

**Title: The Specificity of the Neural Response To Speech at Birth.**

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## Research Highlights:

- At birth, the human brain is specialized for speech.
- Neonates show similar neural activation in language areas to familiar and unfamiliar spoken language, but not to a whistled surrogate language.

**Abstract:** In this work we ask whether at birth, the human brain responds uniquely to speech, or if similar activation also occurs to a non-speech surrogate “language”. We compare neural activation in newborn infants to the language heard *in utero* (English), to an unfamiliar language (Spanish), and to a whistled surrogate language (Silbo Gomero) that, while used by humans to communicate, is not speech. Anterior temporal areas of the neonate cortex are activated in response to both familiar and unfamiliar spoken language, but these classic language areas are not activated to the whistled surrogate form. These results suggest that at the time human infants emerge from the womb, the neural preparation for language is specialized to speech.

From birth, the human brain responds to speech. Similar to adults, temporal and frontal areas of the brain are activated in very young infants in response to spoken language, but not to non-linguistic signals such as scrambled speech, sine-wave contours, tones, monkey calls, and backwards speech (Peña et al., 2003; Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Perani et al., 2011; Minagawa-Kawai et al., 2011; Shulz et al., 2014; Taga, Homae, & Watanabe, 2007). In many (Peña et al., 2003; Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Minagawa-Kawai et al., 2011; Shultz et al., 2014; Sato et al., 2012; Vannasing et al., 2016), but not all (Perani et al., 2011; Taga, Homae, & Watanabe, 2007; May et al., 2011) studies, these effects are most pronounced in the left hemisphere. It is unknown, however, whether neural specialization for language in neonates is restricted to speech. To address this question, we compared neonate neural activation in response to forward and backward familiar spoken language (English), unfamiliar spoken language (Spanish), and unfamiliar whistled surrogate “language”<sup>1</sup> (Silbo Gomero).

Whistled surrogate languages exist in several regions of the world, having evolved primarily to help groups better communicate over long distances. Unlike spoken languages, no known whistled surrogate language is ever acquired as a first language, but instead are learned in addition to the base language. As surrogates, whistled languages are transpositions of a base spoken language in which whistled

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<sup>1</sup> Throughout this paper we will refer to whistled surrogate communication systems such as Silbo Gomero, as “whistled language” or “whistled surrogate language”, as these are the conventional term that have been used previously in the literature. It is important to note, however, that there is significant disagreement as to the linguistic status of such whistled forms, with many considering whistled languages not to be “true” languages (see further Trujillo, 1978, Rialland, 2005; Meyer, 2005).

contours replace speech sounds by way of conventionalized patterns (Trujillo, 1978; Rialland, 2005). They are produced by whistling with the fingers between the lips, thus creating a signal that can be projected much further, but one that involves a very different means of production than spoken language (Rialland, 2005). Whistled surrogate languages are in many ways close in form to their base spoken languages, matched in structure, rhythm, prosody, and communicative intent. However, compared to spoken languages, whistled surrogates have limited phonetic repertoires and reduced acoustic complexity. Because whistled surrogate languages are secondary rather than primary, they are typically not considered “natural” language, as are spoken and signed languages (Trujillo, 1978; Rialland, 2005, see also Hockett, 1963).

The most studied whistled surrogate language is Silbo Gomero, derived from Spanish and still in use in parts of the Canary Islands. The phonemic inventory of Silbo Gomero consists of 2-3 vowels (“acute” and “grave” vowels corresponding to the front vs. central/back vowels of spoken Spanish) and 4-9 consonants (“grave,” “acute,” and “sharp” consonant distinctions corresponding to non-coronal, anterior coronal, and posterior coronal consonant distinctions in spoken Spanish, as well as “interrupted,” “continuous,” and “gradual decay” consonant distinctions corresponding to place of articulation contrasts; Rialland, 2005). In perception tasks, adult Silbo Gomero users are able to identify whistled phonemes at above chance rates (Rialland, 2005).

A study by Carreiras and colleagues (2005) has shown that with experience, the adult brain processes the whistled signal as linguistic: adult users of Silbo Gomero show similar activation in classic left hemisphere language areas in response to both whistled Silbo Gomero and spoken Spanish. However, Spanish monolinguals show specialized activation compared with baseline only to Spanish and not to Silbo Gomero, even though the same rhythm and prosody are shared across both forms. Unknown is whether specialized neural activation in adult Silbo Gomero users is induced through experience using the whistled form, or instead, whether the lack of specialized activation among individuals who do not use a whistled language is the result of loss or reorganization of an initially broader neural specialization present earlier in development.

Whistled surrogate language thus provides an intriguing signal with which to explore the precision of the initial neural specificity for language. While previous research examining the neonate brain response to speech versus non-speech has used non-speech stimuli that are either never used for communication by any species (e.g. backwards speech; synthetic sine-wave speech) or non-human animal calls (Peña et al., 2003; Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Perani et al., 2011; Minagawa-Kawai et al., 2011; Shulz et al., 2014), whistled surrogate language is a non-speech stimulus produced by the human vocal tract and used by humans for communication.

To test the hypothesis that the brain is specialized to respond specifically to spoken language, in two experiments we examined neonate neural activation to forward and backward familiar spoken language (English), unfamiliar spoken language (Spanish), and unfamiliar whistled surrogate language (Silbo Gomero). Neural activation was assessed using functional Near-Infrared Spectroscopy (NIRS), through which cortical activity is measured via relative changes in the concentration of oxygenated and de-oxygenated hemoglobin (Hb) following presentation of a stimulus. NIRS is an ideal method with which to examine neural processing in young infants, as it is non-invasive and has relatively good spatial localization (Lloyd-Fox, Blasi, & Elwell, 2010; Gervain et al., 2011; Aslin, 2013), and has been widely used with infants (Aslin, Shukla, & Emberson, 2015).

## **Study 1**

Languages can be grouped into different rhythmic classes (for a quantification see Ramus, Nespor, & Mehler, 1999): stress-timed languages (such as English and Dutch), syllable-timed languages (such as Spanish and French), and mora-timed languages (such as Japanese). Newborn infants behaviorally discriminate their native language from a non-native language of a different rhythmical class (Mehler et al., 1988; Moon, Cooper, & Fifer, 1993). However, although there are effects of prenatal listening experience on infants' neural processing of native versus non-native languages, specialized activation is seen in neonates to both native language (the language heard in utero) and to unfamiliar—and hence never before

experienced —language (May et al., 2011; Sato et al., 2012). Study 1 extended this work. Neural activation in neonates was measured in response to forward and backward segments of the language heard in utero (English) versus an unfamiliar, rhythmically distinct language (Spanish). Backwards language was used as a matched non-language contrast, as it is equaled to the forward signal in pitch and complexity, but contains sounds that cannot be produced by the human vocal tract.

## **Methods**

### *Participants*

Data from 24 newborn infants (0-3 days postnatal,  $M=1.46$  days) were included in Study 1. All infants were  $\geq 37$  weeks gestation, and in good health (APGAR score of 7+ at birth, and 8+ five minutes after birth). Parents of infants were asked to provide the languages their child was exposed to in utero, and for each language, to estimate the percentage of exposure. According to parental report, all infants were exposed to at least 80% English in utero, and had no exposure to Spanish. An additional 17 infants were tested, but were excluded from analysis due to fussiness (10), insufficient data (6), or machine/computer errors (2).

### *Stimuli*

Two proficient female native speakers of each language (English, Spanish) were recorded reading aloud from bilingual versions of the children's books "The Paper Bag Princess" and "The Three Wishes". From the recorded stories, eight 15s (+1) segments of each language were selected, and backwards versions of all segments were generated using Praat (Boersma & Weenink, 2011).

### *Procedure*

Neonates were tested in a silent, sound attenuated room at a local maternity hospital. Infants were asleep or in a quiet state of rest for the duration of the study (Figure 1). A Hitachi ETG-4000 NIRS machine with a source detector separation of 3 cm and two continuous wavelengths of 695 and 830 nm was used, with a sampling rate of 10Hz. The laser power was set at 0.75mW.

Two chevron-shaped optical probes were placed over the participants' head: one probe over the left temporal region, and one probe over the matched right temporal region. Each probe contained 9 (5 emitters and 4 detectors) 1mm optical fibers, forming 12 optical channels for measurement (Figure 1). Placement of the probes was based on surface landmarks on the neonate scalp, using the chevron design of the probe to nestle above the ear on each hemisphere. Probes were kept in place using soft netting material.



Each infant heard four different language conditions: forward English, backward English, forward Spanish, and backward Spanish. Eight sequential trials of each language condition were presented, with each block comprised of approximately 15 seconds of language followed by 25-35 seconds of silence (Figure 1). This relatively long, jittered silent period was included to allow the hemodynamic response, which is slower in the newborn, to return to baseline (Gervain et al., 2011). We employed a blocked presentation of stimuli, such that each infant heard all 8 trials of a language condition consecutively. The order of the language conditions was counterbalanced across infants. Testing time was 24 minutes.

### *Analyses*

As oxygenated Hb has been found to be the strongest marker of neural activity in infant NIRS (Lloyd-Fox, Blasi, & Elwell, 2010; Gervain et al., 2011; Aslin, 2013), our analyses focused on this variable. Changes in oxygenated Hb were examined from 4.2 to 17.1 seconds after the start of stimulation, averaged over the 8 blocks of each language condition. Data were band-pass filtered between .01 and .7 Hz, and movement artifacts were removed by isolating trials in which there was a change in concentration greater than 0.1mmol x mm over a period of 0.2sec. For each trials, a baseline was established by linearly fitting the 5s preceding the onset of the trials and the 5s occurring 15s after the end of the trial. This timeline allowed the hemodynamic response to return to baseline.

To ascertain cortical regions of interest specially responsive to the primary language (English), permutation analyses (Maris & Oostenveld, 2007) was conducted to identify clusters of channels in which significantly greater activation was seen to forward versus backwards English and to forward versus backwards Spanish. This type of analysis defines regions of interest (ROIs) in a non-arbitrary, data-driven, yet anatomically informed fashion, and has been used successfully in the past with infant NIRS data (Ferry et al., 2015; Mahmoudzadeh et al., 2013). We implemented the cluster-based permutation test using the same parameters as in Ferry et al. (2015).

## **Results**

A permutation analysis revealed a cluster of channels in the left hemisphere (channels 3, 6, & 8) as well as a cluster of channels in the right hemisphere (channels 16, 17, 19, 21, 22) showing significantly greater activation ( $ps < .05$ ) to forward versus backward English (Figure 2).

A neonatal MRI template (Shi et al., 2011) was used to determine the approximate location of these clusters over the newborn brain. For the left hemisphere cluster, target channels were seen to be primarily over the anterior temporal lobe, with the two most anterior channels (3, 8) possibly straddling the frontal lobe. For the right hemisphere cluster, target channels covered this same area, but also extended further posterior (channel 21). Additionally, one channel in the right hemisphere

cluster (channel 16) was located in an area straddling the frontal and parietal lobes. While some differences likely occur between infants, the location of these channels appears to be roughly over Broca's area, with some extending into nearby temporal lobe regions as well as the motor and sensory cortices (particularly in the right hemisphere).

Activation in the identified English cluster regions was analyzed across language (English, Spanish), direction of speech (FW, BW), and between regions (LH cluster, RH cluster). Results revealed no significant main effects,  $ps > .100$ . There was, however, a marginally significant interaction between language and direction,  $F(1,23)=3.737$ ,  $p=.066$ ,  $\eta^2_p=.140$ . Follow-up analyses thus examined activation to English and Spanish separately.

In response to English, a main effect of direction was observed,  $F(1,23)=5.502$ ,  $p=.028$ ,  $\eta^2_p=.193$ , such that greater activation was seen to forward ( $M=.043$ ,  $SD=.064$ ) versus backward language ( $M=-.009$ ,  $SD=.078$ ). The main effect of region was not significant,  $ps > .200$ , nor was the interaction between direction and region. In response to Spanish, no main effects or interactions were observed,  $ps > .200$ .

A second permutation analysis was conducted to explore regions sensitive to Spanish. This analysis revealed no clusters of channels in either hemisphere in which activation was significantly greater to forward versus backward Spanish.

## **Discussion**

Results from Study 1 demonstrate specialized neural processing in newborn infants to the native language in bilateral anterior temporal regions. In these regions, similar activation is also observed to a rhythmically distinct non-native language, supporting previous findings that activation in language areas of the brain is evoked not only to the language experienced in utero, but also to unfamiliar language (May et al., 2011; Sato et al., 2011). However, findings from Study 1 also suggest a role for prenatal language experience. While greater neural activation was observed to forward versus backward native language, greater activation was not seen to forward versus backward unfamiliar language. A similar pattern of greater activation to forward versus backward language only for the native language was also reported in a study with Japanese-exposed neonates (Sato et al., 2011), but in this case with Japanese as the native language, strengthening the likelihood that our results are driven by language familiarity.

## **Study 2**

In Study 1, it was demonstrated that anterior temporal areas in newborn infants show activation to both familiar and unfamiliar spoken language. In Study 2, we investigate whether neonates who have no familiarity with whistled language show specialized activation only to speech-- regardless of familiarity-- and not to whistled surrogate language, or if the initial neural responsitivity is sufficiently broad to also

include whistled language. Using the same design as Study 1, infants heard segments of unfamiliar spoken language (Spanish) and unfamiliar whistled surrogate language (Silbo Gomero).

As described above, the adult brain can process Silbo Gomero as linguistic, but only if there is experience with whistled language (Carreiras et al., 2005). Unknown is whether this difference comes from induction in the case of Silbo users, or loss in the case of non-users.

## **Methods**

### *Participants*

Data from a new set of 20 neonates was included in Study 2 (0-4 days postnatal,  $M=1.21$  days). All infants were  $\geq 37$  weeks gestation and in good health (same criterion as Study 1). Parents reported that all infants heard at least 80% English in utero, and had no experience with Spanish. An additional 14 infants were tested, but were excluded from analysis due to fussiness (11) or insufficient data (7).

### *Stimuli*

The Spanish stimuli from Study 1 were used. Silbo Gomero stimuli were recorded and selected in the same manner as described in Study 1, from two novel proficient

female whistlers in the Canary Islands. A sample of the Silbo Gomero used can be heard at <http://infantstudies.psych.ubc.ca/silbo>. To illustrate the differences between spoken and whistled languages, waveforms and spectrograms from two sets of samples of Spanish and Silbo Gomero are presented in 5. For further information on the acoustic and phonetic structure of Sibbo Gomero, see Rialland (2005).

### *Procedure and Analyses*

The procedure and data preparation were identical to Study 1.

### **Results**

As in Study 1, a permutation analyses were conducted to identify target regions of interest. In Study 2, clusters of channels were first selected based on significant activation to forward versus backward Spanish. The permutation analysis revealed one cluster of channels in the left hemisphere (channels 3, 6,  $ps < .05$ ), and no significant cluster in the right hemisphere. Localization of this cluster using the neonate MRI template (Shi et al., 2011) was again found to be in the anterior temporal lobe, with one channel (3) possibly straddling the frontal lobe (Figure 6).

An ANOVA compared activation in the identified region across language (Spanish, Silbo Gomero) and direction (FW, BW). A main effect of language was found,  $F(1,$

19)=6.208,  $p=.022$ ,  $\eta^2_p=.246$ , such that greater activation was seen to Spanish ( $M=.053^2$ ,  $SD=.062$ ) versus Silbo Gomero ( $M=.005$ ,  $SD=.085$ ). No main effect of direction or interaction between language and direction was observed,  $ps>.100$ .

Because follow-up analyses were done for each language separately in Study 1, similar follow-up analyses were performed to separately examine activation to Spanish and Silbo Gomero within the identified region of interest. In response to Spanish, a significant effect of direction was seen,  $F(1,19)=7.080$ ,  $p=.015$ ,  $\eta^2_p=.271$ , with greater activation to forward ( $M=.087$ ,  $SD=.075$ ) versus backwards language ( $M=.018$ ,  $SD=.095$ ). In response to Silbo, the effect of direction was not significant,  $p>.500$ .

Since the significant clusters that emerged in Study 2 differed from those identified in Study 1 as responsive to forward versus backward native language, a second set of analyses was performed on the Study 2 data using the Study 1 regions of interest. An ANOVA conducted across language (Spanish, Silbo Gomero), direction (FW, BW), and between region (LH cluster, RH cluster) yielded a main effect of language,  $F(1,19)=9.939$ ,  $p=.005$ ,  $\eta^2_p=.343$ . Greater activation was observed to Spanish

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<sup>2</sup> The overall Hb change values to Spanish are greater in Study 2 than in Study 1. While one possible explanation for this difference is the context in which Spanish is presented (with native language in Study 1 versus with whistled language in Study 2), we are hesitant to draw such a conclusion due to laser adjustments made on the NIRS machine between studies that may have contributed to differences in absolute values of activation. Indeed, changes in laser power have been found to result in different absolute values of activation for identical stimuli in previous experiments (see Gervain et al., 2008).

( $M=.052$ ,  $SD=.058$ ) versus to Silbo Gomero ( $M=.010$ ,  $SD=.063$ ). No other main effects or interactions were significant,  $ps>.100$ .

Again, follow-up analyses were done separately for Spanish and Silbo Gomero. To Spanish, a main effect of direction was observed, with greater activation to forward ( $M=.076$ ,  $SD=.072$ ) versus backwards language ( $M=.028$ ,  $SD=.072$ ),  $F(1,19)=6.054$ ,  $p=.024$ ,  $\eta^2_p=.242$ . No main effect of region or interaction between direction and region was seen to Spanish. No effects were significant to Silbo Gomero.

Finally, a second permutation was done on the data from Study 2 to identify any regions showing sensitivity to Silbo Gomero. This analysis revealed no areas of activation with greater activation to forward versus backward Silbo Gomero.

## **Discussion**

In Study 2, two converging sets of analyses revealed selective activation in language areas of the newborn brain to unfamiliar spoken language, but not to unfamiliar whistled surrogate language. This pattern of results was seen both in the left hemisphere region identified in Study 2 as specialized to forward versus backward unfamiliar spoken language (Spanish), as well as in the regions identified in Study 1 as specialized to forward versus backward native language (English).



Study 2 also revealed an intriguing pattern of results with regards to activation to forward versus backward non-native language. In Study 1 (in which infants heard native language and non-native language), activation to non-native language was equivalent across directions. Yet in Study 2 (in which infants heard the same non-native language, but with whistled surrogate language), greater activation *was* seen to forward versus backward non-native language. Moreover, in Study 2, but not Study 1, this activation was left lateralized. These results suggest that there may be a role of context in driving what is processed as language: it may be that in the context of familiar native language, the neonate fails to process any other unfamiliar languages as special—but when there is no familiar language present, the linguistic aspects of unfamiliar language activate language areas in the neonate brain, and the neonate thus shows specialized processing to such signals.

## **General Discussion**

Our results demonstrate that at birth, the brain is highly specialized to respond to speech, showing activation in anterior temporal regions to both familiar and unfamiliar language, but not to whistled surrogate language. It is only with experience as a whistled language user that neural specialization can emerge.

Unanswered by the present work is the genesis of the newborn neural activation to spoken language. While it could reflect an evolutionarily established predisposition, it may not. In the current set of studies, all infants tested were born to hearing,

speaking, mothers. Thus, all the infants were exposed to (English) spoken language in utero. Hence, the specialized processing seen to spoken language—even when unfamiliar—could have been facilitated through prior experience with the properties of speech.

One way to address the importance of fetal experience with spoken language would entail replicating the current work with newborn infants who had not been exposed to language at all in utero. While such a study is theoretically enticing, it is nearly impossible to do, as even hearing children of deaf mothers likely hear some spoken language in utero either from their own mothers or externally from others.

Despite this methodological obstacle, the present work may lend some insight into the role of prenatal exposure for specialization for speech, as whistled surrogate language shares many of the properties of the speech to which infants are exposed to *in utero*. Indeed, previous research has indicated that while transmission properties change across pregnancy, and can vary with the degree of internal digestive sounds, the uterus acts largely as a 400Hz low pass filter. As such, the rhythmical and prosodic properties of speech are well transmitted to the fetus, while many of the phonetic features (particularly consonant sounds) are not (Busnel, Granier-Deferre, & Lecaneut, 1992; Lecaneut & Schaal, 1996; Querleu et al., 1988). Whistled Silbo Gomero maintains the rhythmic and prosodic aspects of its base language, albeit in a higher frequency range than a low pass filter would favor. If the neural response is driven entirely by the similarity between the signal and

that experienced in utero, one might predict a stronger response to a whistled language than the negligible level of activation seen to Silbo Gomero in the present study. Thus while *in utero* experience likely plays some role in the neural specialization seen at birth, it may interact with a sensory apparatus and neural substrate that are optimized for encoding and learning about some signals (such as speech) over others.

Still unknown is what characteristics present in spoken language-- yet absent in whistled language—are necessary for the newborn brain to process a signal as linguistic. Spoken and whistled languages are similar in many ways: as noted above, Spanish and Silbo Gomero have the same prosody, rhythm, and syntactic structure. Both signals can be used to create infinite combinations of meaning (unlike, for example, commands used with dogs or dolphin calls), are composed of smaller semantic and phonemic units, and are acquired through traditional cultural transmission from person-to-person. Both involve changing the shape of the oral cavity to modify an airstream. However, due to the substitution of whistled contours for speech sounds and the difference in production, Silbo Gomero has a more limited phonetic repertoire and lacks the acoustical complexity of speech (Trujillo, 1978; Riialand, 2005). Determining which of these factors are crucial in triggering the newborn brain to detect a signal as language is an area for future research.

One conclusion that might be drawn from this work is that speech is the only form of language that the human brain responds specially to at birth. Yet sign languages

are also acquired naturally, and as a first language. Moreover, they have complex phonetic inventories and a rapid opening and closing of manual articulators similar to that of oral articulators (Petitto, 1994). However, infants have little-to-no exposure to the visual medium before birth. Exploring whether the newborn brain shows similar activation to signed as to spoken languages would help to establish whether it is the medium of communication, prenatal experience, or the characteristics of the signal that underlies the specialized neural activation to speech at birth.

In summary, we observe that by the first days of life, classic language areas of the brain are activated in response to both familiar and unfamiliar spoken language, but not to a whistled surrogate language. These findings provide some of the strongest evidence to date that the human brain is highly specialized, even at birth, to respond to speech.

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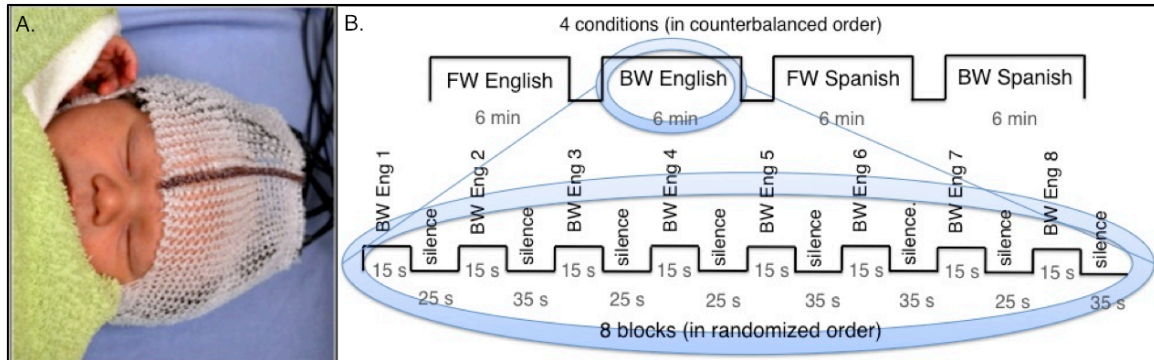
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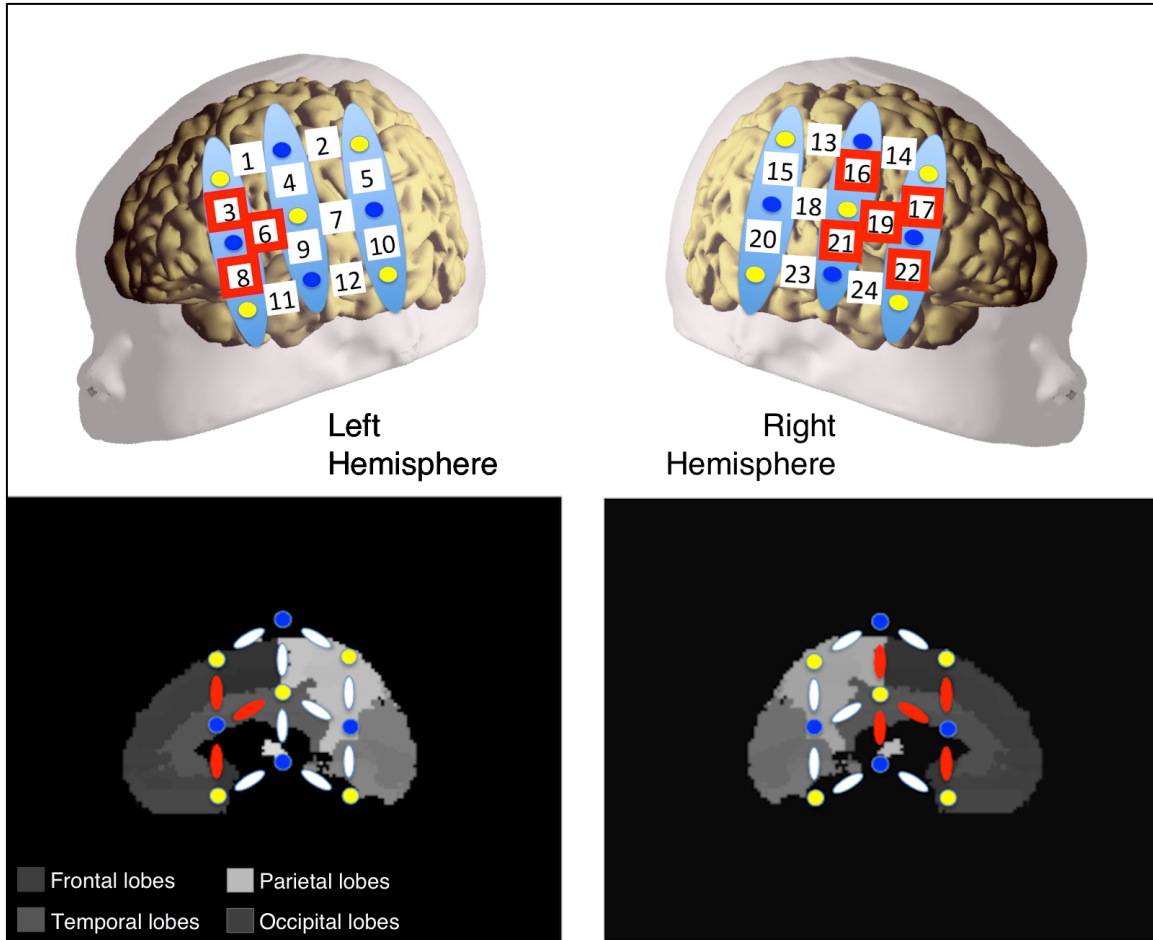
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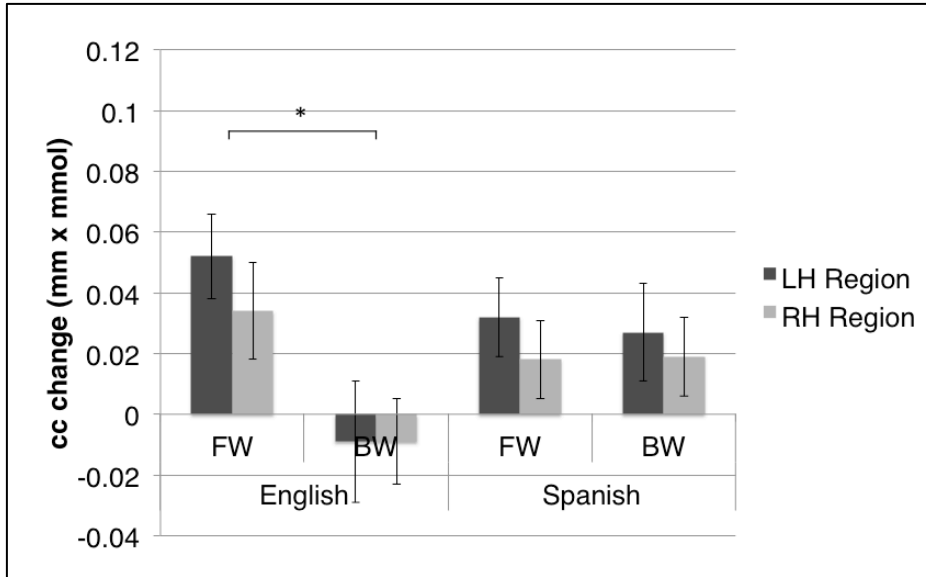
**Figures.**



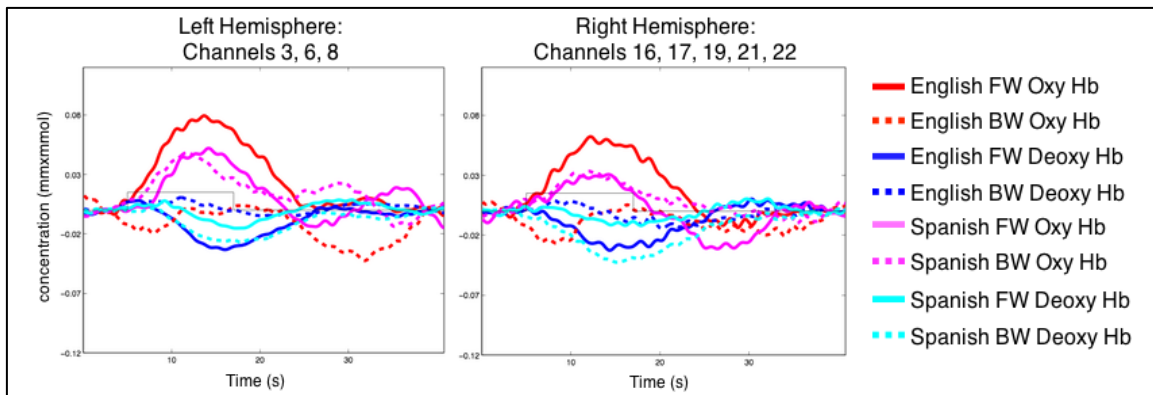
**Figure 1.** A. An infant as tested in the study B. Example of the research design. Order of languages presented was fully counterbalanced across infants (24 orders).



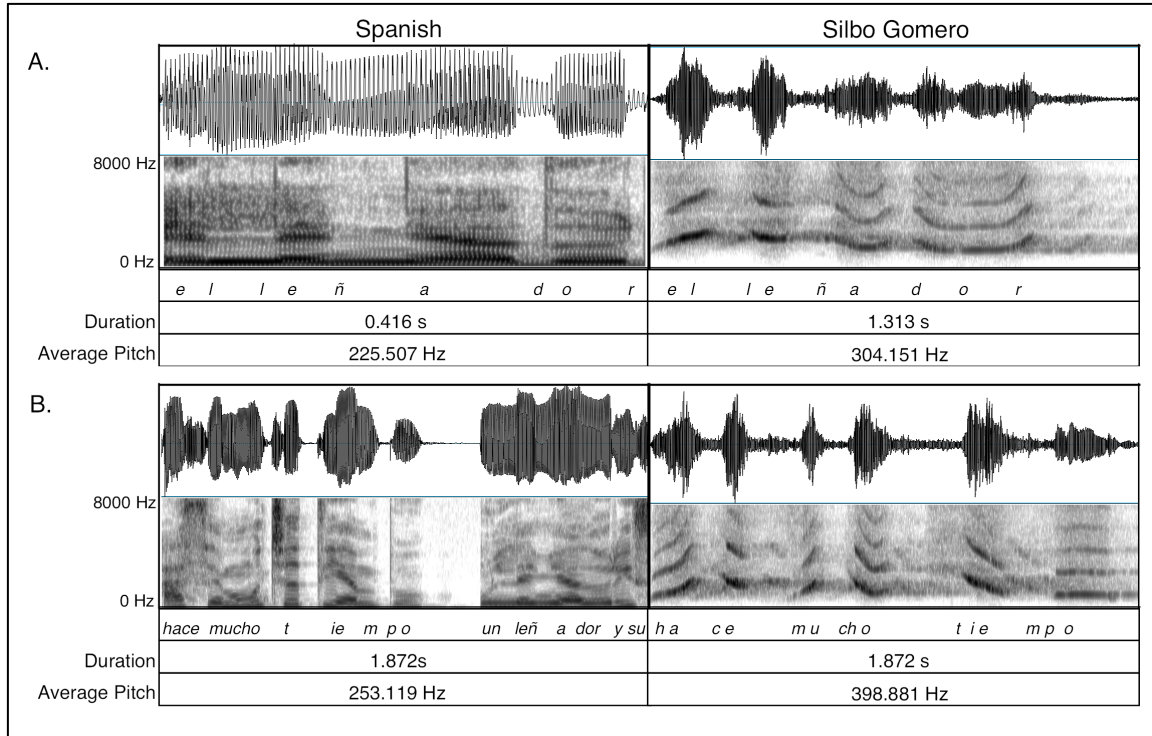
**Figure 2.** Schematic of the optode placement used. Yellow dots represent emitters and blue dots detectors, with white squares/ovals showing channels of measurement. Regions of interest identified by the permutation analysis as showing significantly greater activation to forward versus backward English in Study 1 are highlighted in red, and located on a neonate MRI template.



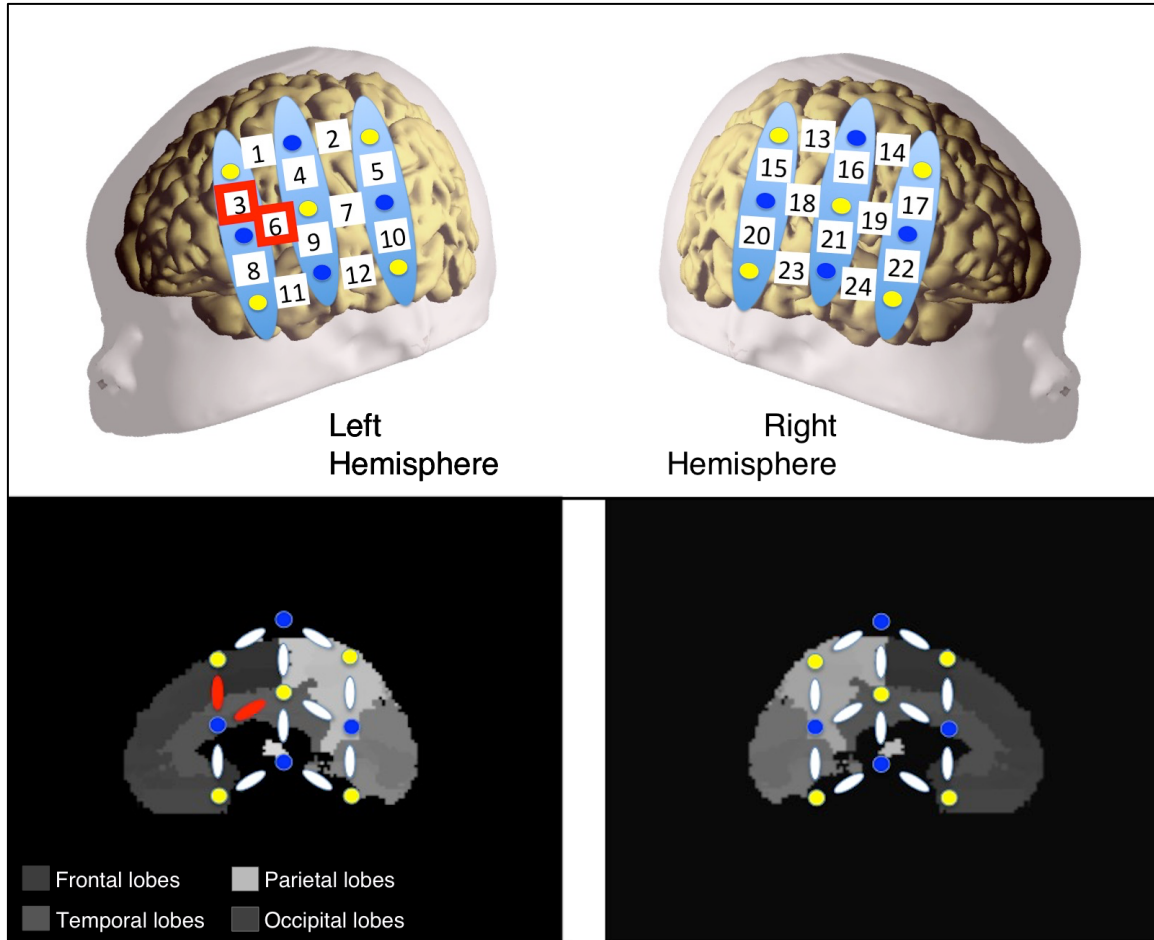
**Figure 3.** Changes in oxygenated hemoglobin as observed to English and Spanish in Study 1. In response to English, significantly greater activation was seen to forward versus backward language, while in response to Spanish, no effect of direction was observed.



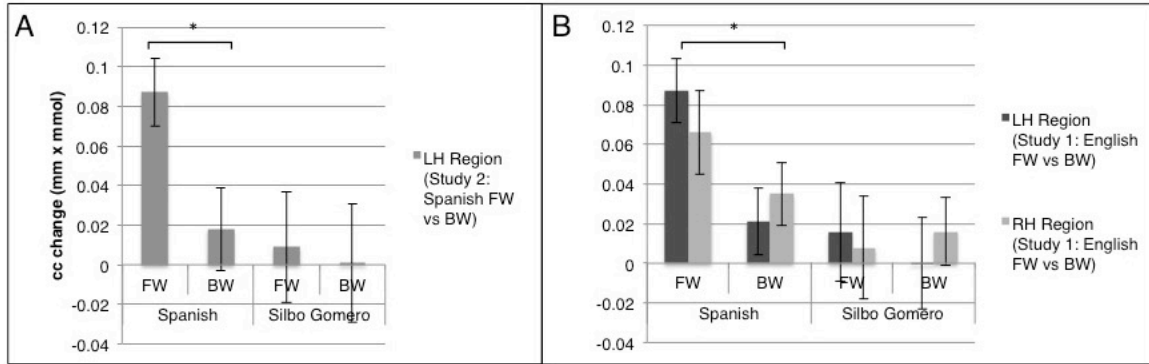
**Figure 4.** Time course results for Study 1. Activation to English and Spanish is shown in channels identified as regions of interest with greater activation to forward versus backward English.



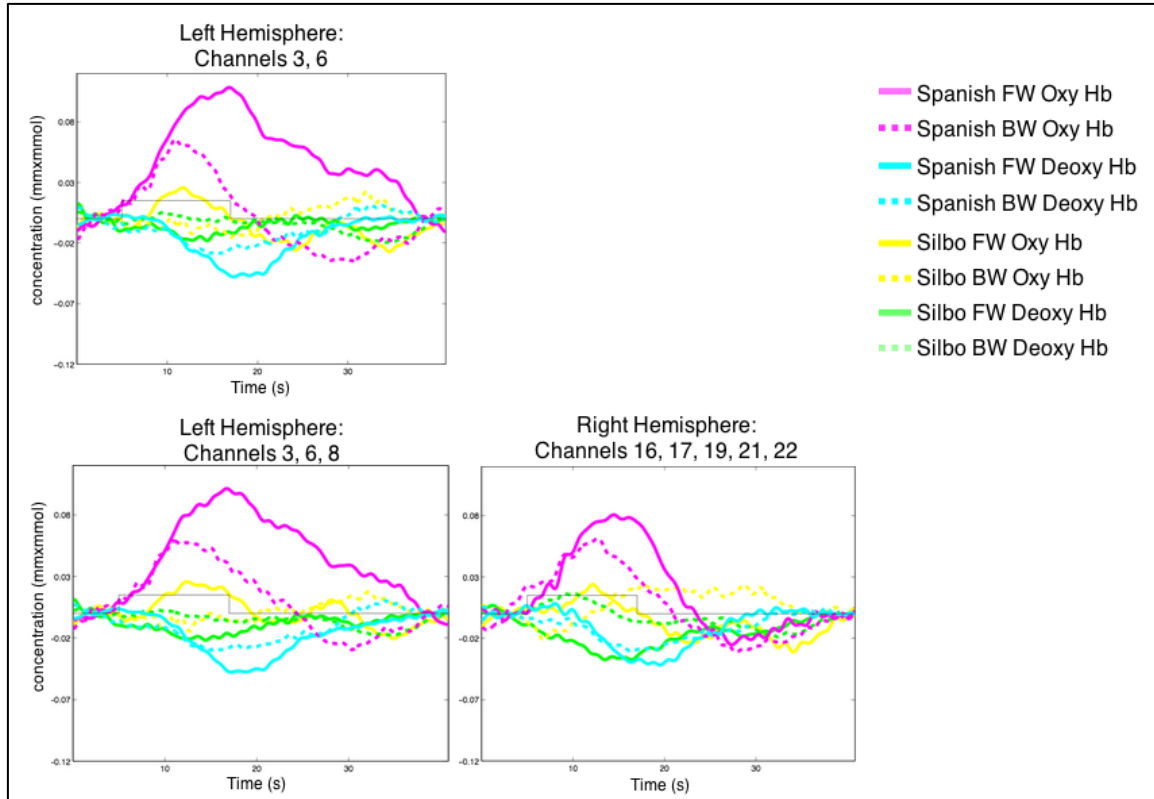
**Figure 5.** Samples of Spanish and Silbo Gomero waveforms and spectrograms. Two sets of samples are presented: A) Spanish and Silbo Gomero samples matched for content, “*el leñador*” (the woodcutter), B) Spanish and Silbo Gomero samples matched for length (1.87 seconds), Spanish: “*hace mucho tiempo, un leñador y su*” (a long time ago, a woodcutter and his), Silbo: “*hace mucho tiempo*” (a long time ago). In the Spanish spectrograms, five formants are apparent (starting with the lowest: F1, F2, F3, F4, and F5). In the Silbo Gomero spectrograms, what can be seen is the first harmonic (H1) ranging from about 1200 to 2700 Hz, as well as 2-3 additional harmonics above. Here, H1 determines fundamental frequency as well as vowel differentiation, as it is the only harmonic loud enough to be heard under normal conditions. Comparing across the two signals, it can be said that H1 is essentially a transposition of the spoken F2 contour in Spanish. For further information on the acoustic and phonetic structure of Silbo Gomero, see Rialland (2005).



**Figure 6.** Area of interest identified in the permutation analysis as showing significantly greater activation to forward versus backward Spanish in Study 2 are highlighted in red, and located on a neonate MRI template.



**Figure 7.** Changes in oxygenated hemoglobin to Spanish and Silbo Gomero as observed in Study 2. Figure A illustrates results from analyses using as the region of interest the left hemisphere cluster of channels shown to have significantly greater activation to forward versus backward Spanish in Study 2. Figure B illustrates results from analyses using the regions of interest identified in Study 2, as clusters of channels showing significantly greater activation to forward versus backward English in Study 1.



**Figure 8.** Time course results for Study 2. The top figure shows activation to Spanish and Silbo Gomero in channels identified as regions of interest responding to forward versus backward Spanish in Study 2. The bottom figures show activation to Spanish and Silbo Gomero in channels identified as regions of interest responding to forward versus backward English in Study 1.