing Monolinguals	40	38.15	24 women 16 men		

Materials and procedure. The materials and procedure were the same as those used in experiment 1.

As in the previous experiment, responses were removed due to discrepancy between the subject's translation and the expected target sign (5.96%). In addition, inaccurate responses were removed for the reaction time analysis (2.64% of responses). Reaction times that were not within 2.5 standard deviations of the average by subject and condition were also discarded (1.84% of responses).

Results. A 2 (Group; Late Learners vs. control) x 2 (list; A vs. B) x 2 (Semantic relation; yes vs. no) x 2 (Phonologic relation; yes vs. no) repeated measures F1 and F2 ANOVAs on accuracy did not show any significant different on interactions or main effects other than that late bimodal bilinguals committed less errors than controls, $F1(1,78)=4.87$, $p<.05$, $F2(1,60)=3.30$, $p=.074$. The data from accuracy were not normally distributed (verified by the Shapiro-Wilk test) and there is also a ceiling effect.

The ANOVA on reaction times revealed a main effect of semantic relatedness. Participants were faster responding to semantically related than unrelated pairs of words, $F1(1,76)=161.39$, $p<.001$, $F2(1,60)=53.51$, $p<.001$. The interaction of semantics and phonology was significant in the analysis by subjects, $F(1,76)=47.54$, $p<.001$, F2(1,60)=2.77, p=.10. Importantly, the triple interaction of semantics and phonology and group was significant, F1(1,76)=32.51, p<.001, F2(1,60)=18.21, p<.001. Table 6 shows the mean RTs and probability of errors of both groups.

Table 6

Experiment 2. Participants. Mean Reaction Times and Mean Probability Error (standard deviations in brackets)

		Semantically related		Semantically unrelated	
		Phonologically		Phonologically	
		related	unrelated	related	unrelated
Mean Reaction Times (ms)	Late bimodal bilinguals	829.50 (155.78)	890.81 (160.86)	1118.90 (239.59)	1020.45 (173.46)
	Hearing monolinguals	831.59 (179)	835.60 (175.55)	1000.49 (186.30)	988.31 (197.13)
Mean Probability Error	Late bimodal bilinguals	.006 (.021)	.005 (.019)	.006 (.02)	.006 (.03)
	Hearing monolinguals	.009 (.026)	.01 (.031)	.017 (.028)	.017 (.031)

Late bimodal bilinguals. The 2 (Semantic relation) x 2 (Phonologic relation) ANOVA showed a significant main effect of semantic relatedness. Late bimodal bilinguals were faster to respond to semantically related than unrelated pairs of words, F1(1,39)=80.66, p<.001, F2(1,60)=49.95, p<.001. The interaction of semantics and phonology was also significant, F1(1,39)=47.45, p<.001, F2(1,60)=7.51, p<.01. Follow-up comparisons revealed that late learners were faster to respond to semantically related words with phonologically related LSE translations than to those that had no underlying relation in LSE, t(39)=-4.5, p<.001. Late learners were also slower to respond to semantically unrelated words with phonologically related signed translations than to those with phonologically unrelated translations, t(39)=5.49, p<.001.

Hearing L1 Spanish controls with no knowledge of LSE. The 2x2 ANOVA revealed a main effect of semantic relatedness, F1(1,39)=85.42, p<.001, F2(1,69)=45.02, p<.001. However, the interaction of semantics and phonology was not significant F1(1,39)=2.29, p=.14, F2(1,60)=.10, p=.75 (see Figure 4).

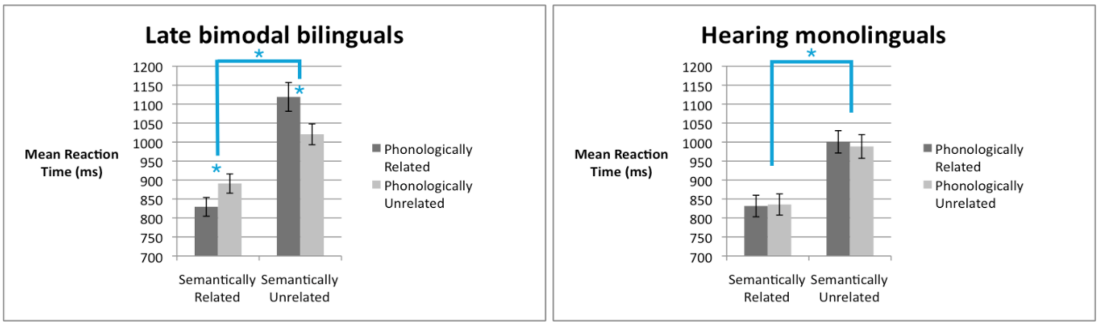

Figure 4. Mean reaction times (in ms) for late bimodal bilinguals (left) and for hearing participants with no knowledge of LSE (right). Error bars show the standard error of the mean (from the F1).

General discussion

This study investigated whether hearing bimodal bilinguals whose dominant language is spoken Spanish and who have acquired LSE at different ages activate signs when hearing words. The results were similar for both groups of bimodal bilinguals, native and late learners, whilst controls showed a different outcome.

All groups were significantly faster in answering the semantically related word pairs compared to the unrelated pairs, a well-established effect that provides support that participants were performing the basic experimental task adequately. More importantly, in native bimodal bilinguals and in late learners the (unseen) phonological relation in LSE had a different effect in each of the semantic conditions. On the one hand, in the presence of a semantic relation, native and late learners bimodal bilinguals showed a facilitatory effect when the implicit signs were phonologically related, since they were faster to respond compared to when the signs were phonologically unrelated. On the other hand, in the absence of a semantic relation, these two groups showed an inhibitory effect when the words were phonologically related in their LSE equivalent, since they were slower to respond than when the signs were phonologically unrelated. In contrast, the control group did not show either of these two effects, as their responses were very similar in each semantic condition regardless of the implicit phonological context. As predicted, this outcome in controls shows no effect from the implicit LSE, since they do not know the (hidden) language.

These results make clear that hearing bimodal bilinguals activate signs while processing spoken words. Moreover, there are no differences in this activation whether the bimodal bilinguals are natives or late learners. A possible outcome was that late learners would perform in the same fashion as the hearing late learners in the Morford et al. (2014) print-sign study, who only showed the inhibitory effect. However, both groups of bimodal bilinguals in our study exhibited the facilitatory effect in addition to the inhibitory effect.[3]

Previous research has repeatedly demonstrated non-selective access to the codes in a monolingual context, mainly illustrated by the interference of the implicit language when there is lack of semantic relation in bimodal bilinguals (Morford et al., 2011; Morford et al., 2014; Kubus et al., 2015). However, the facilitation effect had only been revealed in experiments run on deaf bimodal bilinguals native in ASL (Morford et al., 2011; Morford et al., 2014). Thus, this is the first study that reveals such strong activation in hearing bimodal bilinguals as well. Crucially, this parallel activation is shown when using the dominant language and it does not seem to depend on the AoA of the sign language.

Parallel activation effects (facilitation and inhibition) in hearing bimodal bilinguals may be enhanced by several differences with previous studies: Firstly, the phonological relationship of the implicit signs; Secondly, the primary code associated

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[3] To check this similar behavior in native and late signers, we performed a 2 (Group; CODAs vs. late learners) x 2 (Semantic relation; yes vs. no) x 2 (Phonologic relation; yes vs. no) repeated measures across subjects (F1) and across items (F2) ANOVA. The three-way interaction was not significant, all Fs $<.05$, all ps $>.9$

with the task; and Thirdly, code-blending experience in hearing bimodal bilinguals. Prior research conducted in deaf sign-print bilinguals showed the facilitatory and the inhibitory effect whether the deaf bilinguals were balanced in both languages (Morford et al., 2011) or ASL-dominant (Morford et al., 2014). However, in an experiment run with deaf balanced bilinguals of another language pair, DGS and written German (Kubus et al., 2015), only the inhibition effect was found. The authors related this dissimilar outcome with differences in the parameters that the signed translations shared. While in the ASL studies the common parameters were mainly movement and location, in the DGS study the overlapping parameters were handshape and location. Kubus et al. (2015) point out that signs that share movement are perceptually more similar than signs with a common location or handshape, and as such the phonological relation in the ASL studies was stronger. In the current LSE study, the three parameters mentioned frequently overlap in the signed translations in the [+phonology] conditions: location, handshape and movement (Appendix B).

In their print-sign study, Morford et al. (2014) argued that hearing English-dominant bimodal bilinguals did not show the facilitation effect because the written words in English are directly associated with their corresponding sounds and not with their equivalent signs. Deaf bimodal bilinguals, on the contrary, link the printed words to signs when they learn to read, so the connection between the written forms and the signs is more direct than in the hearing bimodal bilinguals' case. Consequently, the effect was more salient (facilitation and inhibition) in the deaf bimodal bilinguals compared to the hearing bimodal bilinguals (only inhibition). Our experiment addresses this matter, since we have used the spoken form of the language as the explicit language. The presence of both effects (inhibitory and facilitatory) for hearing bimodal bilinguals when listening to *spoken* words suggests that cross-modal activation is more salient from the primary language modality (i.e. auditory). Prior research using the semantic relatedness paradigm in hearing unimodal bilinguals supports this strong connection for the primary language modality, as the parallel activation is of the sounds of the equivalent language translations, rather than the written form (Wu & Thierry, 2010). Additionally, in contrast to previous studies (Giezen et al., 2015; Shook & Marian, 2012), the current experiment did not include visual cues to prompt the activation of signs, so the robustness of the parallel activation can be linked exclusively to the primary dynamic code of the spoken language. Further support for this comes from the third consideration: the connections established through the simultaneous use of both languages.

Preceding research implies that hearing bimodal bilinguals might connect the phonological forms of words with the phonological forms of signs as they can be articulated at the same time, a phenomenon known as code-blending. Bimodal bilinguals mostly produce (simultaneous) code-blends instead of the typical (sequential) code-switches that unimodal bilinguals perform. In a study with ASL-English bimodal bilinguals, these code-blends tended to contain semantically equivalent information in the spoken and in the signed language (Emmorey, Borinstein, Thompson, & Gollan, 2008). Most of the code-blends occurred with English as the matrix language (i.e. the language that provided the syntactic structure of the utterance) and ASL the accompanying language. In fact, signs are produced with speech even when bimodal bilinguals know that their interlocutors do not know any sign language (Casey & Emmorey, 2009). This code-mixing situation changes when signing, as the spoken language (being the dominant language) is suppressed and appears less frequently in signed utterances. This suggests that signs are readily available when using the spoken language but not the other way around, as the dominant spoken language is more inhibited. Future work looking at cross-modal activation of the dominant (spoken) language in hearing bimodal bilinguals could confirm or refute this idea.

The association between spoken and sign phonological forms is strongly established in hearing bimodal bilinguals (Emmorey, Petrich, & Gollan, 2012). This solid connection could have given rise to a stronger parallel activation in the current experiment, compared with the weaker activation primed by printed words (Morford et al., 2014). More evidence for this robust bond between the spoken words and the visual signs in hearing bimodal bilinguals comes from the fact that parallel activation has occurred in the non-dominant language. This contrasts with most of the previous work, where the task was carried out in the L2 and the implicit language was the dominant L1. Our participants were not only highly proficient hearing bimodal bilinguals, whether native or late learners, but also had a uniformly high level of competence, as they all work as sign language interpreters. Therefore, although our experiment cannot provide evidence concerning proficiency, as there is currently no standard way to assess proficiency in LSE, the results seem to suggest that activation is driven by proficiency in this case rather than by AoA. In their print-sign experiment, Morford et al (2014) were able to split the hearing bimodal bilinguals in two groups by proficiency, since the sign language experience of their participants was more heterogeneous. The more proficient ASL users showed a larger degree of inhibition compared to the less proficient, although, in contrast to the findings of the current study, this inhibitory effect did not reach significance. In spite of this, there is a factor that might have had some influence in the results: linguistic awareness. When bimodal bilinguals were recruited, although it was done through direct contact, that is, there was no experiment announcement asking explicitly for a specific profile, some of them might have been conscious of their linguistic background as they could relate their recruitment with the fact that they are sign language users. This awareness could have led to greater activation of LSE while carrying out the experimental task. However, the information they had about the study and the task was quite restricted, as they only knew that they had to perform a task concerning semantic relation in Spanish words. Spanish sign language was never mentioned, so the potential impact of the linguistic awareness might be very limited. Additionally, the task formed part of a larger battery of experiments, so it is quite unlikely that participants were aware that LSE was relevant to the task in hand.

A related issue is the fact that all the bimodal bilinguals were sign language interpreters, and the effect that this could have on the results. It is an open question whether our results will also hold true for other populations. Unfortunately, this is a naturally occurring confound in the population of hearing signer language users: highly-proficient signers tend to be interpreters and it is difficult to find signers matched in proficiency who are not interpreters. Nevertheless, future research ought to examine the relative roles of proficiency and interpreting experience by looking at whether native or late bimodal bilinguals who are not working as sign language interpreters or who are not using the sign language on an everyday basis would perform similarly to our participants.

Finally, our results sit well with a recent study that provides evidence of cross-language activation also in production (Giezen & Emmorey, 2015). This study demonstrated that sign production was influenced by the parallel activation of the equivalent sign of spoken distractor words. The cross-language and cross-modal activation occurred at the lexical level, and could not occur at the sub-lexical level since there is no formal overlap between the two languages.

Thus, our findings in hearing bimodal bilinguals support that there is cross-language activation at the lexical and/or semantic level, given that both languages do not share phonological features. This adds new evidence to revise some models concerning bilingual word recognition, such as the Bilingual Interaction Activation (BIA+) model (Dijkstra & Van Heuven, 2002) or the Bilingual Language Interaction Network for Comprehension of Speech (BLINCS) (Shook & Marian, 2013), as they have emphasized the contribution of cross-linguistic phonological overlap, among other factors. These models focus on unimodal bilingualism but they can benefit from the contributions provided by research in cross-modal bilingualism.

In conclusion, our results confirm that non-selective activation traverses modality, even for hearing bimodal bilinguals who have acquired the sign language at different ages. Spanish and LSE do not share any phonological forms, and yet we provide evidence here that signs are activated when hearing bimodal bilinguals just listen to words, in the absence of visual stimuli. Furthermore, this study confirms that (cross-modal) parallel activation may occur in L2 when L1 is being used, and not only in L1 when L2 is used. For proficient bilinguals who use their languages on an everyday basis, both codes are cognitively active even when they are dealing explicitly with only one of them, and even when those languages operate in distinct modalities.

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Appendix A

Spanish words

Semantically related			Semantically unrelated		
Phonologically			Phonologically		
related	unrelated		related	unrelated	
primes	primes	targets	primes	primes	targets
venta	carrito	compra	edad	carne	signo
bebida	ducha	agua	boli	diente	champán
damas	juego	ajedrez	criada	suerte	golfo
abuelo	sobrino	nieto	cosa	banco	sexo
pasado	presente	futuro	chocolate	plaza	miedo
primo	padre	tío	bici	papel	cojo
flojo	fuerte	débil	ciclo	mueble	uvas
suegra	hija	madre	lupa	mito	porro
bajar	escalar	subir	ganas	lápiz	nube
lunes	jueves	martes	teoría	factura	domingo
juntar	separar	unir	campana	bingo	pera
corto	ancho	largo	préstamo	susto	queso
profesor	escuela	alumno	pueblo	tacón	palabra
médico	hospital	enfermo	normal	sucio	soltero
claro	negro	oscuro	hucha	cuadro	gota
pistola	batalla	guerra	noviembre	seta	militar

Appendix B

LSE translations of the Spanish words

Semantically related			Semantically unrelated		
Phonologically related			Phonologically related		
primes	targets	Shared parameters	primes	targets	Shared parameters
VENTA	COMPRA	hs, loc	EDAD	SIGNO	mov, loc
BEBIDA	AGUA	mov, ori, loc	BOLI	CHAMPÁN	ori, loc
DAMAS	AJEDREZ	mov, loc	CRIADA	GOLFO	mov, loc
ABUELO	NIETO	mov, loc	COSA	SEXO	hs, loc
PASADO	FUTURO	hs, ori	CHOCOLATE	MIEDO	hs, loc
PRIMO	TÍO	hs, loc	BICI	COJO	hs, ori, loc
FLOJO	DÉBIL	hs, ori	CICLO	UVAS	hs, ori, loc
SUEGRA	MADRE	hs, ori, loc	LUPA	PORRO	mov, hs, ori
BAJAR	SUBIR	hs, loc	GANAS	NUBE	mov, hs, ori
LUNES	MARTES	mov, loc	TEORÍA	DOMINGO	hs, ori, loc
JUNTAR	UNIR	mov, loc	CAMPANA	PERA	mov, ori, loc
CORTO	LARGO	hs, ori, loc	PRÉSTAMO	QUESO	hs, ori, loc
PROFESOR	ALUMNO	mov, hs, loc	PUEBLO	PALABRA	mov, hs, ori
MÉDICO	ENFERMO	hs, ori, loc	NORMAL	SOLTERO	hs, ori
CLARO	OSCURO	ori, loc	HUCHA	GOTA	mov, ori
PISTOLA	GUERRA	mov, ori, loc	NOVIEMBRE	MILITAR	mov, ori, loc