On the temporal dynamics of sign production: an ERP study in Catalan Sign language (LSC)

Cristina Baus[1,2] & Albert Costa[1,3]

1. *Center of Brain and Cognition, CBC, Universitat Pompeu Fabra, Barcelona, Spain (costalbert@gmail.com)*
2. *Laboratoire de Psychologie Cognitive, CNRS and Université d'Aix-Marseille, Marseille, France*
3. *Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain*

Word count: 7685 (including the abstract and the manuscript)

*Address for Correspondence:
Dr. Cristina Baus
baus.cristina@gmail.com
Centre National de la Recherche Scientifique (CNRS)
Laboratoire de Psychologie Cognitive – Université d'Aix-Marseille
3, place Victor Hugo
13331 Marseille, France

1. ABSTRACT

This study investigates the temporal dynamics of sign production and how particular aspects of the signed modality influence the early stages of lexical access. To that end, we explored the electrophysiological correlates associated to sign frequency and iconicity in a picture signing task in a group of bimodal bilinguals. Moreover, a subset of the same participants was tested in the same task but naming the pictures instead. Our results revealed that both frequency and iconicity influenced lexical access in sign production. At the ERP level, iconicity effects originated very early in the course of signing (while absent in the spoken modality), suggesting a stronger activation of the semantic properties for iconic signs. Moreover, frequency effects were modulated by iconicity, suggesting that lexical access in signed language is determined by the iconic properties of the signs. These results support the idea that lexical access is sensitive to the same phenomena in word and sign production, but its time-course is modulated by particular aspects of the modality in which a lexical item will be finally articulated.

KEYWORDS: Signed language, word production, ERPs, lexical frequency, iconicity

2. INTRODUCTION

Despite the obvious differences between signed and spoken languages, language production seems to follow the same principles and stages in both modalities. From the intention to speak/sign to its final articulation, information flows through different levels of processing, such as the conceptual, lexical and phonological (Caramazza, 1997; Dell & O'Seaghdha, 1991; Levelt, Roelofs & Meyer, 1999). Evidence for this claim comes from the observation of similar linguistic phenomena in spoken and in signed production (see also, Carreiras, 2010, for a review on language comprehension). For example, momentary failures to retrieve a word-form are present regardless of the output modality. The so-called "tip of the fingers" and "tip of the tongue" can be found for the signed and the spoken modality respectively (ToFs, Thompson, Emmorey & Gollan, 2005; ToTs, Caramazza, 1997). In a similar vein, Stroop-like phenomena in the spoken modality, such as the semantic interference and the phonological facilitation effects, have been shown to be present in the signed modality as well (e.g., Baus, Gutiérrez, Quer & Carreiras, 2008; Corina & Knapp, 2006; see also Navarrete, et al., 2015, for semantic effects in the cumulative semantic paradigm in both modalities). In addition, Corina and Knapp (2006) revealed that semantic and phonological effects have a different time course during signing. In a picture-sign interference task in which sign-distractors were presented prior (SOA-), at the same time (SOA 0) or after the picture (SOA+), semantic effects were observed only when distractors preceded the presentation of the picture. In contrast, phonological effects appeared when distractors were presented in synchrony or after the picture, suggesting that semantic representations are accessed earlier than phonological representations during signed production. Hence, processes underlying spoken and signed language production seem to unfold in a very similar fashion: concepts are retrieved earlier than their corresponding signs/words, and sign/words are retrieved before the corresponding phonemes are accessed. However, besides some indication of sequentiality in these processes, little is known about the temporal dynamics of signed language production. To date, research on the cognitive architecture of signed language is relatively scarce and has mainly focused on indentifying the neural substrates underlying sign production (e.g., Emmorey, Mehta & Grawoski, 2007). In contrast, we have very limited information about the timing of such neural involvement (see, Gutierrez, Müller, Baus & Carreiras, 2012; Leonard et al., 2012; for an ERP and an MEG investigation respectively on sign comprehension) and how particular aspects of the signed modality may affect the temporal dynamics of lexical access during sign production. Thus, for the first time, we explored the time-course of sign production by means of registering the EEG activity associated with such task. This will allow us to assess the parallels and differences between sign and spoken language at early stages of lexical access.

Signed and spoken languages differ in (at least) two important aspects. First, the articulators used for production are different and this may alter the time-course of lexical access during language production. Evidence for this comes from the observation that during production, ERPs associated to lexical frequency appear earlier when participants are asked to name an object than when asked to typewrite its name (e.g., Baus, Strijkers & Costa, 2013a). This result has been interpreted as suggesting that the speed with which participants access the lexicon may depend on the output channel. Thus, the first goal of our study is to further investigate the role of the articulators during language production by comparing the ERPs associated to lexical frequency in sign production and spoken word production (see below). To do so, we tested the signing performance of a group of hearing bimodal bilinguals that use both spoken and signed language. We acknowledge that by selecting this group, we were exploring L2 sign production[1], which may somehow differ from native sign production. However, by testing hearing signers, we can have a direct comparison (i.e., within participant) of when lexical access occurs during signed and spoken production.

A second relevant difference between signed and spoken languages is the distribution of non-arbitrariness within the lexicon (i.e., iconicity, see Perniss, Thompson & Vigliocco, 2010; Thompson, 2011, for reviews). Consider for instance the sign SCISSORS in Catalan Sign Language (LSC): the form of the sign clearly resembles (in handshape and movement) the action of cutting with scissors. Thus, although spoken languages exhibit some degree of iconicity (existence of onomatopoeic forms), this property is much more predominant in signed languages[2] (e.g., Mandel, 1977; Pietrandrea, 2002; Taub, 2001). For instance, one-third of the total sign vocabulary is considered to be iconic in the Swiss-German signed language (Boyes-Braem, 1986) reaching almost half of the vocabulary in the Indo-Pakistani signed language (Zeshan, 2000; see also Pizzuto & Volterra, 2013, for a review). Thus, iconicity seems to constitute a substantial part of the lexicon in most of the signed languages. This offers us an excellent opportunity to explore how the iconic properties of signs influence the speed with which signs are accessed during sign production.

Before presenting the study, we briefly described the effects of lexical frequency and its electrophysiological correlates in language production as well as the accumulated evidence regarding the role of iconicity in signed language.

2.1. *Lexical frequency and its locus in language production*

Lexical frequency is one of the most robust psycholinguistic constructs in language production. Words with a high-frequency are named faster and more accurately than words with low-frequency, the so-called *frequency effect* (Caramazza, Costa, Miozzo & Bi, 2001; Caramazza & Costa, 2001; Jescheniak & Levelt, 1994;

Jescheniak, Meyer, & Levelt, 2003; Kittredge, Dell, Verkuilen, & Schwartz, 2008; Navarrete, Basagni, Alario, & Costa, 2006; Strijkers, Costa, & Thierry, 2010). Similarly, frequency influences lexical access during sign production: high-frequency signs are produced faster and more accurate than low-frequency signs (Emmorey, Petrich & Gollan, 2012; see also, Emmorey, Petrich & Gollan, 2013), supporting the similar architecture of lexical access during word and sign production. It remains to be investigated whether the temporal course of lexical access in sign production is similar to that reported in spoken word production.

Different studies in the spoken modality have reported an early effect of frequency in the course of naming: ERP amplitudes associated with low-frequency words are more positive than those associated with high-frequency ones around 200 ms after the presentation of an object (P200 component; Sahin, Pinker, Cash, Schomer, & Halgren, 2009; Strijkers et al., 2010; 2011; 2013). Modulations of the P200 component are sensitive to the ease with which lexical access proceeds: less accessible words tend to elicit more positive amplitudes than more accessible words. What is important to note for the purposes of this study is that, the moment in which ERPs associated to high and low frequency words start to diverge is not influenced by the language, L1 or L2, of the speaker (Strijkers et al., 2010; Strijkers et al., 2013). That is, ERP frequency effects appear around 200 ms regardless of whether bilinguals are naming objects in their L1 or in their L2, even when naming in L2 is slower than in L1. Accordingly, the time course of lexical access does not seem to be determined by the speed with which words are produced. Conversely, other factors, such as the output channel (mouth or hands), do seem to influence the speed with which lexical access proceeds. When comparing the ERP associated to word frequency during naming and typewriting, Baus et al., (2013a) reported that relative to the spoken modality (P200), frequency effects appear 150 ms later when participants were asked to typewrite a word. These results are important in revealing that lexical access might not occur at a fixed time during language production. However, these results need to be taken cautiously here because although typewriting and signing both involve the hands and fingers as articulators, the two tasks differ in many other important aspects (e.g., natural vs human-created language). With this in mind, our first goal was to determine whether signs and words are accessed with a similar timing during language production. For that, the time-course of lexical frequency was taken as an index of when the brain engages in lexical access during sign production.

2.2. Iconicity in signed language processing

Many sign-forms resemble their conceptual referents (e.g., scissors), while this property is quite marginal in the spoken modality. Surprisingly, despite its pervasiveness on the lexicon, the role of iconicity during signed language processing remains unclear (see Carreiras, 2010; Thompson, 2011; for reviews). For instance, iconicity plays a fundamental role during L2 adult signed language learning. Iconic signs are easier to learn than non-iconic signs by adult hearing signers (Baus, Carreiras & Emmorey, 2013b; Campbell, Martin & White, 1992; Lieberth & Gamble, 1991; Ortega & Morgan, 2014a; Ortega & Morgan, in press; Poizner, Bellugi & Tweney, 1981). However, its impact during native (deaf) processing seems to be somewhat limited to sign comprehension, with iconic signs enjoying a comprehension/recognition benefit (Grote & Linz, 2003; Thompson, Vinson, and Vigliocco, 2009; but see Bosworth & Emmorey, 2010). In sign production, iconicity seems to play a more modest role, not affecting the rate of tip of the fingers (TOFs) or anomic states in aphasic patients (Marshall, Atkinson, Smulovitch, Thacker, & Woll, 2004; Thompson, et al., 2005). To our knowledge there are no studies addressing the potential effects of iconicity on picture naming latencies. Indeed, one could argue that the iconic properties of the signs may affect the speed with which lexical access proceeds. That is, iconic signs might have a privilege status within the lexicon. Note that this is a very tentative hypothesis given that at present we do not know whether iconicity actually affects sign production. Remarkably, up to now, the evidence reporting iconicity effects in bimodal bilinguals is quite mixed (Baus et al., 2013b; Thompson et al., 2009; Ortega & Morgan, 2014a). Thus, the present study aims to shed light on the functional role of iconicity during signed language production as well as the electrophysiological correlates associated to it.

In sum, the present study investigated the temporal dynamics of sign production by means of exploring the electrophysiological correlates of lexical frequency and iconicity. To do so, a group of bimodal (spoken-signed) bilinguals was asked to sign pictures whose corresponding signs were either of high or low-frequency, iconic or non-iconic. Moreover, a subset of the participants was re-tested in the same task, but they were asked to name the pictures in their L1 spoken language. The re-test mainly served to establish when frequency effects occur during speech production within the same participants, allowing us to determine whether differences in the articulators used for production in the signed and the spoken modalities influence the time-course of lexical access.

3. RESULTS

3.1. Behavioral results

First, we analyzed the performance of the control speaking group without knowledge of signed language (unimodal bilinguals) naming pictures in their L1, Spanish. The results revealed the expected frequency effect ($F(1, 19) = 6$, $p < .05$). High-frequency words were named faster (900 ms) than low-frequency ones (923 ms).

Importantly, neither the effect of iconicity (907 ms vs 917 ms iconic and non-iconic words respectively; $F(1, 19) = 1.4$, $p = .25$) nor its interaction with frequency ($F < 1$) were significant. Similar results were observed for the error rates. Participants were more accurate naming pictures with high-frequency names than with low-frequency names ($F(1, 19) = 4.08$, $p = .05$). In contrast, neither the effect of iconicity ($F(1, 19) = 1.9$, $p = .17$), nor the interaction between frequency and iconicity were significant ($F < 1$). These results confirm the expected frequency effect and also suggest that iconicity does not play a role during speech production. Thus, any observation of iconicity in the experimental group should be interpreted as the result of having experience with signed language.

3.1.1. Picture signing

The results of the signing group are represented in Figure 1 (panel A). Signing latencies were faster for iconic than for non-iconic signs ($F_1(1, 22) = 107.2$, $p < .001$; $F_2(1, 229) = 28.4$, $p < .001$) and for high-frequency than for low-frequency signs ($F_1(1, 22) = 15.1$, $p < .001$; $F_2(1, 229) = 5.6$, $p < .05$). The interaction between lexical frequency and iconicity resulted significant ($F_1(1, 22) = 15.7$, $p < .001$; $F_2(1, 229) = 3.88$, $p = .05$), revealing that the iconicity effect was twice as large for low-frequency words (97 ms; $F_1(1, 22) = 108$, $p < .001$) than for high-frequency ones (45 ms; $F_1(1, 22) = 22$, $p < .001$) (see Figure 1A)[3]. Error analyses revealed that iconic signs were produced more accurately than non-iconic signs ($F_1(1, 22) = 13.9$, $p < .01$; $F_2(1, 229) = 9.3$, $p < .01$). In contrast, the main effect of frequency ($F_1(1, 22) = 3.5$, $p = .07$; $F_2(1, 229) = 2.9$, $p = .08$) and its interaction with iconicity ($F_1(1, 22) = 3.6$, $p = .07$; $F_2(1, 229) = 1.2$, $p = .2$) did not reach significance although the pattern of results was the same as reported for the signing latencies.

INSERT FIGURE 1 AROUND HERE

3.1.2. Picture naming

The naming performance of the sub-set of participants was also analysed. Naming latencies in the spoken modality revealed a main effect of frequency $F_1(1, 16) = 14.2$, $p <.001$; $F_2(1, 229)= 6$, $p < .05$). Pictures with high-frequency names were named faster and more accurately than pictures with low-frequency names. The main effect of iconicity only reached significance in the within-participants analysis $F_1(1, 16) = 9.8$, $p <.01$; $F_2(1, 229)= 2.6$, $p = .1$). Participants named faster those pictures considered iconic than those considered non-iconic. The interaction between frequency and iconicity was not significant ($F_1 (1, 16) = 1.2$, $p = .2$; $F_2 < 1$).

When considering the error rate analyses, low-frequency words were retrieved less accurately than high-frequency words ($F_1(1, 16) = 11.6$, $p <.01$; $F_2(1, 229)= 8.6$, $p < .01$). Neither the effect of iconicity ($F_1(1, 16) = 1.2$, $p =.29$), nor its interaction with frequency were significant ($F < 1$).

3.2. ERP results

3.2.1. Picture signing

Table 1 represents the main effects and interactions in the different time-windows. Only significant results are commented in the results' section.

INSERT TABLE 1 AROUND HERE

ERP analyses revealed a main effect of iconicity at a very early time-window (70-140 ms) from the onset of the picture presentation (see Figure 2). Pictures whose corresponding signs were iconic elicited more positive amplitudes than pictures with non-iconic signs [$F(1, 22) = 6.3$, $p < .05$]. As revealed by the interaction between iconicity and region [$F(2.08, 47.9) = 3.3$, $p < .05$], the iconicity effect was significant for all electrode clusters (all $ps < .04$), except those left lateralized electrodes at the anterior and central clusters.

At the 140-210 time-window, only the three way interaction between iconicity, frequency and region revealed a trend to significance [$F(2.4, 56.5) = 2.5$, $p =.07$] revealing that for those electrodes in the occipital region, the frequency effect was significant exclusively for non-iconic signs ($p = .03$). In contrast, when considering the iconicity effect, none of the post-hoc comparisons resulted significant.

At the 280-350 ms time-window, frequency interacted significantly with region [$F(3.2,72.2) = 5.5$, $p =.001$]. Low-frequency signs elicited more positive amplitudes than high-frequency ones at the posterior [$F(1, 22) = 11.07$, $p < .01$] and occipital electrodes [$F(1, 22) = 4.89$, $p < .05$]. Moreover, iconicity interacted with frequency [$F(1, 22) = 10$, $p < .01$], revealing that the iconicity effect, indexed by iconic signs eliciting larger amplitudes than non-iconic signs, was significant for low-frequency signs [$F(1, 22) = 6.4$, $p < .03$] but not for high-frequency ones ($F(1, 22) = 1.2$, $p =.2$).

At the 350-550 ms time-window, as determined by the main effect of iconicity and its interaction with region [$F(2.7, 57.1) = 5.5$, $p < .01$], iconicity was significant at the midline, and the right lateralized electrode clusters (all $ps < .02$). As revealed by the significant interaction between iconicity and frequency [$F(1, 22) = 16.9$, $p < .001$], the iconicity effect remained significant exclusively for those signs of low-frequency [$F(1, 22) = 27.9$, $p < .001$].

At the later time-window (550-750 ms) the main effect of frequency resulted in significance [$F(1, 22) = 6.8$, $p < .05$], revealing a more positive going waveform for those signs of low-frequency than for those of high-frequency. The interaction between frequency and iconicity was significant [$F(1, 22) = 8.6$, $p < .01$], but this time, the iconicity effect was significant for high-frequency signs [$F(1, 22) = 9.8$, $p < .01$] and not for low-frequency ones ($F(1, 22) = 1.4$, $p = .2$).

The onset latency analyses confirmed the early onset of the iconicity effect (see Figure 3, lower panel). ERP amplitudes for iconic and non-iconic signs started to diverge significantly at 84 ms ($p = .03$) after the picture onset presentation and remained significant until 114 ms. The iconicity effect became significant again from 384 ms. The frequency effect reached significance at 304 ms after the picture onset presentation ($p = .03$).

INSERT FIGURE 2 AROUND HERE

INSERT FIGURE 3 AROUND HERE

3.2.2 Picture naming

When considering the ERP analyses for the picture naming in the spoken modality (see Figure 4 and 5), there were no significant effects at the early time window of 70-140 ms (all p's > .12).

In the time range between 140 and 210 ms after the onset of the picture presentation, high-frequency words differed from low-frequency ones as indicated by the main effect of frequency [$F(1, 16) = 5.7$; $p < .05$]. Pictures with low-frequency names elicited more positive amplitudes than pictures with high-frequency names. No other effect resulted significant in this time window (all F's < 1).

In the time-window between 210-280 ms, the effect of frequency only revealed a trend to significance [F(1, 16) = 3.4; p = .08], with low-frequency words eliciting a larger amplitude than high-frequency ones. Moreover, as indicated by the main effect of iconicity [F(1, 16) = 8.3; p < .05], those pictures whose corresponding words (signs) were iconic elicited larger amplitudes than non-iconic words. None of the other effects resulted significant (all Fs < 1).

In the time-window between 280-350 ms, the main effect of frequency [F(1, 16) = 6.1; p < .05], as well as its interaction with electrode cluster resulted significant [F(2.1, 35) = 4.2; p < .05]: frequency effects were observed in central and posterior electrode clusters (all p's < .03). As indicated by the interaction between frequency and iconicity [F(1, 16) = 4.5; p = .05], the iconicity effect was present for low-frequency words (F(1, 16) = 11.7; p < .01, but not for high-frequency ones (F < 1). At the latter time-window (350-550 ms) only the main effect of iconicity was significant [F(1, 16) =19.3, p < .001], with iconic words eliciting more positive ERP amplitudes than non-iconic words.

Onset latency analyses showed that ERP amplitudes for high and low frequency words started to diverge significantly at 174 ms (*p* = .03) after the picture onset presentation. In contrast, the onset of the iconicity effect started later, at 238 ms (*p* = .04) after the picture onset presentation (Figure 5, lower panel)

To further confirm the early iconicity effects (P100) in the signed modality and its absence in the spoken modality, we compared the ERPs of the same 17 participants in both modalities. An ANOVA including modality (signed vs spoken), frequency (high vs low) and iconicity (iconic vs non-iconic) and electrode cluster was performed for the time-window 70-140 ms. The results revealed an interaction between modality and iconicity [$F(1, 16) = 19.3$, $p < .001$] as well as the three way interaction between modality, iconicity and electrode cluster [$F(2.3, 38) = 3.7$, $p < .05$]. Pair-wise comparisons revealed that iconicity effects were significant in the signed modality at centroposterior, posterior and occipital electrode clusters (CentroPosteriorCentral: $p = 0.045$; Posterior: $p = .030$; Occipital: $p = .033$), but not in the spoken modality.

A second analysis was conducted in the time-windows 140-210 ms and 210-280 ms to further confirm the frequency effects (P200) in the spoken modality. The results in the time-window 140-210 ms revealed a main effect of frequency [$F(1, 16) = 6.4$, $p < .05$]. The interaction between frequency and modality did not reach significance [$F(1, 16) = 1.4$, $p = .2$] but the contribution of both modalities to the observed effect was clearly different; frequency effects were significant in the spoken [$F(1, 16) = 5.7$; $p < .05$] but not in the signed modality [$F < 1$]. In contrast, in the time-window 210-280 ms, the interaction between frequency and modality was significant [$F(1, 16) = 6.3$, $p < .05$], confirming a marginal frequency effect in the spoken modality [$F(1, 16) = 3.4$; $p = .08$], and the lack of effects in the signed modality [$F < 1$]. When considering the frequency effects at posterior regions (where it was maximal in the spoken modality), the interaction between frequency and modality resulted significant [$F(1, 16) = 4.6$; $p < .05$], confirming the presence of frequency effects in the spoken modality [$F(1, 16) = 5.2$; $p < .05$] and its absence in the signed modality ($F < 1$).

To sum up the results considering both modalities, an early iconicity effect (70-140 ms) was observed in the signed but not in the spoken modality. In the time-range between 140-210 ms, frequency effects were observed in the spoken modality, supporting previous results in the literature of speech production. Moreover, in the spoken modality, frequency and iconicity effects were observed in the time-range of the

P200 component, revealing that lexical access was similarly modulated by both variables in the spoken modality. In contrast, in the signed modality, frequency effects were restricted to those signs non-iconic. Finally, at latter time-windows, frequency interacted with iconicity in both modalities.

4. DISCUSSION

Importantly, this study is the first to have investigated the temporal dynamics of sign production and how particular aspects of the signed modality (i.e., the articulators used for production and the distribution of iconicity in the lexicon) influence when lexical access occurs during signing. To do so, the effects of lexical frequency and iconicity, both taken as an index of lexical processing during sign production, were explored in a group of bimodal bilinguals while performing a picture-signing task. Moreover, a subset of the participants was re-tested in the same task, but naming the pictures instead. This allowed us to have an estimation of when lexical access occurred in the spoken modality within the same participants.

Our results revealed that both frequency and iconicity had an impact on sign and spoken word production. Behaviorally, the results in both modalities revealed that iconic signs/words and high-frequency signs/words were produced faster and more accurately than non-iconic signs/words and low-frequent signs/words. Importantly, frequency but not iconicity effects were observed in a control group of speakers without any knowledge of signed language.

At the electrophysiological level, the effect of iconicity appeared relatively soon after the presentation of the picture, but only in the signed modality. That is, in the time-window between 70 and 140 ms, ERP amplitudes for iconic signs were more positive going than those corresponding to non-iconic signs. In contrast, ERP modulations associated to frequency appeared at a later time-window (280-350 ms). In the spoken modality, both frequency and iconicity effects appeared in the time-window associated with lexical access during speech production (around 200 ms after the picture presentation). Moreover, frequency and iconicity effects interacted in both modalities in the time window 280-350 ms; iconicity effects were only present for those signs/words of low-frequency. Interestingly, in the signed modality whenever the effect of frequency was significant, it interacted with iconicity.

The present study was the first attempt to explore the electrophysiological correlates of frequency and iconicity during sign production and as such we might not have a clear explanation for all the results. Interestingly however, the comparison with the spoken modality, allows us to determine which effects speak about the nature of the signing task (e.g., the early iconicity effect), and which effects do not (the interaction between iconicity and frequency in the time window 280-350).

In the following, we discuss our results in relation to the late effect of frequency, the early effect of iconicity and the relationship between frequency and iconicity in signed language production.

4.1. On the late frequency effects in signed language

As expected, low-frequency signs were signed slower than signs of high-frequency. These results replicate previous observations in the signed (Emmorey et al., 2012; Emmorey et al., 2013) as well as in the spoken modality (e.g., Caramazza et al., 2001; Jescheniak et al., 2003; Navarrete et al., 2006; Strijkers et al., 2010) Moreover, at the ERP level, low-frequency signs elicited more positive amplitudes than high-frequency signs, supporting the sensitivity of both modalities to the same psycholinguistic phenomena. However, relative to the spoken modality, ERP modulations associated with frequency appeared somewhat delayed in the signed modality. In the spoken modality (including our results), ERP frequency modulations appear around 200 ms during object naming (e.g., Strijkers et al., 2010; Sahin et al., 2009), while frequency effects originated around 300 ms in the signed modality. Indeed, this timing is consistent with that reported in Baus et al., (2013a), where participants were required to type a word instead of producing it orally. The fact that both tasks share the involvement of the hands as articulators supports the idea that the timing of frequency effects during language production is modulated by the output modality (oral/manual) in which words/signs are produced.

Nevertheless, most of our participants were non-native signers and, therefore, we cannot rule out the potential contribution of non-nativeness to the observed ERP modulations. One possibility is that the delayed ERP frequency effect stems from a slower lexical retrieval in the non-native (signed) modality compared to the native (spoken) modality. This is difficult to determine with the present data, but other studies seem to suggest that the speed of lexical retrieval does not affect the timing of the ERP frequency effect. For instance, in the spoken modality, while behavioral differences are obtained between L1 and L2, ERP modulations associated with lexical frequency originate around 200 ms (Strijkers et al., 2010; Strijkers et al., 2013). Thus, it is difficult to explain the delayed frequency effect just as a result of lexical retrieval being slower for non-natives than for natives. This does not mean, however, that other variables rather than speed can affect the timing of frequency effects in natives and non-natives. This is an open issue that deserves further research.

Finally, although rather weak, an effect of frequency was observed for non-iconic signs in the same time-window where frequency effects arose in the spoken modality (140-210 ms). Interestingly, this was the same time-window where frequency effects were observed in the spoken modality. Thus, based on this result, it is possible that lexical access proceeds similarly in both modalities. But unlike the spoken modality, iconicity plays an important role in how lexical representations are selected during sign production. It remains to be investigated whether this observed interaction stems from a general privilege of iconic forms in the signed lexicon or from a specific benefit in the process of learning iconic signs.

4.2. On the early iconicity effects in signed language

Iconicity also influenced sign production: iconic signs were produced faster and more accurately than non-iconic signs. These results provide clear evidence that iconicity influences the speed with which lexical access proceeds during sign production. Thus, at least concerning bimodal bilinguals, iconic signs seem to enjoy a privilege access to the lexicon, both in production and comprehension (e.g., Thompson et al., 2009).

Perhaps the most interesting and clear result of this study is the early ERP iconicity effect observed during sign production, but not during spoken wordproduction. ERP iconicity effects, indexed by iconic signs eliciting more positive amplitudes than non-iconic ones, appeared very early on (P100) in the course of signing.

In object recognition tasks, effects occurring during the first 150 ms after the presentation of an object have been interpreted as indicating an early engagement of the conceptual system in the processing of a visual object (e.g., Hauk et al. 2007; Thorpe, Fize & Marlot, 1996; Johnson & Olshausen 2005). ERP deflections within the P1 time-window are sensitive to conceptual-related variables such as image agreement (Cheng, Schafer & Akyürek, 2010), the structural typicality of the object (Hauk et al., 2007) or how strongly an object is associated with a color (e.g, lemon; Redmann, Fitzpatrick, Hellwig & Indefrey, 2014). Indeed, models of picture naming consider the recognition of an object and its conceptual activation to be the first stage of processing during picture naming (Levelt, Praamstra, Meyer, Helenius & Salmelin, 1998; Indefrey &

Levelt, 2004; Potter, 1984). In this context, the early ERP iconicity effect might result from semantic features of iconic signs being more strongly activated (or more automatically) than those of non-iconic signs (Bosworth & Emmorey, 2010).

Within the signed language literature, Gutiérrez et al., (2012) also revealed an early ERP semantic effect during comprehension when deaf signers processed unexpected signs (e.g., skirt) but semantically related to the expected sign (e.g., dress). This result was interpreted in terms of the richness in the semantic content of signs, which allows a faster interaction between the visual form and its meaning. Similarly, Vigliocco, et al., (2005) suggested that iconicity facilitates lexical retrieval as a result of iconic signs being strongly linked to visual imagery processes (see also models of speech-gesture production for a similar argument; de Ruiter, 1998; Hadar & Butterworth, 1997; Krauss, 1996). Importantly, the fact that iconicity effects originated at a very early stage only during sign production, suggests that any link between iconicity and imagery/conceptual processes is exclusive of the signed modality. Unexpectedly, in the spoken modality, iconicity effects appeared in the same time-range as frequency effects, suggesting that both frequency and iconicity originate at the lexical level. At this point, we do not have a clear explanation of why iconicity effects were present in the spoken modality and why they appeared at the lexical level and not before as in the signed modality. Importantly, any given explanation does not obscure the observation of very early iconicity effects in the course of sign production.

4.3. On the relationship between frequency and iconicity in signed language

In the previous sections, we have discussed the early iconicity effect and the late frequency effect during sign production. Notably, whenever frequency effects were present in the signed modality, they interacted with iconicity (both at early and late time-windows). The same did not occur in the spoken modality, where the typical frequency effect in the P200 was not modulated by iconicity. These contrasting results can be taken as an indication that iconicity in signed language influences the way the lexicon is organized in terms of frequency.

Obviously, there is not much one can say about the peculiarities of the signed modality given that both modalities revealed an interaction between iconicity and frequency in the time-window 280-350 ms. Although this result was surprising, it clearly suggests that the interaction has little to do with the signing nature of the task. For instance, one might argue that the observed interaction in both modalities might result from the distribution of frequency values between iconic and non-iconic signs/words. That is, although we showed that iconic and non-iconic signs did not differ in their average frequency, certain signs might be still biased towards one of the extremes of the frequency distribution. Indeed, this would not be surprising if we consider results from signed databases (i.e., British Sign Language, BSL) showing that iconic signs tend to be more familiar and acquired earlier in life than non-iconic signs (Vinson et al., 2008). As can be appreciated in Figure 6, there is an overall tendency for iconic signs to be more frequent than non-iconic signs (see also the materials section). For instance, this would explain the 10 ms advantage (although it was not significant) for iconic over non-iconic words in the group without knowledge of signed language. However, it would be more problematic for the distribution explanation to account for the larger effects of iconicity obtained for the group of bimodal bilinguals, or for the interaction between frequency and iconicity obtained across all time-windows in the signed modality while restricted to one time-window in the spoken modality. Thus, even when other uncontrolled factors might have contributed to the interaction between frequency and iconicity in both modalities, this does not compromise the idea that the modality in which a language is represented and how it exploits iconicity influence how lexical access proceeds during sign production.

Our results in the signed modality revealed that high-frequency signs do not benefit from iconicity as low-frequency signs do. That is, iconicity effects (behavioral and electrophysiologically) play a more modest role in the retrieval of high-frequency signs than in the retrieval of low-frequency signs. The reason might be simply because in the lexicon, high-frequency signs are more accessible than low-frequency signs, leaving then little room for iconicity (or any other variable) to influence the lexical retrieval of high-frequency signs. For instance, Emmorey et al., (2012) showed that frequency effects in signed language were larger for bimodal bilinguals than for deaf native signers, being the signing disadvantage especially evident for those signs less active in the lexicon. In this context, it is possible that iconicity aids lexical retrieval, especially for those signs in the lexicon that are less accessible. An interesting alternative, is the one offered by Frishbert (1975), who showed that as signed languages change over time, iconicity diminishes and iconic signs tend to become more arbitrary (see Perniss et al., 2010). If this change does not affect signs in a random fashion, then it is likely that those iconic signs more frequently used in the lexicon would become arbitrary more rapidly than those less frequently used in the lexicon. If this were the case, high-frequency iconic signs would tend to be less iconic over time. As it relates to our results, this would mean that differences in iconicity might be less visible within the high-frequency condition than within the low-frequency condition. Although this is an interesting possibility, it is still very premature since we do not actually know how frequency and iconicity interact in signed language. However, it opens an excellent question to be pursued in the future.

5. CONCLUSION

This study presents the first exploration on the temporal dynamics of sign production. Our results suggest that spoken and signed languages are sensitive to the same linguistic phenomena, but differences between the two modalities in some aspects affect the time course of lexical access.

6. METHOD

6.1. Participants

Twenty-six bimodal bilinguals took part in the experiment (23 women; mean age = 26.5; SD = 5.5). All participants were right handed and had normal or corrected-to-normal vision. All of them signed a consent form before starting the experiment and received a monetary compensation for their participation. Three of the participants were CODAs (hearing children of deaf parents) and the remaining learned signed language as adults (mean age of acquisition = 23.9, S.D = 3.7). At the time of testing, nine participants were working as sign-language interpreters and the remaining were in the last year of a two-years intensive course (35 hours/week) of signed language interpretation (mean years of exposure excluding CODAs = 2.6, S.D = 1.1). Before the experiment started, the participants filled in a questionnaire of language proficiency, gathering information from their spoken and signed language. They were asked to rate their comprehension and production fluency in Catalan and Spanish (L1 spoken languages) and in Catalan Signed Language, LSC (L2 signed language) on a scale of 1 (not proficient at all) to 5 (very proficient). As expected, participants declared themselves to be more proficient in their spoken languages, both in comprehension (Catalan mean= 4.8; Spanish mean= 5) and production (Catalan; mean= 4.7; Spanish mean= 5), than in signed language (comprehension = 3.8 (S.D =0.8); production = 3.5 (S.D = 0.9).

From the original group, nineteen participants returned to the lab to perform the same task but this time naming the pictures in their L1 spoken language (Spanish or Catalan). At least one month separated both testing sessions. Note that this second test had the main objective of confirming ERP lexical effects in the spoken modality. Two participants had to be excluded from the analyses due to excessive artifacts. Thus, seventeen participants were included in the final analysis.

Finally, a control group composed by 20 unimodal bilinguals (Spanish-Catalan) without any knowledge of signed language was behaviorally tested in their L1, Spanish. This group served mainly to confirm the presence of frequency effects and the absence of iconicity effects.

6.2. Materials.

Two hundred forty pictures from different semantic categories were selected from different databases (Bates et. al., 2003; Snodgrass & Vandenwart, 1980). Since currently there is no available LSC corpus, frequency values were taken from the Spanish corpus (B-Pal; Davis & Perea, 2004). We acknowledge that there might be some limitations in using spoken databases to define sign frequency. Some studies have relied on subjective-familiarity ratings by signers to define frequency (e.g., Emmorey et al., 2012). However, it has been also questioned to what extent subjective familiarity measures the same as objective frequency in signed language (Johnston, 2012). In any case, to make sure that our materials were selected adequately, we asked a group of deaf signers (n=4) to rate the familiarity of the pictures corresponding signs. All of them were deaf from birth and used signed language as the preferred means of communication. Familiarity ratings of the deaf signers were then compared to familiarity ratings of hearing speakers as well as to the objective frequency values extracted from the Spanish lexical database. The results revealed that frequency interacted significantly with both familiarity ratings (hearing speakers: $r = .35$; deaf signers: $r =.17$).

The corresponding names for half of the pictures (120) were considered of high-frequency (mean frequency per million of occurrences: 49.9; S.D = 76.04) and the remaining pictures were considered as having low-frequency names (mean: 4.04, S.D = 2.5). The cut-off frequency for considering a sign as having a high or a low frequency was 10. In addition, half of the pictures were considered as having iconic forms while the remaining half were considered as having non-iconic forms. Iconic signs included two types of iconicity: signs resembling object actions (e.g., the sign for *glass* resembles the action of drinking) and signs resembling object forms (e.g., the sign DEER resembles the antlers of the animal). In order to ensure that the selection of iconic and non-iconic signs was appropriate, a group of twelve speakers (without any knowledge of signed language) was asked to evaluate the degree of transparency between the picture and its corresponding sign. Naïve speakers were presented with the experimental pictures together with the sign of the corresponding picture name (signed by the experimenter). For each sign, they were asked to rate how transparent the sign was in relation to the object presented on a scale from 1 (not transparent at all) to 5 (fully transparent). Iconic signs were evaluated as being more transparent (mean = 3.8; SD = .9) than non-iconic signs (mean = 2.2, S.D = 1) (t (238) = 12.3, $p < .001$). Additionally, the group of four deaf native signers was asked to evaluate the iconicity of the signs. The results obtained in the native deaf group were very similar to those obtained in the naïve group: iconic signs were evaluated as more transparent than non-iconic signs (3.6 vs 2.7, t (238) = 43.4, $p < .001$). Indeed, both measures of iconicity (naïve and native) correlated significantly (r =.81, p <.001).

Importantly, the degree of transparency was similar across high and low-frequency sets (t (238) < 1). Similarly, high and low-frequency signs were also similarly distributed across iconic and non-iconic signs (t (238) < 1; high-frequency iconic: 54.8 (SD = 93), high-frequency non-iconic: 45 (SD = 53), low-frequency iconic: 4.5 (SD = 2), low-frequency non-iconic: 3.5 (SD = 2).

6.3. Procedure.

The experiment was conducted in a sound attenuated booth. Participants were told that the aim of the experiment was to explore the electrophysiological correlates of sign production, but they were not informed about the experimental manipulation. Before the experiment, participants were familiarized with the pictures and their corresponding signs. During the familiarization, the experimenter showed participants each of the pictures of the experiment and asked them to sign the corresponding name. If the elicited sign did not match the one designated by the experimenter (e.g., the participant knew more than one sign for the object or he/she did not know the sign), the experimenter showed the appropriate sign and the participant had to repeat it.

Moreover, they received 10 practice trials (not included in the analyses) to be familiarized with the task. During the experiment, participants were asked to sign the picture names while ERPs were recorded continuously. The trial structure was as follows: 1) a message on the screen asked the participants to press and hold the space bar in the keyboard, 2) once the space bar was pressed, a fixation point was presented for 500 ms followed by a blank of 300 ms, 3) the picture was then presented for 3000 ms or until a response was given. Signing latencies were measured from the onset of the picture presentation to the moment participants released their hands from the space bar. E-Prime professional was the software used to control the presentation of the stimuli and to record the responses of the participants. The experimental session was videotaped for later evaluation of the incorrect responses. Trials were considered as errors and were excluded from the latency analyses (4.2%) when the sign was different from the one designated by the experimenter or when the participant raised their hands from the keyboard but stopped before signing (considered as hesitations).

The procedure was the same in the spoken modality, except that participants were asked to name the pictures and verbal responses were registered.

6.4. Behavioral analyses.

Signing latencies and error rates were analysed separately for participants (F1) and items (F2) in a 2 x 2 ANOVA with lexical frequency (high-frequency vs low-frequency) and iconicity (iconic vs non-iconic) as factors. Nine words were eliminated because they each elicited more than 25% errors. The same analyses were conducted in the spoken modality.

6.5. ERP recording and analysis.

EEG was continuously registered and linked-nose reference from 30 scalp Ag/Cl electrodes. Extreme caution was taken in placing the reference electrode to avoid interferences from those signs performed close to the nose. Eye movements were monitored by two external electrodes placed horizontally (outer canthus) and vertically to (below) the right eye. The impedance of the electrodes was kept below 5 kΩ (10 kΩ for the ocular electrodes). EEG signal was digitalized online with a 500 Hz sampling rate and a band pass filter of 0.1 to 125 Hz. EEG data was filtered offline to 0.03 Hz high-pass filter and 20 Hz low-pass filter, re-reference to the two mastoids and vertical and horizontal ocular artefacts were corrected by a correction algorithm (Gratton, Coles, & Donchin, 1983). Data was segmented into 850 ms epochs (-100 to 750 ms) and segments with incorrect responses, artefacts (brain activity above or below 100 μV or a change in amplitude between adjacent segments of more than 200 μV) or eye blinks, were excluded (12% of segments). Epochs were then averaged in reference to the -100 ms pre-stimulus baseline. Due to excessive artefacts, three participants were excluded from the analyses, leading to a final analysis comprising 23 participants.

Similar analyses were conducted in the spoken modality, except that data was segmented into 650 ms epochs (-100 to 550 ms) to avoid that ERPs would be contaminated by motor artefacts associated to articulation while speaking.

ERP amplitudes were analysed in a 2 x 2 x 8 ANOVA considering lexical frequency (high vs low-frequency) iconicity (iconic vs non-iconic) and electrode cluster (AnteriorLeft: F7, FC5, F3; AnteriorCentro: Fz, FC1, FC2; AnteriorRight: F8, FC6, F4; CentroPosteriorLeft: C3, CP5, P3; CentroPosteriorCentral: Cz, CP1, CP2; CentroPosteriorRight: C4, CP6, P4; Posterior: Pz, PO1, PO2; Occipital: O1, Oz, O2). Greenhouse-Geisser correction (corrected degrees of freedom and probabilities are reported) and Bonferroni correction for multiple comparisons were applied when necessary. Moreover, the onset latency of the frequency and iconicity effects was explored by running a two-tailed paired t-test at every sampling point (2 ms). The onset of the effect was taken as the first data point in a row of at least ten consecutive significant data points (Guthrie & Buchwald, 1991).

Besides the P200 component associated to lexical frequency, we did not have a clear hypothesis of which other ERP components would be sensitive to frequency and iconicity in sign production. Therefore, ERP analyses covered both early and late components. Based on the global field power measured across the scalp and on the latency of the maximal peak (posterior region), we defined seven time-windows: P1 (70-140 ms), N1 (140-210 ms), P2 (210-280 ms), N3 (280-350 ms) and two late time-windows 350-550 ms and 550-750 ms. This latter time-window was not included in the analyses of the spoken modality.

ACKNOWLEDGEMENTS

This research was supported by two grants from the Spanish Government, PSI2011-23033 and CONSOLIDER-INGENIO2010 CSD2007-00048, one grant from the Catalan Government, SGR 2009-1521, and from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013 Cooperation grant agreement nº 613465 - AThEME). CB was supported by a post-doctoral fellowship JCI-2010-06504 from the Spanish Government and now is supported by the People Program (Marie Curie Actions, FP7-PEOPLE 2014-2016) under REA agreement nº623845.

REFERENCES

Armstrong, D. F., Stokoe, W. C., & Wilcox, S. E. (1995). *Gesture and the nature of language*. Cambridge, England: Cambridge University Press.

Bates. E., D'Amico, S., Jacobsen, T., Székely, A., et al. (2003). Timed picture naming in seven languages. Psychonomic Bulletin Review, 10(2), 344-80.

Baus, C., Carreiras, M., & Emmorey, K. (2013). When does iconicity in signed language matter? *Language and Cognitive processes* 28(3):261-271.

Baus, C., Gutiérrez-Sigut, E., Quer, J., Carreiras, M. (2008). Lexical access in Catalan Signed Language (LSC) production. *Cognition, 108*(3):856–865.

Baus, C., Strijkers, K., & Costa, A. (2013). When does word frequency influence written production? *Frontiers in Psychology, 4*: 963.

Bosworth, R.G., & Emmorey, K. (2010). Effects of iconicity and semantic relatedness on lexical access in American Sign Language. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *36 (6)*,1573-1581.

Boyes-Braem, P. (1986). Two aspects of psycholinguistic research: iconicity and temporal structure. In *Signs of Life: Proceedings of the Second European Congress on Sign Language Research.* Amsterdam: Institute of Linguistics, University of Amsterdam.

Campbell, R., Martin, P., & White, T. (1992). Forced choice recognition of sign in novice British Sign Language learners. *Applied Linguistics, 13,* 185-201.

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology, 14*(1), 177-208.

Caramazza, A., Costa, A., Miozzo, M., & Bi, Y. (2001). The specific-word frequency effect: Implications for the representation of homophones in speech production.

Journal of Experimental Psychology: Learning, Memory, and Cognition, 27(6), 1430-1450.

Caramazza, A., & Costa, A. (2001). Set size and repetition in the picture–word interference paradigm: Implications for models of naming. *Cognition, 80*(3), 291-298.

Carreiras, M. (2010). Sign language processing. *Language and Linguistics Compass, 4*, 430–444.

Cheng, X., Schafer, G., & Akyürek, E.G. (2010). Name agreement in picture naming: An ERP study. *International Journal of Psychophysiology, 76*, 130-141.

Coles, M. G. (1989). Modern mind-brain reading: Psychophysiology, physiology, and cognition. *Psychophysiology, 26*(3), 251-269.

Corina, D. P., & Knapp, H. (2006). Lexical retrieval in American Sign Language production. In: Goldstein, LM.; Whalen, DH.; Best, CT., (eds). Papers in Laboratory Phonology pp 213-240. Berlin: Mouton de Gruyter

Davis, C. J., Perea, M. (2004). BuscaPalabras: A program for deriving orthographic and phonological neighborhood statistics and other psycholinguistic indices in Spanish. Behavior Research Methods, 37, 4, 665-671.

Dell, G. S., & O'Seaghdha, P. G. (1991). Mediated and con- vergent lexical priming in language production: A comment on Levelt et al. *Psychological Review*, 98**,** 604–614.

De Ruiter, J. P. (2000). The production of gesture and speech. In D. McNeill (Ed.), *Language and gesture* (pp. 284–311). Cambridge, UK: Cambridge University Press.

Emmorey, K., Mehta, S., Grabowski, T. J. (2007). The neural correlates of sign versus word production. *Neuroimage, 36*, 202-206

Emmorey K., Petrich J. A. F., Gollan T. H. (2012). Bilingual processing of ASL-English code-blends: The consequences of accessing two lexical representations simultaneously. *Journal of Memory and Language, 67*, 199–210

Emmorey K., Petrich J. A. F., Gollan T. H. (2013). Bimodal bilingualism and the frequency-lag hypothesis. *Journal of Deaf Studies and Deaf Education, 18 (1):* 1-11.

Frishberg, N. (1975). Arbitrariness and iconicity: historical change in American Sign Language. *Language*, 696-719.

Gratton, G., Coles, M. G., Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalographical Clinical Neurophysiology, 55(4),* 468–484

Grote, K., & Linz, E. (2003). The influence of sign language iconicity on semantic conceptualization. In W. G. Müller & O. Fischer (Eds.), *From sign to signing: iconicity in language and literature* (pp. 23-40), Amsterdam: John Benjamins.

Guthrie D, Buchwald J. S. (1991). Significance testing of difference potentials. *Psychophysiology, 28*, 240–244.

Gutiérrez, E., Müller, O., Baus, C., & Carreiras, M. (2012). Electrophysiological evidence for phonological priming in Spanish Sign Language lexical Access. *Neuropsychologia, 50,* 1335-1346.

Gutierrez, E., Williams, D., Grosvald, M., & Corina, D. (2012). Lexical access in American Sign Language: An ERP investigation of effects of semantics and phonology. *Brain Research, 1468,* 63-83.

Hadar, U., & Butterworth, B. (1997). Iconic gesture, imagery and word retrieval in speech. *Semiotica, 115*, 147–172.

Hauk, O., Patterson, K., Woollams, A., Cooper-Pey, E., Pulvermüller, F., Rogers, T. T. (2007). How the camel lost its hump: The impact of object typicality on event-related potential signals in object decision. *Journal of Cognitive Neuroscience, 19*, 1338–1353.

Indefrey, P., & Levelt, W. J. M. (2004). The spatial and temporal signatures of word production components. *Cognition, 92,* 101-144.

Jescheniak, J. D., & Levelt, W. J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(4), 824-843.

Jescheniak, J. D., Meyer, A. S., & Levelt, W. J. M. (2003). Specific-word frequency is not all that counts in speech production: Comments on Caramazza, Costa, et al. (2001) and new experimental data. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 432-438.

Johnson, J.S., & Olshausen, B. A. (2005). The earliest EEG signatures of object recognition in a cued-target task are postsensory. *Journal of Vision. 5,* 299–312.

Johnston, T. (2012). Lexical frequency in sign languages. *Journal of deaf studies and deaf education*, *17*(2), 163-193.

Kelly, S. D., McDevitt, T., & Esch, M. (2009). Brief training with co-speech gesture lends a hand to word learning in a foreign language. *Language and Cognitive Processes, 24,* 313-334.

Kittredge, A. K., Dell, G. S., Verkuilen, J., & Schwartz, M. F. (2008).Where is the effect of frequency in word production? Insights from aphasic picture-naming errors. *Cognitive Neuropsychology, 25,* 463–492.

Klima, U., & Bellugi, U. (1979). *The signs of language*. Cambridge, Mass.: Harvard University Press.

Krauss, R. M. (1998). Why do we gesture when we speak? *Current Directions in Psychological Science*, *7*, 54–60.

Leonard, M. K., Ramirez, N. F., Torres, C., et al., (2012). Signed words in the congenitally deaf evoke typical late lexicosemantic responses with no early visual responses in left superior temporal cortex. *The Journal of Neuroscience*, *32*(28), 9700-9705.

Levelt, W. J. M., Praamstra, P., Meyer, A. S., Helenius, P. & Salmelin, R. (1998). A MEG study of picture naming. *Journal of Cognitive Neuroscience , 10,* 553-567.

Levelt, W. J. M., Roelofs, A., & Meyer, A. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22***,** 1–75.

Lieberth, A. K., & Gamble, M. E. B. (1991). The role of iconicity in sign language learning by hearing adults. *Journal of Communication Disorders, 24,* 89-99.

Mandel, M. (1977). Iconic devices in American Sign Language. In L. Friedman (Ed.), *On the other hand: New perspectives on American Sign Language,* pp. 57 - 107, New York: Academic Press.

Marshall, J., Atkinson, J., Smulovitch, E., Thacker, A., & Woll, B. (2004). Aphasia in a user of British Sign Language: Dissociation between sign and gesture. *Cognitive Neuropsychology, 21*(5), 537-554.

Navarrete, E., Basagni, B., Alario, F. X., & Costa, A. (2006). Does word frequency affect lexical selection in speech production? *The Quarterly Journal of Experimental Psychology, 59*(10), 1681-1690.

Navarrete, E., Caccaro, A., Pavani, F., Mahon, B. Z., & Peressotti, F. (2015). With or Without Semantic Mediation: Retrieval of Lexical Representations in Sign Production. *Journal of deaf studies and deaf education*, 1-9.

Ortega, G., Morgan, G. (2014). The effect of iconicity in the mental lexicon of hearing non-signers and proficient signers: evidence of cross-modal priming. *Language, Cognition and Neuroscience.* DOI: 10.1080/23273798.2014.959533.

Ortega, G., & Morgan, G. (in press). Phonological development in hearing learners of a sign language: the role of sign complexity and iconicity. *Language Learning*.

Perniss, P., Thompson, R, & Vigliocco, G. (2010). Iconicity as a general property of language: Evidence from spoken and signed languages. *Frontiers in Psychology, 1:* 227.

Pietrandrea, P. (2002). Iconicity and arbitrareness in Italian Sign Language. *Sign Language Studies, 2*(3), 296-321.

Pizzuto, E., & Volterra, V. (2000). Iconicity and Transparency in Sign Languages: A Cross-Linguistic Cross-Cultural View. In The Signs of Language Revisited: An Anthology in Honor of Ursula Bellugi and Edward Klima, ed. K. E

Poizner, H., Bellugi, U., & Tweney, R. D. (1981). Processing of formational, semantic, and iconic information in American Sign Language. *Journal of Experimental Psychology. Human Perception and Performance*, *7*(5), 1146-1159.

Potter M. C. (1984). "Rapid serial visual presentation (RSVP): a method for studying language processing," in New Methods in Reading Comprehension Research, (eds Kieras D., Just M.). Hillsdale, NJ: Erlbaum, 91–118.

Redmann, A., Fitzpatrick, I., Hellwig, F & Indefrey, P. (2014). The use of conceptual components in language production: an ERP study. *Frontiers in Psychology, 5:* 363.

Sahin, N. T., Pinker, S., Cash, S. S., Schomer, D., & Halgren, E. (2009). Sequential processing of lexical, grammatical, and phonological information within broca's area. *Science, 326*(5951), 445-449.

Snodgrass, J.G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 174-215.

Strijkers, K., Baus, C., Runnqvist, E., Fitzpatrick, I., Costa, A. (2013). The temporal dynamics of first versus second language production. *Brain and Language, 127,* 6-11.

Strijkers, K., Costa, A., & Thierry, G. (2010). Tracking lexical access in speech production: Electrophysiological correlates of word frequency and cognate effects. *Cerebral Cortex, 20,* 912-928.

Strijkers, K., Holcomb, P. J., & Costa, A. (2011). Conscious intention to speak proactively facilitates lexical access during overt object naming. *Journal of Memory and Language, 65*(4), 345-362.

Strijkers, K., & Costa, A. (2011). Riding the lexical speedway: A critical review on the time course of lexical selection in speech production. *Frontiers in Psychology, 2-356.*

Taub, S. (2001). *Language from the body: iconicity and metaphor in American Sign Language*. Cambridge University Press.

Thompson, R. L. (2011). Iconicity in language processing and acquisition: what signed languages reveal. *Language and Linguistics Compass*, *5*(9), 603-616.

Thompson, R., Emmorey, K., & Gollan, T. (2005). Tip-of-the-fingers experiences by ASL signers: Insights into the organization of a sign-based lexicon. *Psychological Science, 16(11)*, 856-860.

Thompson, R. L., Vinson, D. P., & Vigliocco, G. (2009). The link between form and meaning in american sign language: Lexical processing effects. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 35*(2), 550-557.

Thorpe S., Fize D., Marlot C. (1996). Speed of processing in the human visual system. *Nature, 381,* 520–522.

Vigliocco, G., Vinson, D. P, Woolfe, T., Dye, M. W. G., Woll, B. (2005). Language and imagery: Effects of language modality. *Proceedings of the Royal Society Biological Sciences, 272,* 1859-1863.

Vinson, D. P., Cormier, K., Denmark, T., Schembri, A., & Vigliocco, G. (2008). The British Sign Language (BSL) norms for age of acquisition, familiarity, and iconicity. *Behavior Research Methods*, *40*(4), 1079-1087.

Zeshan, U. (2000). *Sign language in Indo-Pakistan: A description of a signed language*. John Benjamins Publishing.

FOOTNOTES

1. It should be noted that it is not possible to explore L1 signed language within the bimodal bilingual group. Even for those bimodal bilinguals acquiring signed language from birth (CODAs, Children Of Deaf Adults), there is a change in the language dominance by which their spoken language becomes their dominant language (e.g., Emmorey et al., 2012a).
2. This does not mean that signed languages do not contain arbitrary signs (Klima & Bellugi, 1979; but see Amstrong et al., 1995, for considering signs as essentially iconic). There is nothing, for instance, in the form of the sign NEWSPAPER in LSC that resembles its meaning.
3. Given the close relation between lexical frequency and other conceptual variables, we further ensured that the observed signing latencies were not determined by the familiarity and imageability ratings of the words. To do so, a multiple regression analysis was conducted to predict signing/naming latencies from iconicity, lexical frequency, familiarity and imageability. The results showed that the overall regression was a good fit for the data ($F(4, 227) = 10.4$, $p < .001$, $R^2 = .15$). Importantly, not all the variables contributed equally to this significance. Only iconicity ($B = -27$, $t = -5.4$, $p < .001$) contributed significantly to this prediction. Lexical frequency showed only a tendency for significance ($B = -.20$, $t = -1.8$, $p = .06$), while familiarity and imageability did not contribute to the best fit of the model.

   In the spoken modality ($F(4, 227) = 3.47$, $p < .01$, $R^2 = .05$), both iconicity ($B = -12$, $t = -2.7$, $p < .01$) and frequency ($B = -.20$, $t = -2.02$, $p < .05$) contributed significantly to this prediction, while familiarity ($p = .8$) and imageability ($p = .4$) did not.
4. The same analyses including the first language of the participants as a factor (Spanish or Catalan) revealed no differences in the overall naming latencies between these two groups ($F < 1$; Spanish: 803 (34); Catalan: 835 (29)). Moreover, language did not interact with word frequency, nor with iconicity (all F’s < 1)

FIGURE LEGENDS

Figure 1. Signing (panel A) and naming latencies (panel B) of the experimental group (bimodal bilinguals) for iconic and non-iconic signs/words separated by frequency. Error bars represent the standard errors. HF= High-frequency, LF= Low-frequency, ICO= Iconic, NO ICO= Non-iconic. Solid bars represent latencies for iconic signs and dashed lines represent latencies for non-iconic signs.

Figure 2. ERP waveforms obtained in the signed language task. The lines correspond to high-frequency (HF, black line) and low-frequency signs (LF, red line) with iconic (ICO, solid line) and non-iconic (NO ICO, dotted line) names. The two most representative regions are represented (AC: Anterior central, O: Occipital). Positive amplitudes are plotted down.

Figure 3. ERP amplitudes (upper panel) in the signed modality for the main effects of frequency (left panel) and the iconicity (right panel). Two regions of interest are represented for the ERP amplitudes (AC: Anterior central, OC: Occipital). Positive amplitudes are plotted down. For the frequency effect panel (left), solid lines represent high-frequency (HF) signs and dotted lines represent low-frequency (LF) signs. For the iconicity effect panel (right panel), solid lines represent iconic signs (ICO) and dotted lines represent non-iconic signs (NO ICO). The lower panel represents the latency analysis across regions and time. Colors represent significant p-values (below $p < .05$) from paired t-test comparisons at each sampling point (every 2 ms) between high and low-frequency signs (left panel) and iconic and non-iconic signs (right panel).

Figure 4. ERP waveforms in the spoken modality for high-frequency (HF, black line) and low-frequency signs (LF, red line) with iconic (ICO, solid line) and non-iconic (NO ICO, dotted line) names. The two more representative regions are represented (AC: Anterior central, O: Occipital). Positive amplitudes are plotted down.

Figure 5. ERP amplitudes (upper panel) in the spoken modality for the main effects of frequency (left panel) and the iconicity (right panel). Two regions of interest are represented for the ERP amplitudes (AC: Anterior central, OC: Occipital). Positive amplitudes are plotted down. For the frequency effect panel (left), solid lines represent high-frequency (HF) words and dotted lines represent low-frequency (LF) words. For the iconicity effect panel (right panel), solid lines represent iconic words (ICO) and dotted lines represent non-iconic words (NO ICO). The lower panel represents the latency analysis across regions and time. Colors represent significant p-values (below $p < .05$) from paired t-test comparisons at each sampling point (every 2 ms) between high and low-frequency signs (left panel) and iconic and non-iconic signs (right panel).

Figure 6. Distribution of the frequency values (log-transformed) of the items employed in the experiment separated for iconic and non-iconic signs.