Language-switching across modalities: evidence from bimodal bilinguals

Patricia A. Dias[1], Saúl Villameriel[1], Marcel R. Giezen[1], Brendan Costello[1], and Manuel Carreiras[1,2]

[1]BCBL, Basque Center on Cognition, Brain and Language, Donostia, Spain

[2]Ikerbasque, Basque foundation for Science, Bilbao, Spain

Address correspondence to:

Patricia Dias

Basque Center on Cognition, Brain and Language (BCBL)

Paseo Mikeletegi 69-2

20009, Donostia-San Sebastian, Spain

p.dias@bcbl.eu

Abstract

This study investigated whether language control during language production in bilinguals generalizes across modalities, and to what extent the language control system is shaped by competition for the same articulators. Using a cued language-switching paradigm, we investigated whether switch costs are observed when hearing signers switch between a spoken and a signed language. The results showed an asymmetrical switch cost for bimodal bilinguals on reaction time and accuracy, with larger costs for the (dominant) spoken language. Our findings suggest important similarities in the mechanisms underlying language selection in bimodal bilinguals and unimodal bilinguals, with competition occurring at multiple levels other than phonology.

Keywords: bimodal bilingualism; language switching; language interference; lexical access.

Introduction

How bilinguals manage two or more languages has been investigated mostly in spoken languages, raising the question how bilinguals of languages in two modalities (spoken and visuo-gestural) manage the selection and production of their languages. Hearing signers are a unique bilingual population that offer the opportunity of understanding which mechanisms are language-general and which are modality-specific. Here we aim to exploit bimodal bilingualism to investigate language control mechanisms when bimodal bilinguals switch between a spoken and a signed language.

The ability of bilinguals of two spoken languages to control the selection and production of both languages has been extensively studied (for a recent review, see Kroll & Gollan, 2014). Many studies have shown that unimodal bilinguals activate both languages during the early stages of speech production (Kroll, Bobb, & Wodniecka, 2006). For such bilinguals, selection of the lexical item in the target language logically must occur prior to the articulation of the target lexical item since they cannot produce two words at the same time.

According to one influential theory of language control, the Inhibitory Control Model (Green, 1998; Green & Abutalebi, 2013), depending on the bilingual context and related task goals, the selection of the intended language in unimodal bilinguals may require inhibition of nontarget language representations to control interference and ensure the correct selection of the target language representations. An alternative view states that both languages may be active during speech production, but highly proficient bilinguals develop the ability to selectively attend to candidates in the intended language (language-specific selection, e.g., Costa & Santesteban, 2004).

In contrast to unimodal bilinguals, for bimodal bilinguals there is no conflict in the articulatory channels and dual lexical selection is possible, such as when hearing signers produce signs and spoken words in parallel as 'code-blends' in conversations with other bimodal bilinguals (Emmorey, Borinstein, Thompson, & Gollan, 2008). In this interactional context, neither of the two languages has to be suppressed and language control demands might therefore be low (Green, 2016). However, bimodal bilinguals also interact with monolinguals, and switch from speaking to signing (for example, in conversations with nonsigners and deaf signers). In such settings a single language has to be selected for production, and the Inhibitory Control Model would predict language inhibition to occur (Green & Abutalebi, 2013). However, in addition to this competition between sign and speech, sign may also compete with gestures and other non-verbal cues (Green, 2016). If that is the case, inhibitory control in bimodal bilinguals may be markedly different to that found in unimodal bilinguals.

For unimodal bilinguals it has been suggested that there is no fixed locus of competition between lexical items from the two languages, and that nontarget language interference may occur at the conceptual, lexical or phonological level (Kroll et al., 2006; but see also Finkbeiner, Gollan, & Caramazza, 2006, for an alternative view that does not entail competition). While words and signs share features at the first two of these levels, they do not share any phonological features, so language competition at this level is not possible. Investigating language control in bimodal bilinguals can therefore provide unique insight into the role of phonological competition and shared articulators between two languages during bilingual production.

Many studies with bilinguals of spoken languages have used language switching tasks to investigate language control mechanisms in bilingual language production (for a recent review see Declerck & Philipp, 2015a). Language switch costs, that is, larger reaction times and/or higher error rates on trials where a language switch is required compared to trials where a switch is not required, are often interpreted as an index of nontarget language interference and resulting language suppression. Furthermore, language switch costs can be asymmetrical, with a larger cost in one language direction than the other. For example, Meuter and Allport (1999) observed that it takes unimodal bilinguals more time to switch from their weaker language (L2) to their stronger language (L1) than vice versa. They suggested that suppression of the dominant L1 requires more inhibition and that the greater L1 switching cost is associated with removing this stronger inhibition. Although many studies have explained asymmetrical switch costs as the result of inhibition processes, there are alternative explanations (for a review see Koch, Gade, Schuch, & Philipp, 2010). For example, switching from L2 to L1 may involve proactive interference due to persistent activation of the weaker language (e.g., Philipp, Gade, & Koch, 2007), or reduced interference of the weaker language on L1 repeat trials (Verhoef, Roelofs, & Chwilla, 2009). In addition, stimulus type, response preparation and relative task difficulty may contribute to different switch cost patterns (Bobb & Wodniecka, 2013). Finally, asymmetrical switch costs are not the only possible index of inhibitory control processes in language switching (e.g., Christoffels, Firk, & Schiller, 2007; Declerck, Thoma, Koch, & Philipp, 2015), and the presence of symmetrical switch costs does not automatically imply a lack of language inhibition (Gollan & Ferreira, 2009).

Only very few studies have investigated language switching in bimodal bilinguals. Kaufmann and Philipp (2015) compared switching between single responses (speaking or signing) and code-blends in hearing L2 learners of German Sign Language with intermediate signing proficiency. They found smaller switch costs for switching from a single response into a code-blend than for switching from a code-blend to a single response, suggesting that dual lexical selection might be less costly than lexical suppression (cf. Emmorey, Petrich, & Gollan, 2012). However, switching between spoken German and German Sign Language in both directions was not directly contrasted in the analysis.

The current study

In the current study, we aim to explore to what extent language control in language switching is shaped by competition for the same articulators. Using an experimental design modelled after previous language switching studies with unimodal bilinguals (Meuter & Allport, 1999; Costa & Santesteban, 2004), we investigated whether proficient hearing bilinguals of Spanish and LSE (*lengua de signos española*) exhibit switch costs when switching between their two languages, and whether such costs are modulated by the direction of language switching.

If Spanish-LSE bilinguals pattern like unimodal bilinguals and show switch costs when switching between Spanish and LSE, then this would indicate that languages compete for production in bilinguals regardless of whether they use the same or different articulators. Alternatively, if they do not show switch costs, then this would indicate an important role for phonological competition between languages in explaining language switch costs in studies with unimodal bilinguals. Furthermore, if the two languages of bimodal bilinguals compete for production in similar ways as for unimodal bilinguals, then we might expect switch costs to be asymmetrical, in the direction of larger switch costs when participants switch from LSE into Spanish, their more dominant language, (i.e. from L2 into L1) than when they switch from Spanish into LSE (from L1 into L2).

Methods and Materials

Participants

Forty-four right-handed bimodal bilinguals volunteered to take part in the experiment (36 females, 11 native signers and 33 late learners; mean age = 34.55, *SD* =7.47*;* see Table 1). Participants were recruited through interpreter associations around Spain and received 10€ for their participation. A power analysis with G*Power 3.1 software (Faul, Erdfelder, Buchner, & Lang, 2009) indicated that a sample of at least 30 people would be needed to detect medium-sized effects (f = .25) with 90% power using an ANOVA within factors with alpha at .05. Due to the difficulty of finding participants with the target profile, we decided to increase the sample size to ensure sufficient statistical power in case any participants had to be excluded at a later stage. A final sample of 38 bilinguals (N = 38) for statistical analyses after excluding six participants because of technical issues *(n* = 1) and error rates higher than 10% (n = 5). All participants completed a language profile questionnaire, which included questions about their language use, self-rated proficiency in Spanish and LSE (scale 1 to 7), years of experience in LSE and proficiency in other languages. All participants were LSE interpreters for at least two years. Although they used both languages on a daily basis, they considered Spanish as their dominant language. All participants reported regular use of language mixing (code-blending and switching) in their work environment.

Table 1.

Means for participants' characteristics.

	Age (years)	Experience in LSE (years)	LSE self-rating	Spanish self-rating
Spanish-LSE bilinguals (*N*=38)	34.55 (7.47)	10.05 (6.40)	5.85 (0.77)	7 (0)

Note. Standard deviations (SD) are given in parentheses.

Materials

Eight colors were used as stimuli in the experiment: yellow, red, blue, green, purple, white, pink and brown. These were presented as a triangle or a circle on a screen with a black background (see Figure 1). The shape served as the language cue (Spanish or LSE) and was counterbalanced across participants. Since the cue was a feature of the stimulus, there was no opportunity for cue-based preparation. A total of 1056 trials were presented. Following previous studies, the proportion of switch trials was 30% of all trials (e.g. Costa & Santesteban, 2004, Meuter & Allport, 1999). The remaining 70% trials were nonswitch trials. Only a subset of the nonswitch trials were analyzed (30% of all trials) to ensure that performance was compared across the same number of switch and nonswitch trials. Trials immediately following a switch trial (these were always nonswitch trials) were not analyzed. All stimuli appeared the same number of times. Two lists with different trial orders were created and counterbalanced among participants. The experiment was divided into four blocks with a total of 264 stimuli per block and three minute breaks between blocks, and lasted about 45 minutes in total. Each stimulus was presented for up to 1500ms or until the participant responded and was followed by a 1000ms black screen. Two practice blocks, with 32 trials in total, preceded the experiment to familiarize the participants with the task and the cue-language association. The first block presented all color stimuli for one language cue and then the other. The second block presented both language cues in a mixed order, as in the real experiment. The order of items within each practice block was randomized.

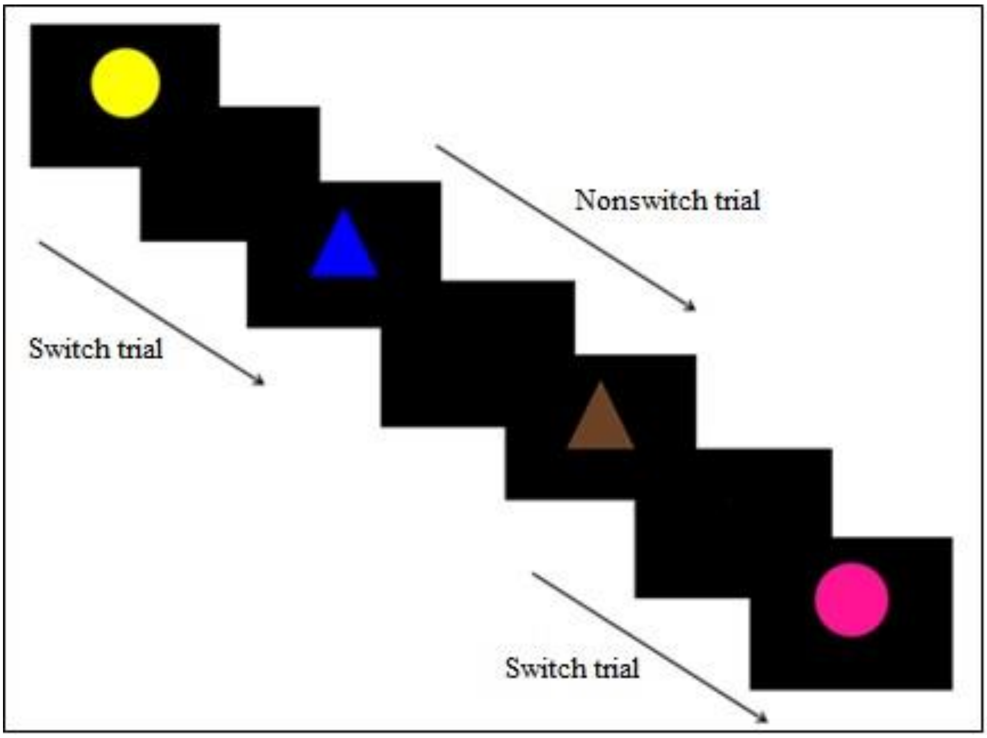

Figure 1. Example of switch and nonswitch trials.

Procedure and design

Instructions were given in Spanish at the beginning of the experiment. Stimuli were presented with Experiment Builder (SR Research) on a 14” Lenovo laptop (1600 x 900 pixels). Participants sat approximately 40 cm from the computer monitor. Participants wore headphones with an incorporated microphone to record vocal responses, which were stored in separate audio file for each trial. To make sure that the voice key values were accurate, online values from Experiment Builder were compared with offline values obtained with Voicekey software[1]. If the difference between the two values was more than 100 ms, the trial was checked manually by listening to the audio recording and visually inspecting the waveform in Audacity[2]. An external video camera was used to record manual responses. At the beginning of each trial participants held

[1] http://www.mrc-cbu.cam.ac.uk/people/maarten-van-casteren/the-voicekey-program/

[2] http://audacity.sourceforge.net/

down the spacebar of the keyboard with their dominant hand. Reaction times for signed responses were collected by using a key lift trigger programmed in Experiment Builder. All reaction times were measured from stimulus onset.

The accuracy of responses was coded for each modality and by reviewing the video and audio recordings. The following responses were treated as errors: (1) response in the incorrect language, (2) response in the correct language but with the incorrect color, (3) code-blend, (4) hesitation or self-correction, and (5) no response.

Results

The experimental design included two main factors: language (Spanish and LSE) and trial type (switch and nonswitch). For clarity, *Spanish switch trials* refer to those trials that required a switch (from sign language) into spoken language (i.e. $trial_n$ = Spanish and $trial_{n-1}$ = LSE). *LSE switch trials* required a switch (from spoken language) into sign language. *Nonswitch trials* (for both Spanish and LSE) are trials with no change in the language. It is important to note that manual reaction times and vocal reaction times were based on different measures, namely voice onset for Spanish and the onset of transitional articulatory movements that precede production of a lexical sign for LSE. Although many studies have used the hand lift technique as a measure of sign production latencies, it is unclear whether the obtained reaction times are functionally equivalent to reaction times based on voice onset (for discussion, see Myers, Lee, & Tsay, 2005). To facilitate comparison with previous language switching studies, in particular, the presence of a language by switch condition interaction that would indicate asymmetrical switch costs, we analyze the reaction times in a two-level ANOVA with language (spoken vs. signed responses) and trial type (nonswitch vs. switch trials). However, we urge caution in interpreting any overall difference between spoken and signed reaction times (i.e., a main effect of language) because this could very well reflect the different measurement techniques, instead of, for example, general L1 slowing (e.g. Christoffels et al., 2007). Importantly, error rates are arguably less affected by these measurement issues and therefore can be directly compared between language modalities (cf. Emmorey et al., 2012; Kaufmann & Philipp, 2015).

Mean RTs were calculated and subjected to analysis for each language after removing errors (2.5%) and outliers by subject and by condition to 2.5 standard deviations from the mean (2.6%). We also conducted an analysis of error types and error rates. The overall results are presented in Table 2.

Table 2.

Mean Reaction Time (RT) in milliseconds and Error rate in percentages for the participants in the four language-switching conditions.

	Condition			
	Switch Spanish	Nonswitch Spanish	Switch LSE	Nonswitch LSE
RT	720.31 (81.41)	638.37 (72.42)	674.08 (91.79)	615.33 (72.54)
Error %	5.56 (4.44)	1.25 (1.05)	2.46 (2.24)	1.09 (1.28)

Note. Standard deviations (SD) are given in parentheses.

Reaction times (RT)

Mean reaction times by language and trial type are shown in Figure 2. A two-level ANOVA with Language and Trial type as factors yielded a main effect of Language [$F_1(1, 37) = 13.19$; $p < .001$, $\eta^2 = .04$; $F_2(1, 7) = 14.43$; $p < .01$, $\eta^2 = .29$] and Trial type [$F_1(1, 37) = 158.58$; $p < .001$, $\eta^2 = .16$; $F_2(1, 7) = 1276.05$; $p < .001$, $\eta^2 = .61$]. Importantly, the interaction between language and trial type was also significant [$F_1(1, 37) = 4.80$; $p = .03$, $\eta^2 = .01$; $F_2(1, 7) = 30.33$; $p < .001$, $\eta^2 = .03$].[3] Post-hoc comparisons

[3] An analysis using linear mixed effects modeling confirmed the ANOVA results reported here.

revealed switch costs for both Spanish [$t_1(37) = -9.90$; $p < .001$, $\eta^2 = .72$; $t_2(7) = -33.36$; $p < .001$, $\eta^2 = .99$] and LSE [$t_1(37) = -8.31$; $p < .001$, $\eta^2 = .65$; $t_2(7) = -20.17$; $p < .001$, $\eta^2 = .98$]. As can be seen in Figure 2, the interaction reflected greater switch costs for Spanish (82 ms) than LSE (59 ms).

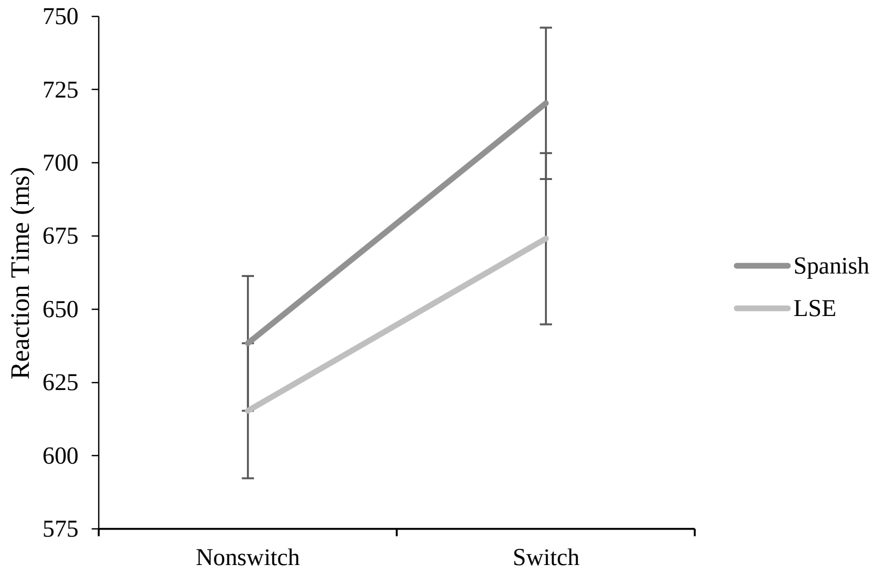

Figure 2. The overall mean RT (in ms) of switch and nonswitch trials for spoken (Spanish) and sign language (LSE). The error bars show the 95% confidence interval.

Error types

Overall, the percentage of errors was only 2.5%. Five types of responses were considered as errors and coded offline using the video recording: Table 3 shows the distribution of different error types across languages and conditions.

Table 3.

Mean error rates by error type and condition. (Percentage of errors across the four conditions is given in parentheses).

Type of Error	Conditions			
	Switch Spanish	Nonswitch Spanish	Switch LSE	Nonswitch LSE
Incorrect language	1.93 (61.07)	0.22 (6.86)	0.81 (25.73)	0.20 (6.34)
Incorrect color	0.25 (34.45)	0.10 (13.47)	0.27 (35.87)	0.12 (16.21)
Code-blend	0.02 (13.24)	0.03 (24.81)	0.03 (24.73)	0.05 (37.22)
Hesitation	2.69 (61.97)	0.40 (9.20)	0.88 (20.24)	0.37 (8.59)
No response	0.66 (33.63)	0.50 (25.26)	0.47 (23.64)	0.34 (17.47)
Total	5.56	1.25	2.46	1.09

The distribution of error types offers further support for the existence of an additional cost when switching into Spanish compared to LSE. Specifically, the greater proportion of hesitation and incorrect language selection errors for Spanish switch trials compared to LSE switch trials suggests greater interference in the language selection process during Spanish production. In contrast, an error type that is unrelated to language selection, namely, producing the incorrect color (in the correct language), shows similar rates for both languages.

Error rates

Mean error rates by language and trial type are shown in Figure 3. A two-level ANOVA on overall error rates with Language and Trial type as factors yielded a main effect of language [$F_1(1, 37) = 24.01$; $p < .001$, $\eta^2 = .09$; $F_2(1, 7) = 11.02$; $p = .01$, $\eta^2 = .09$] and trial type [$F_1(1, 37) = 41.80$; $p < .001$, $\eta^2 = .23$; $F_2(1, 7) = 133.85$; $p < .001$, $\eta^2 =$

.61]. The interaction between language and trial type was also significant [$F_1(1, 37) = 20.44$; $p < .001$, $\eta^2 = .07$; $F_2(1, 7) = 14.64$; $p < .01$, $\eta^2 = .28$]. Post-hoc comparisons showed higher error rates on switch trials than nonswitch trials for both Spanish [$t_1(37) = 6.00$; $p < .001$, $\eta^2 = .49$; $t_2(7) = 7.52$, $p < .001$, $\eta^2 = 0.89$] and LSE [$t_1(37) = 4.79$; $p < .001$, $\eta^2 = .38$; $t_2(7) = 4.72$; $p < .01$, $\eta^2 = .76$]. However, while participants made more errors when switching into Spanish than LSE [$t_1(37) = 4.91$, $p < .001$, $\eta^2 = .40$; $t_2(7) = 3.82$, $p < .01$, $\eta^2 = .67$], error rates for Spanish and LSE nonswitch trials did not differ significantly [$t_1(37) = 0.86$, $p = .40$, $\eta^2 = .02$; $t_2(7) = 0.47$, $p = .64$, $\eta^2 = .03$].

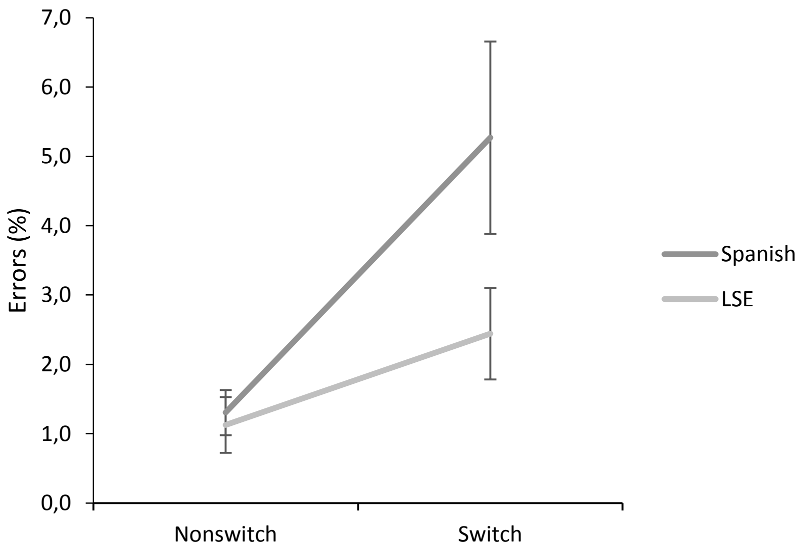

Figure 3. Error rate (%) of switch and nonswitch trials for spoken (Spanish) and sign language (LSE). The error bars show the 95% confidence interval.

Discussion

In the current study we investigated whether hearing signers exhibit switch costs when switching between a spoken language and a signed language. Our results showed significant switch costs for both languages: longer RTs and higher error rates for

Spanish and LSE switch trials than corresponding nonswitch trials (see Table 2). Interestingly, an asymmetrical switch cost pattern was observed: larger switch costs in terms of both RTs and error rates when switching from LSE into Spanish than when switching from Spanish into LSE.

Language competition in bimodal bilinguals

Our results demonstrate that for bimodal bilinguals, like unimodal bilinguals, both languages are activated in the brain and compete for production. Despite the absence of phonological competition between their two languages, Spanish-LSE bilinguals exhibited switch costs when switching between speaking and signing in a cued language-switching task. These findings strongly suggest that, although bimodal bilinguals might not always have to control the activation of the unintended language to the same extent as unimodal bilinguals (for example, when they are code-blending), language-switching contexts require both unimodal bilinguals and bimodal bilinguals to resolve language interference in order to produce the intended language properly.

Furthermore, the asymmetrical switch cost pattern we observed in the current study (larger switch costs when switching into Spanish than LSE) is consistent with studies that showed larger switch costs for unimodal bilinguals when they switch into their stronger language (L1) than into their weaker language (L2). Regardless of whether asymmetrical switch costs are better explained in terms of language suppression or sustained activation (for discussion, see Gade, Schuch, Druey, & Koch, 2014), this additional parallel between unimodal and bimodal language switching invites further speculation on the functional similarities underlying language control mechanisms in bimodal bilinguals and unimodal bilinguals. Importantly, our findings are in line with those of a recent study with hearing German learners of German Sign

Language and English (Kaufmann, Mittelberg, Koch, & Philipp, 2017).[4] They compared language switching performance when participants switched from English into German (unimodal switching) and when they switched from German Sign Language into German (bimodal switching). Switch costs were observed for both types of switching, although the costs for bimodal switching were smaller than those for unimodal switching (see Schaeffner, Fibla, & Philipp, 2017, for a possible explanation of this difference). The two studies therefore converge in showing reliable bimodal language switching costs across different samples of participants and languages.

The locus of competition in bilingual production

Previous studies have suggested that the locus of competition between two lexical items in unimodal bilinguals may be located at different levels during speech production, including the phonological level (Declerck & Philipp, 2015b; Goldrick, Runnqvist, & Costa, 2014; Olson, 2013). In contrast, signed and spoken languages have distinct phonological systems and competition cannot occur at this level for bimodal bilinguals. The similarities between switch cost patterns in bimodal bilinguals and unimodal bilinguals shown by the current study therefore point towards an important role of language competition at an earlier level, for example at the lexical level, before phonological encoding takes place.

At the same time, we might expect bimodal language control not to be limited to the lexical level. Given that bimodal language production involves different sets of articulators, it is possible that switch costs reflect some degree of articulatory competition. Philipp and Koch (2011) examined the role of response modality in cognitive task representations. In this study three groups of participants performed a

[4] We thank Irving Koch for bringing this study to our attention.

numerical judgment task: One group switched between vocal and manual responses (vocal/manual group), a second group changed between vocal and foot response (vocal/foot group), and a third group shifted between manual and foot responses (manual/foot group). All three groups exhibited modality switch costs, reflecting better performance on nonswitch trials (same response modality) than switch trials (different response modality). Importantly, for the vocal/manual group, switch costs were asymmetrical and yielded larger costs when switching to vocal responses than switching to manual responses, which is in line with the current findings. Indeed, the authors raise the possibility that switching between two response modalities might be governed by the same mechanisms as switching between two judgments. However, it is important to note that this study did not completely isolate the impact of a change of articulators: Participants switched between *verbal* vocal responses (saying “left” or “right”) and *nonverbal* manual responses (pressing a left or right response key), and this mixing of a linguistic and a nonlinguistic task may also have contributed to the observed asymmetry in the switch costs. The extent to which inherent asymmetries between the vocal and the manual response modality might have contributed to the observed switch cost pattern for bimodal bilinguals in the current study remains an open question for future studies and would require a direct comparison of switching between vocal and manual responses in verbal and nonverbal domains (within the same subjects).

The possible contribution of articulatory effects notwithstanding, the similarities between these results for bimodal bilinguals and those reported for unimodal bilinguals, point towards switch effects driven by language competition. The presence of language-related switch effects is supported by recent neuroimaging work comparing language and domain-general task switching: both types of task switching shared many common areas, but importantly there were also areas that were unique to each type of switching

(De Baene et al. 2015). Given that in unimodal bilinguals there is no question of articulatory effects (since both languages use the same articulators), and that in bimodal bilinguals there is no question of phonological effects (since the languages have no shared phonology), the convergence in the findings of asymmetrical switch costs for both groups suggest that within the language-driven effects competition occurs at the lexical level, which is common to both uni- and bimodal bilinguals.

Methodological limitations of the current study

An important limitation of the current study is that the reaction time measurements for spoken and signed responses were not obtained in the same way (voice onset for spoken responses and key lift for signed responses). As a result, the functional equivalence of measurements in the two language modalities could be questioned (cf. Myers et al., 2005). In particular, the key lift for signed responses is followed by a transitional articulatory movement that necessarily precedes (and follows) every sign. If this transitional movement differs from sign to sign, then this could introduce biased noise into the measurements. This potential problem was minimized in this study by ensuring that all items appeared the same number of times in each condition and by selecting items that all had a similar place of articulation (on or near the lower face or in neutral signing space) to ensure similar transitional movements across items and conditions. However, the transitional movement might also provide time for participants to monitor and possibly correct their responses. Despite this longer time window, hesitations were much more frequent in the Spanish switch trials than in the LSE switch trials (see Table 3), suggesting that the key lift measurement was not particularly susceptible to this kind of error. Moreover, similar error rates for vocal and manual responses on nonswitch trials (see Figure 2) suggest that the relative task difficulty of manual and vocal production was similar and cannot explain the observed asymmetrical switch cost.

Another limitation of the current study is that all participants were interpreters, who might be considered language switching “experts”. We chose this population to ensure that they used LSE on a daily basis and to guarantee that all participants were highly proficient in both languages. Age of acquisition and proficiency are important factors in language switching studies, as some studies have found symmetrical switch costs for balanced bilinguals with high proficiency in both languages (e.g., Costa & Santesteban, 2004). Although the participants in the current study were also highly proficient in both languages, they considered themselves to be more proficient in Spanish than in LSE, and the results confirmed our predictions that they would show asymmetrical switch costs rather than symmetrical switch costs.

Conclusions

The study of language control in bimodal bilinguals can provide unique insight into the role of phonological competition between two languages during bilingual production. The current study shows that switching between two languages is costly even when one of those languages is a signed language and uses a different set of articulators. Moreover, in line with many previous studies of language switching in unimodal bilinguals we show that this cost is asymmetrical: it is more difficult to switch from the weaker language (LSE) into the stronger language (Spanish), than in the opposite direction. Together, these findings suggest that unimodal and bimodal bilinguals engage similar language control mechanisms during bilingual language selection, and point towards an important role for lexical competition in bilingual language production.

Acknowledgments

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