Modality-Independent Neural Mechanisms for Novel Phonetic Processing

Joshua T. Williams^{1,2,3,*}, Dr. Isabelle Darcy^{2,5}, Dr. Sharlene D. Newman^{1,2,4}

¹Department of Psychological and Brain Sciences, ²Program in Cognitive Science, ³Speech and Hearing Sciences, ⁴and Program in Neuroscience, ⁵Second Language Studies, Indiana University

***Corresponding Author**

Joshua Williams

Address: Cognitive Neuroimaging Laboratory, Indiana University, 1101 E. 10th Street,
Bloomington, IN, 47405.

Phone: +1-812-856-1776

Email: willjota@indiana.edu

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Abstract

The present study investigates whether the inferior frontal gyrus is activated for phonetic segmentation of both speech and sign. Early adult second language learners of Spanish and American Sign Language at the very beginning of instruction were tested on their ability to classify lexical items in each language based on their phonetic categories (i.e., initial segments or location parameter, respectively). Conjunction analyses indicated that left-lateralized inferior frontal gyrus (IFG), superior parietal lobule (SPL), and precuneus were activated for both languages. Common activation in the left IFG suggests a modality-independent mechanism for phonetic segmentation. Additionally, common activation in parietal regions suggests spatial preprocessing of audiovisual and manovisual information for subsequent frontal recoding and mapping. Taken together, we propose that this frontoparietal network is involved in domain-general segmentation of either acoustic or visual signal that is important to novel phonetic segmentation.

Introduction

Our understanding of language processing has grown considerably since neuroimaging came to the forefront, and has been significantly refined by examining not only aural spoken languages but also manual sign languages. The study of sign languages contributes to a greater understanding of language universals and modality-independent and -dependent neurocognitive mechanisms (Peoppel, Emmorey, Hickok, & Pylkkanen, 2012; Sandler & Lillo-Martin, 2006). Today, we understand that the brain processes spoken and sign languages in many of the same ways (Emmorey, 2002; MacSweeney, Capek, Campbell, & Woll, 2008). A goal of the present study was to expand our understanding of modality-independent neural mechanisms for processing phonetic information of language. To do so, effective monolinguals (or very beginning second language learners) were examined in order to characterize the neural substrates of phonetic segmentation in novel languages across modalities.

It has long been established that speech is segmented and processed in a left-lateralized network of frontal, temporal, and parietal areas (Geschwind, 1979). The neural processing of speech can be bifurcated into cortical streams through which speech is either mapped onto semantic (i.e., ventral stream) or articulatory (i.e., dorsal stream) representations (Hickok & Poeppel, 2004, 2007). Specifically, speech segmentation has been localized to prefrontal regions such as the inferior frontal gyrus (IFG; Burton, Small, & Blumstein, 2000, Zatorre, Evens, Meyer, & Gjedde, 1992; Zatorre, Meyere, Gjedde, & Evens, 1996).

There is a growing literature that suggests that Broca's area is not wholly linguistic. Instead, Broca's area is involved in many higher-order, domain-general cognitive processes. For example, relationships between action sequence processing and the left IFG have been reported (Fazio et al., 2010; Clerget, Winderickz, Fadiga, & Oliver, 2009). These studies suggest that

Broca's area is involved in the sequential and hierarchical processing of goal-directed movement. Additionally, Dominey et al (2003) has proposed that language processing is in part predicated on the ability to extract and use sequential structure. Broca's area has also been implicated in other non-linguistic tasks, such as music processing. For instance, Tillman et al. (2003) investigated the neural correlates of music processing in a priming study. Their imaging results indicated that there were higher levels of activation in the IFG for unrelated prime-target pairs, which is taken to mean that the IFG is involved in the processing and integration of sequential information over time (see also Fadiga, Craighero, & D'Ausilio, 2009 for a review).

Given evidence of IFG activation for both speech and nonspeech information, some have argued that the IFG is responsible for separating auditory stimuli for further processing and may not be specific to speech itself (Burton, 2009; LoCasto et al., 2004). Together, activation of prefrontal cortex for speech and nonspeech segmentation leads us to question whether the IFG may be responsible for multimodal integration. Perhaps the study of phonetic segmentation in different language modalities (i.e., sign versus spoken) can shed light on the modality-specificity of IFG activation.

American Sign Language (ASL) is a natural language that is primarily produced and perceived in a sensorimotor language modality (i.e., manual-visual) different from spoken languages. Sign languages, like other natural languages, possess all of the same linguistic characteristics of spoken language (e.g., phonology, morphology, syntax, semantics; Sandler & Lillo-Martin, 2006). ASL phonology includes at least three major phonetic features: handshape, movement, and location (Liddell & Johnson, 1989; Sandler, 1989; Brentari, 1998). Handshape is the configuration and the selected fingers and joints of the articulating hands during sign production. Movement is the directionality of the hands during sign production. Location is the

place on the body where the sign is being articulated. Together, these three phonetic features must be combined in some manner in order to have a well-formed sign (Brentari, 1998). These features are analogous to those of spoken phonology where the features include voicing and place and manner of articulation, which describe the amount and, type of air flow constriction in the vocal tract. Given that the phonetic structure of sign languages diverges in modality from that of spoken languages, one might question the amodal nature of phonetic processing within the brain. However, cross-modal phonetic features are related to the perception of motor actions and therefore, overlap in processing may also be expected.

Numerous studies over the last two decades have shown that languages are processed similarly in the brain, regardless of language modality. For instance, multiple studies have shown that sign languages are processed in a left-lateralized language network, similar to that of spoken languages (Campbell, MacSweeney, & Waters, 2008; Corina, Vaid, & Bellugi, 1992; MacSweeney et al., 2008). Broca's (i.e., inferior frontal gyrus) and Wernicke's (i.e., posterior superior temporal gyrus) areas are activated for both sign and spoken language processing (Campbell et al., 2008; Emmorey, 2005; Emmorey et al., 2003; Emmorey, Mehta, & Grabowski, 2007; MacSweeney et al., 2002, 2006, 2008). Evidence from these same studies have found that deaf signers activate perisylvian areas, which are classically thought to be involved in auditory processing, when perceiving sign language. Additionally, studies have shown parietal (e.g., supramarginal gyrus, superior parietal lobule) activation for signs for both hearing and deaf signers (Emmorey et al., 2003; Emmorey, 2005; Capek et al., 2008). From these studies, the parietal lobe has been thought to combine spatial features that are essential to phonological processing in signed language for all signers (Mayberry, Chen, Witcher, & Klein,

2011). Together, these studies have shown a consistent pattern of activation for both spoken and sign languages in monolingual populations.

In the present study, we aimed to investigate whether prefrontal regions (e.g., inferior frontal gyrus) are responsible for amodal phonetic segmentation. Given evidence that the inferior frontal gyrus segments multimodal information, including speech, nonspeech, tones, music, actions, and signs, it is important to empirically test its amodal processing explicitly. Given that learners of a second language at the beginning level have little phonological (as well as grammatical) knowledge of the target language, like true monolinguals, they provide an interesting population to investigate phonetic segmentation. That is, they must learn to segment incoming linguistic information to form phonological categories (see Best & Tyler, 2007 for L2 phoneme category learning). Thus, we used absolute beginning learners of Spanish and American Sign Language from a larger longitudinal study to test the neural activation to words that differed based on their phonetic categories (i.e., initial phoneme or location parameter for Spanish and ASL, respectively) before they started to learn the language. In this way, we were able to investigate 1) whether phonetic segmentation of an unknown language elicited activation in prefrontal regions, and 2) whether similar patterns of activation were seen across languages in different modalities.

Results

Behavioral data

The accuracy data were analyzed using an analysis of variance (ANOVA) with Language (English vs. ASL vs. Spanish) as the within-subjects factor and Length of Instruction as a covariate. All subjects were analyzed because they were all considered effective monolinguals and as such should not perform differently across groups. There was a significant

main effect of Language [$F(2,72) = 6.634, p < 0.01$, eta-squared = 0.156; English: 86.23% (19.6); ASL: 88.97% (22.66); Spanish: 79.40% (23.83)]. There was no significant interaction between Language and Length of Instruction [$F < 1$]. Post-hoc t-tests indicated that there was no significant difference between performance on the ASL and English tasks [$t(38) = 1.263, p = 0.214$], but Spanish was significantly lower than both ASL [$t(38) = 4.972, p < 0.001$] and English [$t(38) = 3.112, p < 0.01$].

The reaction times only on correct trials were included in the same ANOVA as above with length of instruction as a covariate. There was a significant main effect of Language [$F(2,72) = 7.678, p < 0.001$, eta-squared = 0.172; English: 1932 ms (468); ASL: 1680 ms (482); Spanish: 1801 ms (573)]. There was no significant interaction between Language and Length of Instruction [$F < 1$]. Planned t-tests revealed no differences in reaction times for English and Spanish [$t(38) = 1.550, p = 0.130$] and Spanish and ASL [$t(38) = 1.690, p = 0.099$]; however, ASL was significantly faster than English [$t(38) = 6.632, p < 0.001$].

fMRI data

<Figure 1 about here>

<Table 1 about here>

English stimuli significantly activated the occipital lobe including the left cuneus and occipital-temporal regions like the left fusiform gyrus. English also activated temporal regions including the left superior temporal gyrus and right middle temporal gyrus. The right angular gyrus, as well as the superior parietal lobule, was also activated. ASL stimuli significantly activated similar occipital regions such as the left precuneus and right middle occipital gyrus and similar parietal regions including the left superior parietal lobule. Additionally, there was

activation of frontal regions, including left inferior frontal gyrus and middle frontal gyrus. Spanish elicited greater activation across the cortex, especially in frontal and temporal areas. Frontal activation included bilateral inferior frontal gyrus and left superior frontal gyrus. Temporal activation included left insula, bilateral superior temporal gyri, and left middle temporal gyrus. Similar occipital and occipitotemporal activation was observed in the left cuneus and right lingual gyrus. Spanish uniquely activated the left crus of the cerebellum as well.

Conjunction

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In order to further delineate the common activation across the novel languages and language modalities, a conjunction analysis was performed between activation to ASL and Spanish stimuli. The conjunction analysis indicated that there was significant activation for both ASL and Spanish in the left precuneus (BA 19), superior parietal lobule (BA 7), and inferior frontal gyrus (BA 44). Additional conjunction analyses were performed to further investigate if the overlapping activation between the novel languages was due to modality or novelty. Thus, activation was compared between English (L1) and both of the novel language (ASL and

Spanish). Conjunction analyses indicated that visual areas were common for all three languages (i.e., left cuneus for Spanish and right primary visual cortex for ASL). Additionally, there was significant activation in the left superior parietal lobule for English and Spanish. Unlike the conjunction between Spanish and ASL, there was no significant activation in IFG. A post-hoc reduction of the extent threshold to 20 voxels indicated a relatively small amount of IFG activation in English [-52, 28, 10] (as well as other temporal and occipital-temporal regions). We did not include length of instruction as a covariate in the aforementioned functional analysis since the behavioral data did not significantly vary with length of instruction; however, a post-hoc examination of activation co-varied with length of instruction also did not change the results.

General Discussion

The goal of the present study was to examine neural activation in response to novel languages in different language modalities. To this end, effective monolinguals viewed various lexical items in both Spanish and American Sign Language (ASL) and performed a phonetic discrimination task. Additionally, all participants performed this task in their first language. The results indicated similar activation in left prefrontal areas for Spanish and ASL, despite the divergence in their language modality. Activation in prefrontal language areas is particularly surprising given that these participants had minimal exposure these languages. Additionally, there was no significant activation in the region in response to native language processing. In addition to left prefrontal activation, there was common left superior parietal activation in response to all languages. Together, these findings provide insights into modality-independent

processes that underlie language segmentation and processing, which is proposed to be more generally related to action perception and sequencing.

IFG Activation

Activation in left prefrontal regions, specifically the left inferior frontal gyrus (IFG), has long been implicated in language processing (Geschwind, 1979). Specifically, the left IFG has been implicated in speech processing such that incoming acoustic speech signals are mapped onto articulatory representations (Hickok & Peoppel, 2004, 2007; Zatorre et al., 1996). Thus, it has been argued that phonetic segmentation and phonological processing may reside in inferior frontal regions (Burton, 2001; Burton, Small, & Blumstein, 2000; Zatorre et al., 1992, 1996; Newman et al., 2001). A meta-analysis of several neuroimaging studies of the neural substrates of phonological processing linked phonological processes to the posterior, superior portion of the left IFG, which is functionally separated from areas responsible for syntactic processing (Burton, 2001).

Additionally, studies investigating the perception (Corina et al., 2007; Emmorey et al., 2010) and production (Braun et al., 2001; Corina et al., 1999) of sign language have shown activation in the left IFG. It has been argued that perhaps the left IFG is involved in multimodal perception and action (Skipper et al., 2005). In other words, it seems that the region is involved in the discrimination and segmentation of multimodal information that can be recoded and mapped onto articulatory-motor representations.

As such, the findings from the present study positively contribute to this interpretation: the activation of the left posterior, superior regions of IFG during phonetic processing of novel languages by effective monolinguals suggests that the left IFG may be involved in segmenting

incoming linguistic/phonetic information. Importantly, similar activation for the segmentation of both Spanish and ASL suggests that the IFG processes multimodal information. In other words, the IFG seems to be involved in amodal phonetic processing.

The activation observed in the left IFG may not be linguistic in nature, even though it was elicited by linguistic stimuli. Recently it has been argued that left prefrontal activation may not be specific to speech (Burton & Small, 2006) but it is instead important for discrimination and segmentation for both speech and nonspeech (including tones (Müller et al., 2001) including music (Maess, Koelsch, Gunter, & Friederici, 2001; Tillmann, Janata, & Bharucha, 2003). So while Broca's area (i.e., left inferior frontal gyrus) has long been considered a quintessential language-specific processing region, it may not be a language-specific area.

There is a growing literature related to action sequence processing and the left IFG, particularly the posterior, superior portion (Fazio et al., 2010; Clerget et al., 2009). These studies suggest that the region is involved in the sequential and hierarchical processing of goal-directed movement. Additionally, Dominey et al (2003) has proposed that sequential cognition, the ability to extract and use sequential structure, plays a significant role in language processing, including both phonology and syntax. Therefore the area is responsible for domain-general sequencing and processing of hierarchical dependencies (Fadiga, Craighero, & D'Ausilio, 2009; Fadiga & Craighero, 2006; Müller & Basho, 2004; Rizzolatti & Arbib, 1998). The present task was aimed at tapping amodal linguistic processing; however, the phonetic information can be considered to be novel actions unrelated to language given that these participants had no previous experience with either Spanish or ASL.

In addition to the IFG activation possibly being due to the sequential processing related to phonetic processing, it is also possible that using finger responses to the stimuli activated the

IFG (Müller & Basho, 2004). The left IFG has been shown to be activated during action observation and execution in both primates and humans (Gerlach, Law, & Paulson, 2002; Kellenbach, Brett, & Patterson, 2003; Rizzolatti & Arbib, 1998). Lesions to the left IFG also impair patients' abilities to understand the details of actions (Tranel et al., 2003). As Müller and Basho (2004) argue, the region is involved in many nonlinguistic functions that are prerequisites for language acquisition and processing. We should note that the left IFG has also been shown to be activated during motor tasks, such as the finger responses during our task (Müller & Basho, 2004). However, it is unlikely that the activation observed here is due to the finger movements necessary for responding given that there was no such common IFG activation for English and the novel languages despite similar visuomotor responses across the language conditions. As such, the findings from the present study support the claim that the left IFG is involved in amodal (i.e., domain-general) action sequencing and segmentation, which can be bootstrapped for cross-linguistic phonetic segmentation.

Parietal Activation

Results also indicated common activation of the left superior parietal lobule (SPL) during phonetic discrimination in all languages. The SPL has been conventionally associated with spatial-motor behavior (Grafton et al., 1996; Grefkes et al., 2004) and audiovisual and multisensory integration (Molholm et al., 2006). Additionally, the parietal lobe (including the superior parietal lobule) has been shown to be activated during sign language comprehension and production (Corina & Knapp, 2006; Emmorey et al., 2002, 2003; MacSweeney et al., 2002). SPL activation in the present study for both audiovisual and manuovisual phonetic discrimination support these findings. Additionally, it contributes to our understanding of

language modality-independent mechanisms insofar as the parietal cortex is involved in spatial-linguistic processing, whether the discrimination is from the lips or the hands.

Interestingly, there was another significant cluster of activation in the parietal-occipital regions, more inferior to the SPL cluster for ASL and Spanish (i.e., novel language), but not for English (i.e., native language). This region was part of the left precuneus activation seen in the conjunction analysis. Similar to SPL, the precuneus has been associated with spatial attention and processing (Cavanna & Tribble, 2006; Culham et al., 1998; Le et al., 1998; Wallentin et al., 2007). Activation in both the left SPL and precuneus for novel audiovisual and manuovisual tasks indicates greater need for spatial attention and processing for visuophonetic discrimination, particularly for unfamiliar languages.

The co-activation of frontal and parietal regions is not uncommon. The precuneus has been shown to have projections to frontal cortices, especially BA 44 (Cavanna & Tribble, 2006). The co-activation of inferior frontal and parietal regions in this task imply similar mechanisms for audiovisual spoken language and manuovisual sign language processing. Specifically, visuophonetic information (from either the hands or mouth) is first spatially processed in the parietal region and subsequently sent to frontal cortices to be segmented and abstracted for linguistic processing.

In the present study, we have shown that there are modality-independent mechanisms for language processing. Specifically, the left inferior frontal gyrus, superior parietal lobule, and precuneus are activated for both audiovisual (i.e., spoken language) and manuovisual (i.e., sign language) phonetic processing. The left inferior frontal gyrus may be involved in segmenting phonetic information regardless of the modality of the input and the segmentation process becomes more efficient with increased language proficiency. The superior parietal lobule and

precuneus may also integrate and process multisensory information across language modalities. Co-activation of frontoparietal cortices during novel phonetic discrimination may indicate a connected network of brain regions involved in modality-independent language processing, or, more specifically, domain-general action sequencing and segmentation that are required for linguistic processing.

Experimental Procedure

Participants

Thirty-nine (male = 7) hearing English-speaking college students participated in this study. All participants were right-handed according to the Edinburgh Handedness scale ($M = 82.6$, $SD = 20.1$). Their mean age was 20 years and 3 months (range 19-30 years). All participants reported English as their first language. These participants were part of a larger longitudinal study that tracked neural changes due to second language acquisition. The participants in this study were recruited from introductory semester Spanish ($n = 6$) and American Sign Language courses ($n = 33$) at Indiana University. The participants had little to no exposure to Spanish or ASL before enrollment in these courses and had on average 1.06 (range = 0 – 5, $SD = 1.49$) hours of instruction. According to course instructors, the instruction in the first week of classes included introduction to the course, the target language and culture, but little linguistic instruction. Furthermore, most to all instruction was conducted in English during the first week. For these reasons, we consider the following subjects “effective monolinguals”, or absolute beginning learners. That is, these participants had minimal to no linguistic knowledge of the target languages, which would not benefit them in processing the

language. All participants gave written consent to perform the experimental tasks, which was approved by the Indiana University Institutional Review Board.

Experimental Design

The participants were tested in three languages: English (L1), Spanish, and ASL. Each experimental task was composed of 30 trials and lasted approximately 9 minutes, for a total of 30 minutes. For the spoken languages (i.e., English and Spanish), participants viewed a native speaker saying various words in either English or Spanish. The speaker's full face and torso were shown in front of a blue-gray backdrop. All stimuli were high frequency monomorphemic words from various word classes (i.e., nouns, verbs, adjectives). All stimuli were constrained to four phones in length. Half of the stimuli began with labial sounds (i.e., bilabial and labiodental; e.g., /m/, /p/, /b/, /f/, /v/); the other half started with non-labial sounds (i.e., alveolar, velar, and liquid; e.g., /k/, /g/, /s/, /t/, /l/). Additionally, the second set of stimuli did not contain bilabials in the word (except for *come* in English; refer to the Appendix for a table of the stimuli).

For sign language, participants viewed a native signer signing words from the same word classes as above. However, signs were split into two groups: signs with place of articulation (i.e., location) on the head or face and signs with the location on the body, non-dominant hand, or neutral space (i.e., not on the face). By splitting the signs into these two conditions, we were able to force participants to phonetically process the signs by attuning to the location phonetic feature. Additionally, this design was selected to provide the same visual input across the languages and to match for a similar perceptive task while processing the languages. Moreover, this design required subjects to segment the words and signs based on a similar, cross-linguistic phonetic/phonological feature (e.g., place of articulation).

The functional task was presented in an event-related design. For each trial a 500-millisecond fixation point was presented before the video appeared. Each stimulus video varied in duration ($M = 1593.33$, $SD = 2.53$ ms) and was followed by a jittered interstimulus interval (ISI range = 4000 – 8000, $M = 6000$ ms). Participants were told to press the right index finger for words that began with a visible phone (i.e., labial sounds) or signs that were produced on the face, and to press the left index finger for words that began with phones not visible on the lips (i.e., alveolar, velar, or liquid) or signs that were produced on the body. They were instructed to make their responses as quickly and accurately as possible. In addition to the ISI, a 30 second fixation was presented at the beginning of the task and was used as a baseline.

Imaging Parameters

Participants underwent 4 scans using a 32-channel head coil and a Siemens 3 Tesla TIM Trio MRI scanner. The first scan was an anatomical T1-weighted scan used to co-register functional images. An MPRAGE sequence (160 sagittal slices; FOV = 256 mm, matrix = 256x256, TR = 2300 ms, TE = 2.91 ms, TI = 900 ms, flip angle = 9°, slice thickness = 1 mm, resulting in 1-mm × 1-mm × 1-mm voxels) was used. The remaining scans were the experimental functional multiband EPI scans (59 axial slices using the following protocol: field of view = 220 mm, matrix = 128x128, iPAT factor = 2, TR = 2000 ms, TE = 30 ms, flip angle = 60°, slice thickness = 3.8 mm, 0 gap).

Data analysis

Data was analyzed using SPM8 (Wellcome Imaging Department, University College, London, UK, freely available at <http://fil.ion.ucl.ac.uk/spm>). During preprocessing images were

corrected for slice acquisition timing, and resampled to $2 \times 2 \times 2 \text{ mm}^3$ isovoxels, spatially smoothed with a Gaussian filter with a 4 mm kernel. All data was high-pass filtered at 1/128 Hz to remove low-frequency signals (e.g., linear drifts). Motion correction was performed and motion parameters incorporated into the design matrix. Each participant's anatomical scan was aligned and normalized to the standardized SPM8 T1 template and then fMRI data was co-registered to anatomical images. At the individual level, statistical analysis was performed using the General Linear Model and Gaussian random fields. The video onsets and durations were entered as regressors in the model (Friston et al., 1995). For the second level (random effects) analysis on group data, a conjunction analysis was performed using a one-way analysis of variance assuming dependence between scans. Thresholds for the functional contrasts were set to an uncorrected p -value of 0.001 with an extent threshold of 80 voxels (which was above the cluster extent for multiple comparisons as calculated by 5000 Monte Carlo simulations).

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Appendix

A1. Stimuli for phonetic classification task.

Frontal Phonemes		Back Phonemes		Head	Not Head
English				ASL	
band	/bænd/	kids	/kɪ dz/	HOME	TIME
born	/bɔ ɹ n/	land	/lænd/	DRINK	NIGHT
bank	/bæŋk/	gold	/gold/	FOOD	WORK
bend	/bɛ nd/	last	/læst/	PARENTS	HAPPY
belt	/bɛ lt/	come	/kʌ m/	BORED	TOILET
film	/fi lm/	sold	/sold/	MISS	WEEK
park	/pɑ ɹ k/	card	/kɑ ɹ d/	SEARCH	SORRY
post	/post/	lost	/lɒ st/	CANDY	MILK
plan	/plæn/	sink	/sɪ ŋk/	DEAF	PLAY
mark	/mɑ ɹ k/	size	/sajz/	SICK	SAME
mute	/mjut/	told	/told/	MAN	FEEL
pump	/pʌ mp/	coast	/kost/	WOMAN	LIFE
mint	/mɪ nt/	star	/sta ɹ /	GIRL	GAME
vent	/vɛ nt/	tent	/tɛ nt/	BOY	SCHOOL
plus	/plʌ s/	send	/sɛ nd/	LAUGH	HARD
Spanish					
bebe	/beβe/	tren	/tr en/		
bien	/bjen/	caer	/kaer /		
boca	/boka/	casa	/kasa/		
frio	/fr ijo/	gato	/gato/		
foto	/foto/	nada	/naða/		
mesa	/mesa/	todo	/toðo/		
vaso	/baso/	seco	/seko/		
bajo	/baxo/	atun	/atun/		
vaca	/baka/	azul	/aθul/		
bota	/bota/	calle	/kaʎ e/		
flor	/flor /	cara	/kar a/		
mano	/mano/	dedo	/deðo/		
mono	/mono/	duro	/dur o/		
pelo	/pelo/	hoja	/oxa/		
beso	/beso/	jugo	/xuɣ o/		

Figure Captions

Figure 1 depicts activation in response to each language --- English (top), ASL (center), and Spanish (bottom) --- during a phonetic classification task. Activation for each contrast was set at an uncorrected $p < 0.001$ with a cluster extent threshold of 80, which is above the extent corrected for multiple comparisons determined by 5000 Monte Carlo simulations.

Figure 2 depicts common regions of activation from three separate conjunction analyses --- ASL and Spanish (top), English and Spanish (center), and English and ASL (bottom) --- during a phonetic classification task. Activation for each contrast was set at an uncorrected $p < 0.001$ with a cluster extent threshold of 80, which is above the extent corrected for multiple comparisons determined by 5000 Monte Carlo simulations.

Figure 3 demonstrates activation to English during the phonetic classification task when the cluster extent threshold was lowered to 20. This post-hoc investigation determined if IFG activation was specific to novel languages or to general phonetic segmentation in general.

Figure 1

Figure 2

ASL + Spanish

English + Spanish

English + ASL

Figure 3

$k = 20$

-52 28 10

Table 1 *Activation for each target language. ($p < 0.001$; $k = 80$)*

Cerebral regions (Brodmann Area)	No. of voxels	Coordinates (MNI)		
		<i>x</i>	<i>y</i>	<i>z</i>
English				
L cuneus (BA 18)	1345	0	-80	36
R angular gyrus	338	32	-54	40
L fusiform gyrus (BA 37)	193	-40	-52	-24
L superior parietal lobule (BA 7)	146	-28	-70	54
L superior temporal gyrus	107	-58	-42	6
R middle temporal gyrus	106	56	-6	-12
ASL				
L precuneus	175	-26	-82	36
L inferior frontal gyrus (BA 46)	127	-48	32	18
L middle frontal gyrus	118	-34	-10	50
R middle occipital gyrus	116	26	-94	14
L posterior cingulate gyrus	102	-4	-34	38
L superior parietal lobule (BA 7)	94	-32	-64	58
Spanish				
L insula	1682	-26	24	4
L supplementary motor area	539	0	10	60
R inferior frontal gyrus (BA 46)	349	52	28	20
L superior temporal gyrus	297	-56	-52	18
L superior frontal gyrus	292	-34	52	18
L cuneus (BA 18)	252	-2	-100	0
R superior temporal gyrus	234	52	-38	8
L superior parietal lobule (BA 7)	198	-24	-68	48
L precuneus	198	-26	-80	30
R precuneus (BA 7)	176	8	-76	36
L middle temporal gyrus	154	-62	-8	-8
R lingual gyrus	101	14	-92	-4
L crus	91	-8	-74	-34

Table 2 *Conjunction Analyses ($p < 0.001$; $k = 80$)*

Cerebral regions (Brodmann Area)	No. of voxels	Coordinates (MNI)			
		<i>x</i>	<i>y</i>	<i>z</i>	
ASL & Spanish					
L precuneus	131	-28	-80	34	
L superior parietal lobule (BA 7)	131	-28	-72	50	
L inferior frontal gyrus (BA 46)	101	-46	26	16	
English & Spanish					
R lingual gyrus (BA 17)	103	14	-94	-4	
L cuneus	154	-12	-96	-2	
L superior parietal lobule (BA 7)	86	-24	-70	50	
English & ASL					
R primary visual cortex (BA 17)	93	16	-96	-4	