INTRODUCTION TO RESUBMISSION APPLICATION

This is a resubmission of F31 HD087085-01 reviewed October 2015. As a Ph.D. candidate, I am grateful for the opportunity to present this revised application and thank you for your valuable time in reviewing this application. I have worked earnestly to address all concerns raised by each reviewer. My research strategy and training plan are now more robust, with important clarifications. Changes in the application are [[bracketed]].

Strengths. Panel members rated this proposal as "excellent," expressing "high levels of enthusiasm." Reviewers highlighted this study's "highly significant topic" incorporating linguistic, educational, and neuroscientific viewpoints, and noted its "clearly articulated hypotheses." They also commended the selection of Dr. Petitto as my sponsor and my "superb" academic and scientific environment at Gallaudet University. Also noted were my "excellent" candidacy, "extensive background in neuroscience," high levels of motivation, "clear goals," and my "impressive" publication record. I thank you for the comments. I have built upon these strengths, publishing a first-authored study in PLoS ONE (Stone et al., 2015), resubmitting a major theory paper with Dr. Petitto (Petitto et al., under 2nd review), and submitting one behavioral paper (Williams et al., under 1st review). I have advanced my fNIRS methodological, analytical, and training skills, including the delivery of a month-long fNIRS training program to University of Hong Kong faculty in Summer 2015 (funded by NSF) and the creation of fNIRS analysis video tutorials for open source use.

Concerns. Reviewers noted "minor weaknesses," addressed here and within the application. **(1) fNIRS Spatial Resolution:** One reviewer noted fNIRS' relative lack of spatial resolution compared to fMRI. This is a traditional misunderstanding of fNIRS capabilities. Modern advances in 3-D head mapping and NIRS-SPM now permit systems and localization analyses of neural activity to the gyrus level, even in infants (Petitto, 2007, 2009; Petitto et al., 2012). fNIRS possesses temporal resolution superior to fMRI, excellent spatial resolution, the ability to track the time course of neural activity across hemispheres via measurements of both blood oxygenation and de-oxygenation, and a decade of studies consistently identifying STG activity in infants and adults (including fMRI/MRI and fNIRS neuroanatomical co-registration; Kovelman et al., 2008). Selection of the most appropriate measurement tool in science is crucial and, compared to fMRI, fNIRS is the more optimal tool for the study of *infant brain development over time*. **(2) Probe Placement:** Reviewers noted contradictions between Research Strategy Figure 2b illustrating placement of fNIRS probe arrays on the temporal lobes, and text discussing the occipital lobe (V1). I apologize for this confusion and have clarified that the only areas discussed here are the bilateral temporofrontal cortices. **(3) Hearing, Language, & Aphasia:** Reviewers suggested additional coursework and training in neural bases of hearing and aphasias. A current core class (by Dr. Guinevere Eden), "Guided Studies III: Theory," involves producing a 10,000-word review manuscript discussing the functions of STG/Wernicke's area, the auditory cortices, and related tissue in language processing in neonates and infants, and in signing vs. non-signing adults. Recently, I participated in clinical observations of aphasic deaf signing adults at Gallaudet's Hearing & Speech Center. In Spring 2016, I will take "Brain & Language" at Georgetown University, which will further my knowledge. **(4) Implications for Phonology Acquisition:** The proposed study addresses if humans are born with neural tissue dedicated to acquisition of phonology, and clarifies on a modality-free level, how this tissue may interact with auditory or visual functions. This will help us better understand which linguistic capabilities infants possess in the beginning of life and, in turn, to identify on a neural level children at risk of phonology-based disorders. **(5) Contributions:** My research objectives focus on the neural bases of language in deaf and hearing infants. I am fortunate to work with my advisor, Dr. Petitto, whose laboratory and funding cover this same topic, permitting me to receive top-notch training in the theoretical areas in which I seek to excel, and to conduct this proposed study. Dr. Petitto has supported me in conceptualizing and designing this proposed study. However, as a deaf neuroscience student scholar (and recently awarded a Fellow in the Society for Neuroscience's Neuroscience Scholars Program), I also bring unique life experiences and knowledge to Dr. Petitto's research program in the form of perspectives on neuroplasticity in the human brain and the impact of experience-dependent changes to neural structure and processing. **(6) Differential Responses to Stimuli:** One reviewer remarked on "insufficient attention to differences in response to linguistic stimuli across deaf and hearing samples that may be attributed to modality alone." I emphasize we *do not* predict differences among 6-month-old infants based on hearing status, since babies continue to exhibit universal phonetic discrimination abilities at this age; attenuation to one's own phonemic categories begins at around 10 months. To discover differences in hemodynamic activity in temporal lobes based on hearing status would be a remarkable finding indicating that experience-based changes begin much earlier than theorized. **(7) Goal Specifications:** One reviewer noted my Training Plan lacked "specification" of my long-term goal of becoming an independent academic in Educational Neuroscience. This is now clarified.

Conclusion. I believe this revised proposal, detailing a first-ever developmental neurobiological investigation of visual language, will meet your highest standards and help us understand how all infants begin life with brain mechanisms predisposed for discovering the core parts of their languages. Thank you for your consideration.

GALLAUDET UNIVERSITY | BRAIN AND LANGUAGE LABORATORY

[[December 13, 2015]]

To Whom It May Concern:

Please find enclosed my [[resubmission of application F31 HD087085-01 (reviewed October 2015)]] for a Ruth L. Kirschstein National Research Service Award for Individual Predoctoral Fellowships to Promote Diversity in Health-Related Research (F31), PA-14-148. My proposal, "Neural Systems for Infant Sensitivity to Phonological Rhythmic-Temporal Patterning," is composed of a dissertation-level neuroimaging and eye tracking investigation of how young infants discover the finite set of phonetic units in their native language from the infinite combinations of sensory stimuli surrounding them. The acquisition of phonology in early life has been argued to be vital to healthy language learning, vocabulary growth, and reading success, with delayed language and phonological input in infancy linked to poorer reading, academic, and cognitive outcomes throughout the lifespan. Here, we test multiple hypotheses about the nature and timing of young infants' sensitivities to specific rhythmic-temporal patterning in the input as a mechanism for segmenting and categorizing the constantly varying linguistic stream. We test these hypotheses in infants acquiring sign language and in infants acquiring spoken language. Understanding the young infant's biological sensitivities and brain mechanisms that support their discovery of phonology in any language, signed or spoken, will provide powerful new knowledge of how experience-dependent brain changes provide infants with the neural circuitry necessary for learning phonology and language in any modality. Findings will advance our understanding of how all young children learn language and reading, and will carry important clinical implications for identifying and supporting infants at risk for phonology-based language and reading disorders.

Please assign this application to the following:

Institutes/Centers:
National Institute on Child Health and Human Development– NICHD

I have discussed this project with Dr. Lisa Freund [[and Dr. Ruben Alvarez]]. Both have recommended that my project be assigned to NICHD CDBB. On this basis, please direct my application to Dr. Lisa Freund [[and/or Dr. Ruben Alvarez]]. This project is appropriate for assignment to the NICHD because of its focus on infants and the neurobiological underpinnings of language acquisition. I am also thrilled that NICHD has made it a priority to support biomedical and behavioral research career opportunities for deaf individuals like myself via the NRSA program.

Following is an alphabetical list of referees (full affiliations in application):

1. Steven Pinker, Ph.D., Department of Psychology, Harvard University
2. Ioulia Kovelman, Ph.D., Department of Psychology, University of Michigan
3. Carol Padden, Ph.D., Department of Communication, Dean of Social Sciences, University of California, San Diego
4. Rain Bosworth, Ph.D., Department of Psychology, University of California, San Diego
5. Thomas Allen, Ph.D., Ph.D. in Educational Neuroscience Program, Program Director, Gallaudet University

Thank you for your consideration.

Sincerely,

Adam M. Stone
Ph.D. [[Candidate]], Educational Neuroscience
Gallaudet University

PROJECT TITLE

Neural Systems For Infant Sensitivity to Phonological Rhythmic-Temporal Patterning

SPECIFIC AIMS

Human infants are understood to begin life with a complex of brain mechanisms and sensitivities to environmental and social factors that, together, appear to contribute to our species' unique ability to learn language. However, we are only beginning to understand the nature and development of these brain mechanisms and sensitivities, especially as they contribute to the central question posed here: *How does the infant discover the finite set of phonetic units in their native language from the infinite combinations of sensory stimuli around them?* The acquisition of phonology in early life has been argued to be vital to healthy language learning, vocabulary growth, and reading success, with delayed language and phonological input in infancy linked to poorer reading, academic, and cognitive outcomes.

Background: Cracking the code for how infants discover phonology and its role in early reading has rendered competing hypotheses. One hypothesis proposes that infants are born with sensitivities to specific rhythmic-temporal patterning at the nucleus of human language phonological structure that permits segmentation and categorization of the continuously varying linguistic stream (c.f., Petitto & Marentette, 1991; Maye, Werker, & Gerken, 2002; Petitto et al., 2001a, 2012; Petitto, 2005), with more recent hypotheses suggesting the superior temporal gyrus (STG) to be a key neural site governing this capacity. While the STG plays a central role for adult phonological processing in multiple languages (Buschbaum et al., 2001; Penhune et al., 2003; Petitto et al., 2000; Zatorre et al., 2002), the novel hypothesis is that the STG is the brain mechanism that enables infants' sensitivity to the rhythmic-temporal patterning of maximally contrasting phonetic units (Petitto et al, 2012) and, in turn, makes possible the discovery of elementary phonetic units with which infants engage in statistical learning for vocabulary and syntax acquisition (Aslin, Saffran, & Newport, 1998; Nazzi, Jusczyk, & Johnson, 2000). Sensitivity to rhythmic-temporal patterning may also play a vital role in reading acquisition, because children who have deficits processing such patterns also demonstrate phonological and reading difficulties (Benaisch & Tallal, 2002; Goswami, 2011). While it has been suggested that babies are born with sensitivity to rhythmic-temporal patterns in maximal contrasts at around ~1.5 Hz (Kovelman et al., 2012; Petitto et al., 2001a, 2005), the precise frequencies to which babies are biologically attracted are *unknown*. Further, we do not know if this sensitivity is linked to *only* the pure timing of the signal (*the temporal-general property*), or *also* requires the alternation of maximally contrastive units present in both sign and speech phonology (*the phonology-specific property*) (Brentari, 2001; Ito, 1986).

Cognitive neuroscience has uncovered contradictory findings about infant sensitivity to temporal-general or phonology-specific properties in rhythmic-temporal patterning (Gomez et al., 2014; Minagawa-Kawai et al., 2009; Peña et al., 2003; Obrig et al., 2010; Telkemeyer et al., 2009). Here, the addition of signed language is useful. Signed languages are identical to spoken languages for linguistic organization (Klima & Bellugi, 1979) and are acquired by infants at the same maturational milestones (Petitto & Marentette, 1991; Petitto et al., 2001b). Remarkably, deaf adults recruit the STG during sign phonological processing—the identical neural site traditionally attributed to the processing of sound phonology only (Emmorey et al., 2011; MacSweeney et al., 2008; Penhune et al., 2003; Petitto et al., 2000). Because signed languages are biologically and structurally homologous to spoken languages, they provide an ideal test of the present hypotheses. Past studies have used sound to test whether the properties of sound *(temporal-general)* or language *(phonology-specific)* are most salient for infants. Here, we use sign to extract sound from this equation, disambiguating on a *modality-free level* whether infants are sensitive to general temporal patterns or to specific linguistic phonetic contrasts, providing insights into language acquisition universals.

Aim: To identify whether infants differ in STG recruitment for phonology-specific rhythmic-temporal patterning versus temporal-general rhythmic-temporal patterning. We use integrated functional Near Infrared Spectroscopy (fNIRS) and Tobii eye tracking to examine 40 deaf and hearing infants' response to sign phonetic-syllabic units and moving point-light scenes presented at different frequencies (.5, 1.5, 3 Hz) at a key developmental age, 5-6 months. Hemodynamic response and eye gaze data will be used to adjudicate between the following hypotheses: *(H1 Temporal-General Hypothesis)* Infants are sensitive only to temporal-general properties of rhythmic-temporal patterning presented at 1.5 Hz, with bilateral STG recruitment for both phonetic-syllabic and point-light stimuli. *(H2 Phonology-Specific Hypothesis)* Alternations of maximal contrastive phonological units, presented at an optimal frequency of 1.5 Hz, is important to capture and maintain infants' attention, with left STG activation for phonetic-syllabic units only and not for point-light scenes. We test both deaf infants acquiring sign and hearing infants acquiring speech at 5-6 months, when they are still sensitive to all phonetic contrasts in any language, as to provide the strongest test of the hypotheses (Baker, Golinkoff, & Petitto, 2006; Krentz & Corina, 2008; Petitto et al., 2012; Stone, Bosworth, & Petitto, 2015).

Impact: [[The proposed study addresses if humans are born with neural tissue dedicated to acquisition of phonology, and clarifies on a modality-free level, how this tissue may interact with auditory or visual functions.]] Discovering the elements of rhythmic-temporal patterning to which babies are biologically attracted will advance our knowledge about how babies acquire the core parts of their language, allowing us to support clinicians in identifying on a neural level infants at risk for phonology-based language disorders. Finally, this first-ever developmental neurobiological investigation of signed language perception will permit new understanding of the importance of early visual language experience for learning and reading outcomes in deaf children, and indeed, all children.

RESEARCH STRATEGY

Significance.

What early life experiences are required for optimal language learning and reading success in all children, and especially young deaf and hard of hearing children? More crucially, when do these experiences need to occur? Human infants are understood to begin life with a complex of brain mechanisms and sensitivities to environmental and social factors that, together, appear to contribute to our species' unique ability to learn language. However, we are only beginning to understand the nature and development of these brain mechanisms and sensitivities, especially as they contribute to the central question posed here: *How does the infant discover the finite set of phonetic units in their native language from the potentially infinite combinations of sensory stimuli around them?* The acquisition of phonology in early life has been argued to be vital to healthy language learning, vocabulary growth, and reading success, with delayed language and phonological input in infancy linked to poorer reading, academic, and cognitive outcomes.

Cracking the code for how infants discover phonology and its role in early reading has rendered competing hypotheses. One hypothesis proposes that infants are born with sensitivities to specific rhythmic-temporal patterning at the nucleus of human language phonological structure that permits segmentation and categorization of the continuously varying linguistic stream (c.f., Petitto & Marentette, 1991; Maye, Werker, & Gerken, 2002; Petitto et al., 2001a, 2012; Petitto, 2005). We further suggest that the superior temporal gyrus (STG) is a key neural site that governs this capacity. While the STG plays a central role for adult phonological processing in multiple languages (Buschbaum et al., 2001; Penhune et al., 2003; Petitto et al., 2000; Zatorre et al., 2002), the novel hypothesis here is that the STG is the brain mechanism that enables infants' sensitivity to the rhythmic-temporal patterning of maximally contrasting phonetic units and therefore the discovery of elementary units with which infants may engage in statistical learning for vocabulary and syntax acquisition (Aslin, Saffran, & Newport, 1998; Nazzi, Jusczyk, & Johnson, 2000). While it has been suggested that babies are born with sensitivity to rhythmic-temporal patterns of maximally contrastive phonetic units at around ~1.5 Hz (Kovelman et al., 2012; Petitto et al., 2001a, 2005, 2012), the precise frequencies to which babies are biologically attracted is *unknown*. In addition, we do not know if this sensitivity is linked to *only* the pure timing of the signal (*the temporal-general property*), or *also* requires the alternation of maximally contrastive units present in both signed and speech phonology (*the phonology-specific property*) (Brentari, 1998; Ito, 1986).

Sensitivity to rhythmic-temporal patterning further appears to play a vital role in early reading acquisition, because children who have deficits perceiving these patterns also demonstrate phonological and reading difficulties (Benaisch & Tallal, 2002; Goswami, 2011). These perceptual deficits may actively prevent the child from efficiently segmenting and categorizing the very same phonetic-syllabic segments with which they must use to map onto text as they learn how to read (Ehri, 2014; Kovelman et al., 2012; Harm & Seidenberg, 2004; Jasinska & Petitto, 2013; Ziegler & Goswami, 2005). Recent research supports strong parallels to be drawn in the case of deaf children and how they learn to read. We know that deaf children exposed to sign language early in life are able to form internal representations of *visual* phonology homologous to hearing children acquiring spoken language, composed of *sign* phonetic-syllabic units extracted from the linguistic stream's *visual* rhythmic-temporal patterning (Allen & Enns, 2013; Petitto & Marentette, 1991; Petitto, 2005; Petitto et al., 2012; Stone, Bosworth, & Petitto, 2015). As the young sign-exposed deaf reader approaches the age where they learn to read, they, too, map phonetic-syllabic segments onto print in order to extract meaning from text (McQuarrie & Abbott, 2013; Morford et al., 2011; Petitto, Langdon & Stone, 2015). Deaf children who *do not* have early exposure to signed language in infancy do not receive this vital *visual* rhythmic-temporal patterned input and struggle to construct what are ultimately impoverished internal representations of phonology, leading to weakened abilities to map phonetic-syllabic units onto print, and subsequently, lifelong reading difficulties (Allen & Morere, 2012; Chamberlain & Mayberry, 2008; Knoors & Marschark, 2012; Mayberry & Eichen, 1991; Mayberry, Lock, & Kazmi, 2002; Padden & Ramsey, 1998; [[Petitto et al., under review;]] Strong & Prinz, 1997; Traxler, 2000). Infants' hypothesized sensitivity to rhythmic-temporal patterning may, in fact, be *critical* for healthy language learning and reading success.

A paucity of cognitive neuroimaging studies exists on this topic, with roughly a handful attempting to investigate infant sensitivity to temporal-general and/or to phonology-specific properties in rhythmic-temporal patterning. However, these studies offer contradictory findings. Obrig et al. (2010) and Telkemeyer et al. (2009) investigated infant sensitivity to pure auditory signals that were temporally modulated to mirror linguistic speech on the phonetic level, and found bilateral neural activation (including the left STG, thought to be specialized for phonological processing) for these sounds even though the signal in itself was *not* linguistic and *did not contain* alteration of maximally contrastive units—a finding that supports the temporal-general hypothesis. However, Minagawai-Kawai et al. (2009) found greater left STG neural activation for native vs. non-native speech in infants, suggesting that infants do pay attention to phonological-specific properties *in addition* to the pure timing of the signal. Likewise, Pena et al. (2003) studied neonates' perception of forward and backward speech (such that both contain the *same* timing, but different ordering of alternating maximally contrastive linguistic units) and observed a left STG bias for forward speech only. Gomez et al. (2014) also observed, via

imaging neonates' brains, a greater left STG sensitivity for more well-formed syllables over less well-formed syllables based on changes in sonority values; again, here the timing was similar across conditions but the ordering of maximally contrastive units was different. Infant neuroimaging studies from Petitto et al. (2007, 2009, 2012) also have found activation in the left STG for phonetic contrasts over pure tones but it remains wholly untested whether the STG is selectively sensitive to specific frequencies above others. Together, the few neuroimaging studies, along with behavioral data regarding the timing of infant babbling rhythms (Petitto & Marentette, 1991; Petitto et al. 2001a, 2004), leads to the present hypothesis that the STG possesses a sensitivity to rhythmic-temporal frequencies at around ~1.5 Hz and plays a vital role in the infant's capacity to discover (segment and categorize) the finite set of units that will make up its native language phonology. However, the precise temporal parameters of this critical sensitivity remains unknown, and whether this sensitivity is restricted to all rhythmically patterned stimuli (*temporal-general)* or only to the alternation of maximally contrastive phonetic units present in all human language phonology (*phonology-specific*) is also not known.

Unique Contributions of Proposed Research: The controversy about temporal-general or phonology-specific theories of infant sensitivity to rhythmic-temporal patterning remains vibrant. The present study proposes to offer a new resolution to this debate—one not possible through the study of spoken languages alone. It entails discoveries made possible only through the new lens provided by the study of a soundless language: sign language. Signed languages are naturally evolved human languages with levels of linguistic organization including phonology, morphology, and syntax identical to spoken languages (Klima & Bellugi, 1979). They are acquired by infants at the same maturational milestones (Petitto & Marentette, 1991; Petitto et al., 2001b) and are subject to the same perceptual narrowing of their phonological inventory to their native language in the first year of life as is observed in children acquiring spoken languages (Baker, Golinkoff, & Petitto, 2006; Krentz & Corina, 2008; Palmer et al., 2012; Stone, Bosworth, & Petitto, 2015). Remarkably, deaf adults robustly recruit the left STG during sign phonological processing—the identical neural site traditionally attributed to the processing of sound phonology only (Emmorey et al., 2011; MacSweeney et al., 2008; Penhune et al., 2003; Petitto et al., 2000). Because signed languages are biologically and structurally homologous to spoken languages, they provide an ideal test of the present hypotheses. Past studies have used sound to test whether the properties of sound *(temporal-general)* or language *(phonology-specific)* are more salient for infants. That has introduced a circular logic of using sound to test for sensitivity to sound. Here, we use sign to extract sound from this equation, disambiguating on a *modality-free level* whether infants are sensitive to general temporal patterns or to specific linguistic phonetic contrasts, providing insights into language acquisition universals. A neuroimaging and eye tracking study using signed language would allow us to determine the exact properties of rhythmic-temporal patterning to which all infants are sensitive and the role of brain sites and systems, including the left STG, dedicated to the discovery of phonology in any language.

Here, we ask: *Do infants differ in STG recruitment when processing phonology-specific rhythmic-temporal patterning versus temporal-general rhythmic-temporal patterning?* To answer these questions we investigate the neural and behavior responses of 40 infants, 20 deaf infants acquiring sign language and 20 hearing infants acquiring spoken language, at a key developmental period, 5-6 months of age. Participants will be shown short videos of signed phonetic-syllabic units versus short videos of moving point-lights, both presented at three frequencies: 3 Hz (hypothesized to be too fast), 1.5 Hz (hypothesized to be optimal, Petitto et al., 2001a; 2012; Petitto, 2005, 2007), and .5 Hz (hypothesized to be too slow). Hemodynamic responses will be measured using functional Near Infrared Spectroscopy (fNIRS) neuroimaging, and eye gaze behavior will be measured using Tobii eye tracking technology, with both technologies already integrated for time-locked data collection and housed in the Petitto Brain & Language Laboratory for Neuroimaging (BL2). Neural data and behavioral eye gaze data will be analyzed to test the following hypotheses:

H1 *Temporal-General Hypothesis*: Infants are sensitive only to temporal-general properties of rhythmic-temporal patterning presented at 1.5 Hz. *Behavioral prediction:* Both deaf and hearing infants show increased looking time for *both* phonetic-syllabic and point-light stimuli types, when presented at 1.5 Hz. *Neuroimaging prediction:* We see bilateral STG recruitment for both stimuli types presented at 1.5 Hz in all babies.

H2 *Phonology-Specific Hypothesis*: Alternations of maximal contrastive phonological units, presented at an optimal frequency of 1.5 Hz, is important to capture and maintain infants' attention. *Behavioral prediction:* Only sensitivity to phonetic-syllabic stimuli presented at 1.5 Hz is seen in deaf and hearing infants via increased looking time, and not for point-light stimuli. *Neuroimaging prediction:* The left STG is recruited in both groups of infants but only when observing phonetic-syllabic stimuli presented at 1.5 Hz.

Key here is that we expect hearing infants acquiring spoken language to demonstrate the *same* observed responses as deaf infants acquiring signed language. This expectation follows from [[classic percetual narrowing studies]] indicating that infants at 5-6 months of age [[exhibit universal phonetic discrimination abilities]] in any language, signed or spoken (Baker, Golinkoff, & Petitto, 2006; Krentz & Corina, 2008; Palmer et al., 2012; Petitto et al., 2012; Stone, Bosworth, & Petitto, 2015; Werker & Tees, 1984). Thus, we also test hearing infants viewing *soundless* signed and visual stimuli as to provide the strongest test of either hypothesis. [[To discover group differences based on hearing status would be a remarkable finding indicating that experience-based changes begin much earlier than theorized.]]

Approach.

Strategy. Participants will undergo *integrated* Tobii eye gaze tracking and functional Near Infrared Spectroscopy (fNIRS) neuroimaging already housed in Dr. Petitto's Brain and Language Lab for Neuroimaging (BL2). Eye gaze and hemodynamic response data will be processed and a three-way mixed ANOVA analysis (within-subjects: frequency x video type; between-subjects: deaf/hearing) will be used to test our hypotheses. fNIRS is an ideal neuroimaging technology to assess infants on linguistic tasks (see Shalinsky et al., 2009 for a review). [[Modern advances in 3-D head mapping and NIRS-SPM software now permit systems and localization analyses of neural activity to the gyrus level, even in infants (Petitto, 2007, 2009; Petitto et al., 2012). fNIRS possesses temporal resolution (10Hz, or 10 times per second, which is superior to fMRI) and now excellent spatial resolution (~5 cm depth).]] fNIRS further yields separate measures of deoxygenated and oxygenated hemoglobin in "real time" during recording, compared to fMRI's combined blood oxygen level density (BOLD) measure, [[allowing for the ability to track the precise temporal course of neural activity across hemispheres. Moreover, fNIRS has a decade of studies consistently identifying STG activity in infants and adults (including fMRI/MRI and fNIRS neuroanatomical co-registration; Kovelman et al., 2008).]] Notably, it does not use radiation or require that participants be strapped down and rolled motionless and flat into the donut. Further, it is virtually silent, safe to use with infants who may have cochlear implants (whereas fMRI and other neuro-recording systems are not), and, crucially, tolerates infants' movement while seated on their parents' laps. This latter feature makes possible an exciting and fuller complex of human language research, as participants can now be studied both comprehending (perceiving) language and, crucially, producing language. The production of speech (or sign) is not possible in other contemporary neuroimaging systems and is a feature of fNIRS that has revolutionized the types of scientific questions that are now possible to study higher cognition. With the use of fNIRS in babies, it is possible to follow specific tracts of brain tissue and neural systems known to participate in natural language processing over time (Jasinska & Petitto, 2013, 2014; Petitto, 2007, 2009; Petitto et al., 2012). Taken together, these advantages have led to the explosive use of fNIRS as one of today's leading brain imaging technologies. The innovative integration of fNIRS and eye tracking is a powerful design feature, as it allows us to associate the specific behavioral measure involving human visual attention (eye tracking) with the neural sites and systems that govern them (Aslin, 2011; Bosworth et al., 2013; Kita et al., 2010; Righi et al., 2014). The combined, time-locked hemodynamic response and eye gaze data allow the strongest test of the hypotheses over either technology alone: with eye gaze data only, we would not know the timing or location of neural sites and systems implicated in rhythmic-temporal processing or whether infants' looking behavior was supported by linguistic or visual neural networks. Likewise, with hemodynamic response data alone, we would not know whether infants, in fact, attend to the frequency differences presented in sign language stimuli. We are ideally situated to carry out this proposed study due to our experience integrating BL2-housed fNIRS and Tobii eyetracking technologies, presently conducting studies of reading, language, and visual attention development in children using this yoked setup (Petitto, Langdon, Stone, 2015).

Participants. We will recruit 40 healthy, full-term infants age 5-6 months. One group (n=20) will be deaf infants acquiring sign language natively from deaf parents and the other (n=20) will be hearing infants acquiring spoken language natively from hearing parents. We choose to focus on age 5-6 months because this age is when we see infants possessing a universal biological capacity to discriminate phonetic units, be they signed or spoken. After this age, infants begin to attenuate down to language-specific sensitivities based on experience (Baker, Golinkoff, & Petitto, 2006; Bosworth et al., 2013; Krentz & Corina, 2008; Petitto et al., 2001b, 2012; Stone, Bosworth, & Petitto, 2015; Werker & Tees, 1984).

We are ideally situated for the recruitment of deaf infants in particular, due to our location at Gallaudet University in the metro D.C. area, which holds an exceptionally large population of signing deaf parents with hereditary deafness and thus, many deaf babies (Gallaudet University, 2010). We will draw from our NSF Science of Learning Center VL2 Volunteer Participant Database (which contains deaf infants of deaf parents), the National Deaf Education Center's on-campus parent-infant program, Kendall Demonstration Elementary School Parents-Teachers Association (a formal VL2 partner), Deaf Parents of DC, Deaf Families in Northern Virginia, Montgomery County Deaf Parents, Maryland Kids of Deaf Adults groups, and we further enjoy a VL2 partnership with Maryland School for the Deaf.

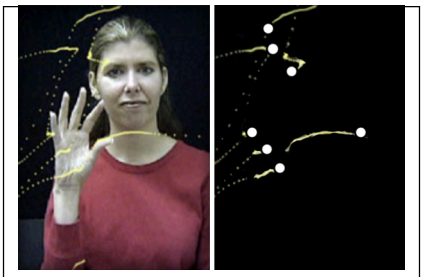

Figure 1. The 2 stimuli types. Left: phonetic-syllabic units. Right: point-light scenes. *(yellow movement lines are for demonstration purposes).*

Stimuli & Design. The stimulus consists of two types: (1) phonetic-syllabic units and (2) point-light stimuli (*Figure 1)*. The first type, short videos of signed phonetic-syllabic units produced by a native signer with neutral facial expression (previously piloted and published: Petitto et al., 2000) are homologous to the auditory presentation of short spoken consonant-vowel units (e.g., /ba/+/ka/, /ga/+/pa/) used in classic psycholinguistic studies (Kuhl, et al., 2006; Petitto et al., 2012). The phonetic-syllabic videos present language in the most ecologically authentic way possible, similar to how classic infant language acquisition studies

use audio clips of natural speech (Nazzi, Jusczyk, & Johnson, 2000). From the *exact same* phonetic-syllabic videos, we develop point-light stimuli where white dots move against a black background; points of lights correspond to specific joints on the articulating fingers, hands, and arms (Johannson, 1973; Poizner, 1983). Point-light representations of signing have been used as "non-linguistic" stimuli in studies assessing adult and infant sensitivity to phonological features in sign language (Krentz & Corina, 2008; Poizner, 1983). Thus, the two types of stimuli present a powerful subtraction design, where the phonetic-syllabic unit videos contain both [+phonology] and [+timing], while the point-light stimuli contain only [+timing]. As will be explained below, both types will have identical time, duration, velocity, and spatial trajectories, and are visually homologous in precision to speech fundamental frequency, F_0 (as advanced by Petitto et al., 2001a, 2012; also Borden et al., 1994). Neural recruitment of the STG with soundless visual stimuli is plausible because other studies have demonstrated that the STG, classically associated with phonological processing in spoken language, can be recruited with non-auditory stimuli such as lights and vibrations (Finney et al., 2001; Levänen et al., 1998) although in both cases it was left untested whether the STG possessed sensitivity to specific frequencies above others—key to this present study.

All stimuli are presented at three frequencies hypothesized to range from too fast, to just right, to too slow: 3 Hz (too fast), 1.5 Hz (optimal), and .5 Hz (too slow). The frequency, measured in Hertz, is equal to the number of full movement cycles per second. We calculate the number of full open-close movement cycles per second, or, the number of "syllables" produced in signed language per second. Sign syllables are homologous to an open/vowel and closed/consonant CV syllable in spoken language. Therefore, a full open-close movement cycle is the time and velocity of a signer's hands (articulators) to make the phonetic-syllabic unit that requires a transition from maximal opened handshape to maximal closed handshape and back to maximal opened handshape (Battison, 1978; Brentari, 2001; Wilbur, 2010). Open-close maximally contrasting alternations, and the time, velocity, etc., are among the features that define speech fundamental frequency (F_0), which is the time for the vocal chords to go from maximal open position to maximal closed position and back to maximal open position (Borden et al., 1994), and, for sign, first advanced in published studies using OPTOTRAK recording (c.f., Petitto et al., 2001a, 2004).

The phonetic-syllabic units will be based on previously published phonetic-syllabic units used in infant and adult sign perception studies (Baker et al., 2005, 2006; Petitto et al., 2000). An adult signer will sign the units while in the MoCap setup (more below); that is, they will be *simultaneously* video-recorded and motion-captured. To create the three frequencies from the same phonetic-syllabic video stimuli, the video recordings will be sped up or slowed down by digitally deleting or duplicating frames such that the actual open-close movement cycles matches the three frequency conditions of .5, 1.5, and 3 Hz but preserving an overall 30 frames-per-second (fps) across all conditions. Because the phonetic-syllabic stimuli were recorded while the native signer was in the MoCap setup and being motion-captured, the resulting point-light stimuli will have identical time, duration, velocity, and spatial trajectories as the phonetic-syllabic video. Therefore, they will undergo identical digital alteration methods in order to create the three frequency conditions.

Innovation in Point-Light Stimuli Creation. The point-light stimuli will be generated via motion capture hardware (MoCap). They will be based on the phonetic-syllabic units that the signer makes (and that were videotaped) while simultaneously undergoing MoCap data collection. This will permit the MoCap system to achieve homologous temporal frequency, velocity, and spatial matching of key locations (e.g., fingers, joints, arms). Crucially, the point-light stimuli generation will be built using the new, state-of-the-art 8-camera Motion Capture (MoCap) system that Dr. Petitto proposed and was awarded in her Keck Foundation grant as PI (see Petitto Biosketch). The MoCap is presently housed in Gallaudet University's Motion Light Laboratory (ML2) directed by Melissa Malzkuhn (a Keck Grant Co-PI) and a "sister" laboratory to Dr. Petitto's BL2. Petitto, her students (including this applicant, Stone), and Malzkuhn have worked collaboratively on many projects since 2011 to generate visual stimuli (using other point light-generating equipment) for lab studies and translational products, including 3-D generated signing scenes using point-lights as key spatial coordinates. It is emphasized that point-light stimuli have already been used with babies for sign language perception studies (Krentz & Corina, 2008) and this applicant (Stone) has previously carried out sign perception studies using point-light stimuli under Dr. Carol Padden and her lab at UCSD (see Doctoral Dissertation and Other Research Experience).

fNIRS Neuroimaging Design: We will use an event design of 24 randomized 6-second trials: 4 trials of each type (phonetic-syllabic, point-light) x each frequency (.5, 1.5, 3 Hz), with a 20-second initial baseline and an 8-sec rest period in between each trial (Bortfeld et al., 2009; Lloyd-Fox et al., 2011; Petitto et al., 2012; Wilcox et al., 2005). Baseline and rest periods are low-salience videos of fireworks to maintain visual attention and engagement (Emberson et al., submitted; Taga et al., 2003). The testing time per infant is 8-9 minutes including fNIRS probe placement and eye tracker calibration. The applicant (Stone) has already piloted a very similar experimental design, with testing time at 11-12 minutes, using eye tracking only in 15 infants with successful outcomes (Stone, Bosworth, Petitto, 2015; see Pilot Studies and Feasibility).

Apparatus and Recording. The eye tracker setup follows from Stone, Bosworth, & Petitto (2015) and is yoked with the fNIRS on-site at the Petitto Brain and Language Laboratory for Neuroimaging (BL2), with data collection time-locked and synchronized with stimulus presentation (Macguire et al., 2012; Petitto, Langdon, & Stone, 2015). A Tobii X120 eye tracker is placed below a 21-inch monitor and aimed towards the infant. Tobii Studio has an Infant Calibration

mode in which a 9-point calibration procedure is performed (~20 s). The Tobii X120 tracks eye gaze by using near infrared illumination to create reflection patterns on the cornea and pupil of the eyes. Internal image sensors are used to capture images of the eyes and the reflection patterns. Image processing algorithms and a physiological 3D eye model are used to estimate the position of the eye in space and the point of gaze. Raw eye movement data are collected every 8.33 ms (120 Hz sampling rate), identified by a timestamp and (x,y) coordinates, and sent to E-Prime.

To record the hemodynamic response we use a Hitachi ETG-4000 with 24 channels. The [[10]] lasers and [[8]] detectors are split into two 3x3 arrays *(Figure 2)*. Channels are the area between adjacent lasers and detectors. The ETG-4000 emits infrared light at two wavelengths, 690 and 830 nm, through optical fibers. The reflected light is sampled every 100 ms and separated into two signals, one for each wavelength, by synchronous lock-in detectors. These measures allow us to estimate changes in oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) concentrations during tasks and baseline.

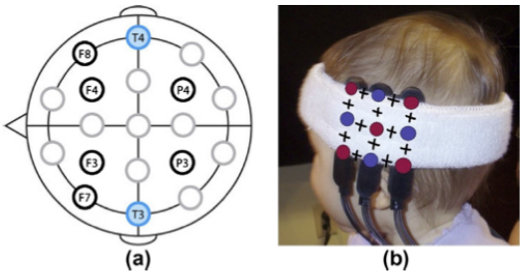

Figure 2. Placement of fNIRS probes. (a) Key locations in Jasper (1958) 10-20 system. (b) fNIRS probes held in place by headband. Red circles represent the laser emitters; blue the fNIRS detectors; the x's the channels.

For recording, the infant sits on the parent's lab, seated on an adjustable-height, non-swiveling chair and positioned approximately 65-75 cm in front of the monitor. The parent will wear occluding glasses. Once comfortably seated and with a cartoon playing, one array is placed on each side of the infant's head. The arrays are held in place by a soft terrycloth headband. Positioning of the array is accomplished using the 10–20 system (Jasper, 1958, *Figure 2*) to overlay regions classically involved in language and homologues in both hemispheres [[and further specified via our Polhemus 3-D head mapping system recording the location of each optode)]]. Following calibration, the task is presented via E-Prime, which collects the eye gaze data while the ETG-4000 collects the brain activity data. Both eye gaze and hemodynamic response data are time-locked and synchronized with stimulus presentation. Sessions will be ended if infants demonstrate fussiness. Photographs will be taken of the probe arrays on the baby's head before and after recording to ensure that probes remained in their anatomically correct placement. The ETG-4000 also collects video recordings of participants in order to identify movement artifacts that may impact data collection.

Data Processing. The first step in eye tracking data processing is to discard the points where the system has only recorded one eye or failed to identify whether it is the left or the right eye (this does not discard data for very short blinks, but interpolates across these short ~75 msec gaps). Data points are aggregated into fixations using a fixation filter algorithm to allocate clusters of close gaze points to a single fixation, i.e., where the participant's eye gaze hovers around a point of interest. Then the fixations are represented graphically with gaze plots showing connected saccades over time and heat maps showing the gaze point concentration on the stimuli. AOIs will be determined *a priori* as the face, the hand, and the neutral signing space in phonetic-syllabic stimuli and determined from heat maps of looking behavior on the point-light stimuli. Data analysis software will be used to calculate several metrics per subject, across all trials, including duration of first fixation, total looking duration, and number of fixations for AOIs drawn around fingers vs. arms vs. face, or around point-lights (Bosworth et al., 2013; Petitto, Langdon, & Stone, 2015; Stone, Bosworth, & Petitto, 2015).

For the fNIRS data, using published techniques (Jasinska & Petitto, 2013; Petitto et al., 2012; Shalinsky et al., 2009), after the recording session, data from all trials will be exported and analyzed using Matlab. Raw data are converted to hemoglobin values by calculating the attenuation for each wavelength via comparing the optical density of light intensity during the task to the calculated signal baseline, and then using the attenuation values for each wavelength and sampled time points to convert the wavelength data to HbO and HbR values. The HbO values are then used in all subsequent analyses (Kovelman et al., 2009; Shalinsky et al., 2009). Once converted from laser attenuation, channels then refer to the HbO and HbR changes in the regions between the emitters and detectors. Next, we perform a whole brain analysis and PCA to identify clusters of channels with robust activity. From these PCA results, we match these channels to their brain regions. In turn, this will help us to verify our hypothesized ROIs. We expect the ROIs to be the STG/temporal cortex and homologous RT STG (BA 21/22) due to its role in infants' recognition of acoustic-phonetic patterns and phonological features in human language (Berent et al., 2014; Bortfeld et al., 2009; Dehaene-Lambertz et al., 2002; Gomez et al., 2014; Imada et al., 2006; Minagawa-Kawai et al., 2011; Peña et al., 2003; Petitto et al., 2012; Telkemeyer. 2009), and the LIFG (BA 45/47) due to possible added linguistic processing (Petitto et al., 2000, 2012). As a "safety measure" in our ROI identification process, our final ROIs will be selected relative to a control site for which neural activity to linguistic or visual stimuli would not be predicted. For each participant, each channel overlays the same brain areas due to 10-20 probe placement, and selected channels are grouped across participants for further analysis.

Planned Statistical Analyses. First, we perform 3-way mixed ANOVAs (within-subjects: frequency x type; between-subjects: deaf/hearing) on total looking time, and on whole-brain all-channels mean HbO peak values, to detect for differences in stimuli type and frequency processing in deaf and hearing babies. Next, we will ask whether there are

similarities and differences in the left STG activation (and separately for left inferior frontal gyrus, LIFG, activation as well, an area associated with search/retrieval of information about the meanings of words) for infant responses to stimuli type and frequency, using the same 3-way mixed ANOVA using average HbO peak values of the STG channels from the left hemisphere (*Figure 3*). We also will perform laterality analysis by adding hemisphere as a fourth factor in both STG and IFG ANOVA models to determine brain lateralization for left vs. right STG and IFG. Following testing of main effects, we will use posthoc analyses to determine which conditions significantly differ.

H1 Temporal-General	**H2 Phonology-Specific**
Main effect of frequency No effect of stimuli type No effect of group	Main effect of frequency Main effect of stimuli type No effect of group
Main behavioral response: mean looking time per trial Main neuroimaging response: mean peak HbO value in STG channels	

Figure 3. Predictions for each hypothesis.

In accordance with the applicant's training plan, we intend to explore analyses integrating eye tracking data with hemodynamic data (Emberson et al., submitted), modeling both as predictor and response variables in a multiple regression model using stimuli type and frequency as variables. This is feasible given the eye tracking and hemodynamic response data have already been time-locked and synchronized; we hope to discover whether looking behavior could be a reliable indicator of brain activity or vice versa, providing powerful insights into how internal linguistic and cognitive processing within the brain, especially the hypothesized sensitivity to rhythmic-temporal patterning, drive external observations of attention, interest, and arousal. In addition, BL2 has recently begun to explore connectivity analyses (Jasinska & Petitto, 2013, 2014) made possible by fNIRS's outstanding temporal resolution (~100ms); the applicant is also keen to gain training in connectivity analyses and apply these approaches to the proposed study.

Pilot Studies and Feasibility. It is emphasized that the Petitto Brain & Language Laboratory (BL2) has already carried out adult behavioral and neuroimaging studies using sign phonetic-syllabic units (Petitto et al., 2000; Kovelman et al., 2014), and infant behavioral and neuroimaging studies using speech phonetic-syllabic units (Petitto et al., 2012). In addition, the applicant (Stone) interned at the UCSD Infant Vision Lab (Dobkins & Bosworth) in Summer 2014 and conducted a pilot study using eye tracking of infant sensitivity to well-formed sign phonetic-syllabic units, with n=15 sign-naïve infants at two different developmental ages. Using eye gaze data alone from a Tobii X120 eyetracker, younger sign-naïve infants looked at well-formed phonetic-syllabic units significantly longer than ill-formed phonetic-syllabic units ($p = 0.01$) with a large effect size (Cohen's $d = 0.68$) while older babies failed to discriminate between the two stimuli types (Stone, Bosworth, Petitto, 2015). Power calculations suggest that with our preliminary observed effect sizes, we would have a power of >0.90 (alpha = 0.05, two-tailed) with 20 subjects per group to detect group differences in total looking time (the behavioral response variable used for the proposed study). Based on our experience of collecting infant data, the experimental design and stimuli are quite promising. Also, our projected sample sizes are in line with BL2-published effect sizes (Kovelman et al., 2009; Jasinska & Petitto, 2013; Petitto et al., 2012). Following the applicant's summer lab internship, Stone successfully integrated BL2's neuroimaging and eye tracking technologies such that hemodynamic response and eye gaze data could be collected in a time-locked manner while the participant viewed visual stimuli presented via E-Prime (Petitto, Langdon, & Stone, 2015). In Spring 2015, 15 young participants (4-7 years) participated in studies of reading and visual language perception; this setup has proved to be feasible and adaptable to different populations (infants, adults, children) and for different stimuli (auditory, visual, live). All together, the applicant (Stone) who is in the Petitto BL2 Lab (with its advanced technologies) has the capability to successfully perform an integrated fNIRS-eyetracking investigation of infant sensitivity to rhythmic-temporal patterning.

Summary and Innovation.

[[The proposed study addresses if humans are born with neural tissue dedicated to acquisition of phonology, and clarifies on a modality-free level, how this tissue may interact with auditory or visual functions.]] Discovering the frequency and type of rhythmic-temporal patterning to which babies are biologically sensitive will advance our knowledge about how babies discover the core parts of their languages—especially phonology—and the related neural structures and systems implicated in language acquisition, providing powerful new knowledge of how experience-dependent brain changes provide infants with the neural circuitry necessary for learning phonology and language in any modality. [[This, in turn, will help us better understand which linguistic capabilities infants possess in the beginning of life and, in turn, to identify on a neural level children at risk of phonology-based disorders]] and will promote interventions aimed at healthy language learning and reading (Beattie & Manis, 2014; Goswami, 2011; Petitto, Langdon, & Stone, 2015; Tsao et al., 2004). From a methodological view, this study is innovative in the developmental cognitive neuroscience field because it creatively joins together measurements of brain activity *and* cognitive attention, allowing us to test previously unanswerable hypotheses about how neural systems drive attention and learning. Moreover, this first-time developmental neurobiological investigation of signed language perception will permit new scientific understanding of the importance of early visual language experience for lifelong cognitive and reading outcomes in deaf children.

PROJECT NARRATIVE

The goal of this research is to understand how all infants discover the finite set of language units in their native language from the infinite combinations of sensory stimuli around them. Specifically, we explore whether infants are sensitive to the pure *timing* of the stimuli (the frequency), or whether they also are sensitive to *linguistic information* within the stimuli (alternation of phonetic-syllabic units). The findings will help us better understand [[on a modality-free level]] how infants begin life with brain mechanisms predisposed for discovering the core [[phonological]] parts of their languages, and how we can support clinicians in identifying infants at risk for phonology-based language and reading disorders.

PROJECT SUMMARY

Human infants are understood to begin life with a complex of brain mechanisms and sensitivities to environmental and social factors that, together, appear to contribute to our species' unique ability to learn language. However, we are only beginning to understand the nature and development of these brain mechanisms and sensitivities, especially as they contribute to the central question posed here: *How does the infant discover the finite set of phonetic units in their native language from the infinite combinations of sensory stimuli around them?*

One hypothesis proposes that infants are born with sensitivities to specific rhythmic-temporal patterning at the nucleus of human language phonology in both spoken and signed language, which permits segmentation and categorization of the continuously varying linguistic stream. We suggest that the superior temporal gyrus (STG) is a key neural site that governs this capacity and is the brain mechanism that enables infants' sensitivity to the rhythmic-temporal patterning from which it will build all the words and sentences of its native languages. While it has been suggested that babies are born with sensitivity to rhythmic-temporal patterns in maximal contrasts at around 1 to 1.5 Hz, the precise frequencies to which babies are biologically attracted to *remain unknown*. In addition, we do not know if this sensitivity is linked to *only* the pure timing of the signal (*the temporal-general property*), or *also* requires the alternation of maximally contrastive units present in both signed and speech phonology (*the phonology-specific property*). We use integrated functional Near Infrared Spectroscopy (fNIRS) and Tobii eye tracking to examine deaf and hearing infants' response to sign phonetic-syllabic units and moving point-light scenes presented at different frequencies (.5, 1.5, 3 Hz) at a key developmental age, 5-6 months to adjudicate whether infants are sensitive to the temporal-general property or also to the phonology-specific property within rhythmic-temporal patterning.

[[The proposed study addresses if humans are born with neural tissue dedicated to acquisition of phonology, and clarifies on a modality-free level how this tissue may interact with auditory or visual functions.]] Discovering the properties of rhythmic-temporal patterning to which babies are biologically attracted will advance our knowledge about how babies discover the core parts of their languages. The use of signed language stimuli allows us to determine whether infants are sensitive to general temporal patterns or to specific linguistic phonetic contrasts, [[advancing our knowledge of]] language acquisition universals. We will gain insight into how experience-dependent brain changes provide infants with the neural circuitry necessary for learning [[the phonology of their]] language(s), allowing us to support clinicians in identifying infants at risk for phonology-based language and reading disorders. Finally, this first-ever developmental neurobiological investigation of signed language perception will permit new understanding of the importance of early visual language experience for learning and reading outcomes in deaf children, and indeed, all children.

GOALS FOR FELLOWSHIP TRAINING AND CAREER

1. Master design, data collection, and analysis of language & reading studies using fNIRS neuroimaging and eye tracking of infants, children, and adults
2. Gain in-depth knowledge of Educational Neuroscience, [[Language & Aphasia]], and Child Development topics
3. Further develop skills in statistical analyses including applied multivariate analysis and computational modeling
4. [[Develop university classroom instruction skills and materials especially for neuroimaging and neuroscience education of the next generation of young student scholars]]
5. Training in dissemination/translation of scientific findings, scientific leadership, and student mentorship

My current research experiences are preparing me for my professional goal of becoming *an independent educational-cognitive neuroscientist in a tenure-track faculty position*, investigating developmental cognitive neuroscience questions. I particularly wish to explore neural plasticity issues surrounding early vs. delayed language experiences on all infants and children. I am especially fascinated in the role of early exposure to rhythmic-temporal patterning at the core of human language's phonological organization. Furthermore, I am especially interested in the implications of such early language exposure for all human language learning, vocabulary and sentence knowledge growth, and successful reading. Per the two-way collaboration philosophy at the heart of Educational Neuroscience, I also envision my career having a role for achieving principled translational science in which scientific findings are disseminated to parents, educators, policymakers, and administrators following field-tested remediation and interventional strategies for children who are at risk of phonological or reading disorders. I have a passion for the scientific study of educational neuroscience, which promotes the union of hard-core developmental cognitive neuroscience and central issues in the development and education of children; my past expertise as a classroom teacher and as a deaf person has helped me identify critical knowledge gaps in the fields of deaf education, visual language, and human language development. I have chosen this Ph.D. program and my sponsor, Dr. Laura-Ann Petitto, specifically because my scientific and translational interests align with hers and the program, and because of her rich experience in infant and child neuroimaging and behavioral studies centering on language acquisition, infant development, bilingualism, and reading.

I specifically wish to gain additional training in neuroimaging and eye tracking methodologies and data analysis for studying infant and children and how they acquire language and reading. These technologies are at the very leading edge of current research in visual language and visual learners and may revolutionize current theories about how all children learn to read. Dr. Petitto's NSF-funded lab provides an ideal place in which to receive this type of specialized training. Dr. Petitto herself is an ideal mentor owing to her decades of expertise in these fields. Dr. Petitto is also a founder of the new field of Educational Neuroscience, in which my Ph.D. program is grounded, and thus also is an ideal mentor to support my scholarly growth in this area. With this grant, I would be better positioned to collaborate with our partner labs to keep abreast of current innovations in infant fNIRS studies and gain additional training in formidable fNIRS data analysis software (e.g. HOMeR2, AtlasViewer) and customized MATLAB scripts for specialized data investigations, especially to resolve challenges of integrating fNIRS and eye tracking data analyses.

In addition, studying deaf children has its unique challenges. Research in this area is often marked by small sample sizes. Traditional statistical analyses often mask nuances about how this population acquires language and literacy, and the impact of specialized intervention approaches such as cochlear implants. Newer statistical approaches may better capture the variance in this population and allow discovery of real effect sizes. Through Gallaudet University's consortium program with other Washington, D.C.-area universities, I will take advanced statistics courses including multivariate analysis and multilevel modeling at George Washington University. I also desire deeper knowledge in classical [[language processing, and aphasias]] and infant cognitive and linguistic development. [[In particular I will take "Brain & Language" at Georgetown University, co-taught by renowned scholars in the field (e.g. Dr. Peter Turkeltaub)]].

[[Universities increasingly desire junior faculty who *already* possess strong teaching. Here, I will undergo internships in university instruction, engage in syllabi and content development, deliver guest lectures in diverse contexts, and eventually teach my own neuroscience course to undergraduate students, which would be a first for my university.]]

Finally, I wish to enhance my scientific dissemination skills. While I have delivered more than 15 invited workshop presentations on the use of e-literacy technology in bilingual classrooms, I seek to [[further]] hone those skills for scientific talks such as at Society for Neuroscience [[as I did in October 2015]] or Society for Research on Child Development. I also desire to become a [[highly productive]] junior research scientist, and I intend to [[continue]] writing up and publishing research findings from my graduate assistantship at BL2, my courses, and my summer lab rotations.

As a deaf scientist-in-training, I am excited to complete the proposed research and training plan which will facilitate my envisioned career of research, teaching, and disseminating research findings in the fields of educational neuroscience with a special focus on deaf children, visual language, and literacy development. The training outlined here and in other sections and my research project offers truly transformative opportunities to make breakthroughs in science, enhancing our understanding of the neural underpinnings of language and reading and expanding our knowledge and abilities to successfully educate all children.

ACTIVITIES PLANNED UNDER THIS AWARD

Semester	Coursework	Research	Training	Teaching	Key Milestone
Spring 2016	35%	25%	40%	--	Dissertation Proposal
Summer 2016	--	50%	50%	--	Data Collection
Fall 2016	20%	30%	40%	10%	Data Collection
Spring 2017	20%	30%	40%	10%	Data Collection & Analysis
Summer 2017	--	50%	50%	--	Data Analysis & Writing
Fall 2017	--	50%	40%	10%	Data Analysis & Writing
Spring 2018	--	50%	40%	10%	Dissertation Defense

As a [[3rd]] year doctoral student in Gallaudet University's Ph.D. in Educational Neuroscience program, my time allocations for coursework, research, training, and teaching will follow my program guidelines. As a graduate research assistant in Petitto's Brain & Language Laboratory for Neuroimaging (BL2), I will continue my student leadership role in their ongoing neuroimaging studies of reading, bilingualism, language acquisition, and visual sign phonology in infants and children. As part of my assistantship, I attend Petitto's weekly Brain Seminars exploring infant language acquisition, reading, and cognition, as well as neuroimaging and behavioral research design and data analysis, and weekly meetings with my advisor/sponsor Dr. Petitto, which involve intense 1:1 training and mentorship in the science associated with my research aims. I will attend weekly mentoring meetings by the Student Leadership Team (SLT) in our NSF Science of Learning Center, Visual Language and Visual Learning (VL2), called the "VL2 Student Network Lecture Series." [[(I served as an elected member of the VL2 SLT for three years and earnestly continue to support SLT activities.)]]

Scholarly Activities Taking Place Prior to Proposed Award. [[For my 2nd PEN Cognitive Neuroscience Lab Rotation in Summer 2015, with NSF funding, I trained at the University of Hong Kong's Hearing & Speech Sciences Laboratory with mentors Dr. I-Fan Su and Prof. Brendan Weekes. There, I learned EEG/ERP methodologies and data analysis, focusing on bilingual reading studies with children. I also first-authored a publication in PLoS ONE, and was awarded a fellowship at the Society for Neuroscience's Neuroscience Scholars Program (NSP). This Fall semester, my core course was Educational Neuroscience Guided Studies III: Theory (Dr. Guinevere Eden, at Georgetown University) where I wrote a 10,000-word publishable review manuscript discussing functions of STG/Wernicke's area and related neural tissue in language processing in infants and signing vs non-signing adults. To come: Georgetown University's fMRI Theory & Methods (Dr. John VanMeter), and a Seminar in University Instruction & Supervision (requirement).]]

[[Spring-Summer 2016. In Spring, I will develop my Dissertation Proposal (a core program course), and take Brain & Language at Georgetown (Dr. Peter Turkeltaub), discussing neural bases of hearing and aphasias, and Applied Linear Models at George Washington University.]] I will also complete and submit a manuscript from my 1st PEN cognitive neuroscience lab rotation project (UCSD Infant Vision Lab; PI, Dr. Rain Bosworth). I will continue my hands-on training as a lead graduate student in Dr. Petitto's child, and adult fNIRS studies, by doing data collection and advanced analysis. I will pilot the stimuli (previously published, Petitto, 2000) for this proposed study (see Research Strategy). [[In Summer, with Dr. Petitto's guidance, I will begin infant data collection for my dissertation at BL2. I will also participate in SfN NSP training/mentoring webinars and live chats and begin write-ups from Dr. Petitto's studies.]]

[[Fall 2016-Spring 2017-Summer 2017. I will enroll in my final PhD program core courses, Dissertation Research I and II, perform my Doctoral Teaching internship, and continue taking electives in advanced statistics (e.g., multivariate analysis).]] I will also be mentoring junior Educational Neuroscience doctoral students and undergraduate interns by training them in eye tracking and neuroimaging methodologies. I will also co-author findings from Dr. Petitto's NSF fNIRS-eye tracking neuroimaging study of reading development in deaf children (Petitto, Langdon, & Stone, 2015). [[As I complete dissertation-level data collection (expected at end of Spring 2017), I will also focus specifically on advancing my fNIRS data analysis skills (NIRS-SPM, HOMeR2, AtlasViewer) via training with identified partnering labs including Dr. Ioulia Kovelman's Language and Literacy Lab (University of Michigan) and Dr. Lauren Emberson's Baby Lab (Princeton University).]]

[[Fall 2017-Spring 2018. My focus will be on completing my dissertation neuroimaging analysis and writing, in preparation for my Defense in Spring 2018. I also expect to teach one introductory neuroscience courses for undergraduates, a first for Gallaudet University.]] Throughout all of the above, I will submit to scientific conferences (e.g., SfN, SRCD, AERA, CNS), write manuscripts, and continue mentoring students. In consultation with my advisor/sponsor Dr. Petitto and the anticipated support of this training grant, I will participate in various student-centered workshops, including University of Maryland Language Science Center's "Winter Storm," Dalhousie University's "Summer Institute in Neurotechnology, Innovation, and Commercialization," and University of Connecticut's Language Plasticity IGERT. These workshops will provide additional training in neuroimaging study design, data analysis, teaching, and research translation, all which will position me to be [[an *independent educational-cognitive neuroscientist in a tenure-track faculty position*.]] I am requesting additional funds ($6,720 across two years of support) to utilize sign language interpreting in the situation where the workshop or conference is financially unable to provide such services.

DOCTORAL DISSERTATION AND OTHER RESEARCH EXPERIENCE

Pre-Graduate Language Research Experience. My interest in research exploring the intersections of language, education, psychology, and neuroscience developed early in my post-baccalaureate career. I volunteered for nine months at a school for the deaf in Sri Lanka; there, I saw the paucity of visual language and literacy resources for students, parents, and teachers. My most notable accomplishment was spearheading the creation of the country's first-ever conversational sign language dictionary, *An Introduction to Sri Lankan Sign Language (http://www.rohanaspecialschool.org/sri-lankan-sign-language-dictionary/)*. This effort involved the careful selection of more than 350 signs, categorizing them in an educationally appropriate sequence, leading a team of artists and translators, and performing all layout and desktop publishing tasks. This was a formidable task not unlike those undertaken by linguists in field studies, made the more remarkable by the fact that I had no formal training in linguistics. 1,000 copies of this dictionary was printed and distributed free of charge to school families and deaf communities across Sri Lanka.

Graduate (MA) Research Experience.

Master's Thesis: After volunteering in Sri Lanka, I entered University of California, San Diego (UCSD) to earn a master's in Teaching & Learning in Elementary Education with ASL/English Bilingual Education Emphasis. Part of the program is conducting a qualitative study to assess efficacy of an original curriculum. I created a curriculum centering on the use of graphic storytelling media (e.g. comics) to teach early literacy skills in both English and American Sign Language. This study required the collection and triangulation of multiple data sources from students, classroom artifacts, and teacher notes. I concluded that graphic storytelling media was an effective teaching tool to promote language and literacy development in a bilingual context. Dr. Carol Padden served on my thesis committee, and I defended my thesis successfully in August 2010.

Laboratory for Language and Cognitive Neuroscience. I was also a research assistant at Laboratory for Language and Cognitive Neuroscience (LLCN) at San Diego State University, supervised by Dr. Karen Emmorey. The LLCN studies phonology, psycholinguistics and neuroscience theoretical questions, including human language universals, the neural correlates of sign language vs. spoken language, and the nature of the bimodal bilingual brain. There, my tasks included recruiting and running subjects for a NSF-funded study on phonological and orthographic processing skills in adult Deaf readers. In addition, I scored video recordings of interpreters and Deaf people for the norming of new ASL proficiency assessments. I also worked to create promotional materials, maintain the subject database, and design posters for national and international conferences, one of which won a top award due in part to its visually innovative design.

Center for Research on Language (now Padden Lab). I was also a research assistant at the Center for Research on Language (CRL) at University of California, San Diego, supervised by Dr. Carol Padden. The CRL carries out research on sign language structure, the role of gesture in sign and speech, emergence of phonology and morphology in village sign languages, and cultural transmission of language. My duties included recruiting and running subjects on a study of *perception of phonological and morphological patterning in visual language using point-light stimuli*. Also, I supported Dr. Padden's ongoing research in lexicalization and word formation patterns among world sign languages by eliciting and analyzing vocabulary from Deaf subjects in different countries (e.g., Denmark, United Kingdom, Hong Kong, Japan) using video conferencing, and by providing technical and design support for her many invited talks on her research in Al-Sayyid Bedouin Sign Language and ASL fingerspelling.

Doctoral Research Experience.

Lab on Visually-Based Language, Cognitive, and Literacy Development. I was a research student at Dr. Marlon Kuntze's Lab on Visually-Based Language, Cognitive, and Literacy Development at Gallaudet University. The lab examines the use of longitudinal, naturalistic data to discover correlations and predictions for literacy and language development in deaf children. There, the focus was on analyzing a large longitudinal video data set of a cohort of 5-14 deaf children in preschool, pre-kindergarten, kindergarten, first, and second grade at a school for the deaf (data collection funded by VL2, NSF SBE-1041725). With 8-10 visits per year using four video cameras to capture all angles, the total hours of video footage was nearly 1,000 hours. With Dr. Kuntze's support, I formulated and initiated a research project looking at the role of iconicity in early language acquisition by sampling first-year and third-year video data. Using ELAN, I annotated every individual sign used by five specific students from a total of 5.75 hours of video footage. I created a lexical database and developed an iconicity rating system that was tested in the lab with high interrater reliability. Results showed that, while overall vocabulary increased from Year 1 to Year 3 (Preschool to Kindergarten), the total proportion of iconic signs significantly decreased ($p < 0.01$), indicating younger children's vocabularies are more likely to have iconic signs than older children's vocabularies. Overall, the iconicity of a child's lexicon changes over time, and we hypothesized that this was due to two factors: (1) iconic signs are easier to acquire earlier, and (2) the iconicity of the language used by adults around them decreased. Dr. Kuntze and I wrote up these findings, which were accepted for

presentation at the 11th Theoretical Issues in Sign Language Research conference in London in July 2013 (acceptance rate was less than 15%) and as part of a symposium organized by Dr. Asli Ozyürek (MPI) and Dr. Gabriella Vigliocco (UCL) for the International Association for the Study of Child Language meeting (July 2014) in Amsterdam.

Petitto Brain & Language Laboratory for Neuroimaging (BL2). I am a doctoral research assistant, supervised by Dr. Laura-Ann Petitto, in her Brain & Language Laboratory for Neuroimaging (BL2) at Gallaudet University. BL2 is focused on uncovering the biological mechanisms and environmental factors that together determine how the human species acquires language, as well as how language is organized in the brain. It is also one of the few neuroimaging centers in the world specialized towards investigating deafness and sign language, and even more so for having its very own, dedicated Hitachi ETG-4000 fNIRS neuroimaging equipment, along with a Tobii X120 eye tracker. Via BL2's NIH-approved (NICHD R01, R21, Petitto PI) fNIRS operations and methodologies training course, I am now formally certified in fNIRS principles, procedures, standards of ethical usage, and fundamentals of experimental design and analyses. I have personally worked for the last year to yoke together the fNIRS and eye tracking technologies for time-locked data collection of hemodynamic response and eye gaze data from children and adults. The integration of these technologies allows us to better understand the complex relationship between brain activity, cognitive attention, and visual language in all populations, allowing us to associate regions of brain activiation with specific observed in-laboratory attentional behavior. Creating this integrated apparatus was a technologically-formidable challenge requiring the use of intensive E-Prime and Matlab programming skills and considerable computer troubleshooting acumen.

I was selected as the lead graduate student on Dr. Petitto's study of visual attention, language experience, and reading in young children, using this integrated fNIRS+eye tracking technology. We examined whether differences in early life visual language experience (AoE) impact visual attention and allocation in the young emergent reader. I was in charge of designing and programming the experimental stimuli, completing ethics requirements, recruiting participants, and developing experimental protocols. I also selected the data analysis approaches (using multiple methods, e.g. t-tests, ANOVA, hierarchical/multiple regression), wrote custom Matlab scripts to process our raw fNIRS data and resolved unique challenges/issues arising out of this integrated data collection approach. I also devised data analysis approaches integrating eye gaze, hemodynamic response, and behavioral data to better understand how specific attention patterns are associated with measured brain activity. While data collection is still ongoing, I presented preliminary findings at the recent Society for Research on Child Development meeting last March in Philadelphia. Our data suggests that young sign-exposed deaf readers have increased visual allocation to text and deeper, additional integration of multiple surface visual representations, and a deeper phonological level of word processing compared to hearing non-signers, a finding that strongly suggests the existence of an unique route to reading proficiency in deaf, sign-exposed children.

Infant Vision Lab. As part of my doctoral program (Ph.D. in Educational Neuroscience), I conducted a four-week summer lab rotation at the Infant Vision Lab (PI, Dr. Karen Dobkins) at the University of California, San Diego (UCSD), working closely with Dr. Rain Bosworth. This lab investigates how vision develops in early infancy as well as brain and behavioral development relevant to visual language acquisition, autism and other developmental disorders. During my lab rotation, I piloted behavioral data collection from 70+ adults and eye gaze data collection from 12 infants in order to verify my stimulus and experimental design, gain experience in working with infants, and analysis of eye gaze data, which I was able to use later in BL2 and the study mentioned above. I deepened my formal knowledge of in infant and child development and language acquisition, gained training in infant eye tracking and the Tobii X120 eye tracker and Tobii Studio program, and took advantage of opportunities to disseminate preliminary results to senior scientists at UCSD and SDSU including Dr. Carol Padden and Dr. Karen Emmorey.

[[Hearing and Speech Sciences Lab. For my second four-week summer lab rotation, I was placed with Prof. Brendan Weekes and Dr. I-Fan Su at the Hearing and Speech Sciences Lab at University of Hong Kong (funded by NSF). This particular research team investigates bilingualism, dyslexia, and reading acquisition in children and adults, using both Chinese and Western languages. During my lab rotation, I gained training in EEG/ERP methodologies and data analysis software (e.g., EEGLab), further broadening my overall expertise in cognitive neuroimaging technologies.]]

Dissertation. My next tasks are to continue my training and studies with the ultimate goal of completing my dissertation proposal, the study proposed here: an investigation of infant sensitivity to the timing and type of rhythmic-temporal patterning in language. Every research environment I have worked at (above) has directly prepared me to approach this topic as a deaf doctoral student at Gallaudet University. I gained foundational training in linguistics and phonology from Dr. Padden at CRL and Dr. Emmorey at LLCN, child development and infant eye tracking with Dr. Bosworth at Infant Vision Lab. In addition, BL2 and Dr. Petitto have afforded me a great deal of training in designing and running neuroimaging studies with infants, children, and adults, and tacking technological and data analysis challenges. Dr. Petitto continues to provide me with necessary training in fNIRS neuroimaging and statistical data analysis. I stand dedicated and thoroughly prepared to initiate this proposed research, and, as my rich track record reveals, to bring every aspect of it to completion and advance our scientific understanding of infant sensitivity to rhythmic-temporal patterning in language.

ADDITIONAL EDUCATIONAL INFORMATION REQUIRED

Graduate Program Description.

Gallaudet's Ph.D. Program in Educational Neuroscience (PEN) pioneers how humans learn, spanning early child development and adults, with a special interest in the neuroplasticity of visually-guided learning processes sub-serving higher cognition. The PEN Ph.D. program at Gallaudet further provides a unique strength in, and contribution to, pioneering advances in the learning and education of the young deaf visual learner. The Doctor of Philosophy in Educational Neuroscience at Gallaudet University offers graduate students access to a state-of-the-art curriculum on how humans learn across the lifespan. Graduate students are provided with the most cutting-edge knowledge, powerful critical analysis and reasoning skills, and advanced knowledge of, and expertise in, contemporary neuroimaging and behavioral research—and its ethical and principled application—which are vital to education and society.

Graduate students will marry leading scientific discoveries about how children learn knowledge at the heart of early schooling (e.g., language, reading, math and numeracy, science, and social-emotional) with core challenges in contemporary education, and to do so in principled ways through "two-way" communication and mutual growth between science and society. Graduate students will also conduct state-of-the-art neuroimaging and behavioral research that renders new knowledge that both advances science and is useable, and meaningfully translatable, for the benefit of society (spanning parents, teachers, clinicians, medical practitioners, and beyond). The knowledge content of Gallaudet University's Ph.D. Program in Educational Neuroscience will be utterly contemporary, with exciting focus drawn from prevailing questions and challenges in contemporary education. At the most general level, students can expect to leave the Ph.D. Program with general knowledge of overarching issues in language learning and bilingualism, reading and literacy, and child development (including early visual attention/processing, higher cognitive processes, number, and scientific concepts), educational assessments/interventions, schools/educational policy, and social-emotional family processes associated with young children, especially young deaf visual learners. Crucially, graduate students can also expect to achieve expert and specific knowledge in a select domain above, especially through their advanced doctoral dissertation research. In addition, graduate students may expert to achieve outstanding competence in contemporary brain-based neuroimaging and behavioral research as it is applied in ethical and principled ways to prevailing problems in education-indeed, scientific knowledge, experimental mastery, and translational significance at the very heart of Educational Neuroscience. Also unique to this program, PEN offers special resources, including study of Neuroethics and has an in-house, research dedicated neuroimaging facility in which interested students may select to achieve neuroimaging certification.

This is Gallaudet University's first interdisciplinary Ph.D. program, and it includes the National Science Foundation Science of Learning Center on Visual Language and Visual Learning, (VL2), the Ph.D. program's administrative home, and the Departments of Psychology, Linguistics, Interpretation, Education, and Hearing Speech and Language Sciences. Dr. Thomas Allen is the program director. The PEN program at Gallaudet University was co-founded by my advisor, Dr. Laura-Ann Petitto (Co-PI and Science Director of the NSF Science of Learning Center, VL2, and also the co-founder of the discipline of Educational Neuroscience), Dr. Thomas Allen (Co-PI, NSF Science of Learning Center, VL2), and Dr. Melissa Herzig (Research and Translation Manager, NSF Science of Learning Center, VL2).

The program curriculum timeline is 4 years, inclusive of summer semesters, and an optional fifth year for dissertation work if needed. Below are milestones through the duration of the PEN program.

Year 1: Core courses in both semesters. Midterm student evaluation after fall semester. Preliminary exam and student evaluation at end of spring semester. 1st summer lab rotation at a partnering cognitive neuroscience lab.

Year 2: Core courses and guided studies courses, both semesters. Qualifying exam and student evaluations at end of spring semester. 2nd summer lab rotation at a partnering cognitive neuroscience lab.

Year 3: Guided studies courses and teaching seminar in fall semester. Comprehensive exam at end of fall semester. One course as instructor in spring semester. Dissertation proposal and elective courses in spring semester. Dissertation proposal defense and student evaluation at end of spring semester.

Year 4: Dissertation research courses and electives in both semesters. Dissertation defense and conferral of degree by summer if completed.

Year 5: *Optional, if dissertation research is not completed.*

APPLICANT BIOGRAPHICAL SKETCH

Use only for individual predoctoral and postdoctoral fellowships, dissertation research grants (R36),and Research Supplements to Promote Diversity in Health-Related Research (Admin Suppl). DO NOT EXCEED FIVE PAGES.

NAME OF APPLICANT: Adam Stone

eRA COMMONS USER NAME (credential, e.g., agency login): adamstone

POSITION TITLE: Ph.D. Student, Educational Neuroscience; Graduate Research Assistant

EDUCATION/TRAINING *(Most applicants will begin with baccalaureate or other initial professional education, such as nursing. Include postdoctoral training and residency training if applicable. High school students should list their current institution and associated information. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	START DATE MM/YYYY	END DATE *(or expected end date)* MM/YYYY	FIELD OF STUDY
Rochester Institute of Technology	B.S.	09/2000	05/2004	Communication
University of California San Diego	M.A.	06/2008	08/2010	Bilingual Education
Gallaudet University	Ph.D.	08/2012	05/2018	Educational Neuroscience

A. Personal Statement

Within the context of the National Science Foundation's Science of Learning Center Visual Language and Visual Learning, VL2, and Gallaudet University's *Ph.D. in Educational Neuroscience program*, my primary research goal is to understand the neurobiological foundations of language in humans, with a special focus on the role of both visual language and the rhythmic-temporal patterning underlying phonological organization in the young deaf child's language and literacy development. To answer these questions, I am trained in the use of classical psycholinguistic approaches, eye tracking technology with infants and children, and I am certified for functional Near Infrared Spectroscopy (fNIRS) neuroimaging at the Petitto Brain and Language Laboratory for Neuroimaging (BL2). I have six years' experience working in medical, linguistic, child developmental, and cognitive neuroscience research laboratories, supporting and leading challenging psycholinguistic and neuroscience studies from conceptualization to execution. I also have considerable experience in project management for universities and Federal agencies (e.g., NSF, USDA, DHS) for training programs and workshop planning. In addition, my role as a "NSF Science of Learning Center VL2 Student-Scholar," has afforded me scientific training and mentorship from a constellation of well-established cognitive neuroscience, educational, and developmental cognitive researchers all studying visual language. I have two first-authored publications (Stone, 2014; Stone et al., 2015) with more manuscripts submitted and in preparation, and a sizeable list of peer-reviewed conference abstracts.

In keeping with my Educational Neuroscience discipline, which strives to marry cognitive neuroscience scientific discovery with principled translation to education, I am also interested in the translation of basic science to advance literacy in deaf and hearing children. As a former elementary bilingual teacher, and as a deaf person, I have years of experience working with deaf and hearing children primarily focusing on reading instruction and am a children's book author and nationally recognized expert on using contemporary technology (e.g., iPads) to scaffold language/literacy instruction for deaf children. My experience extends beyond national borders; I spent one year volunteering as an English teacher at a school for the deaf in Sri Lanka which opened my eyes to worldwide disparities in deaf education and language policies.

My sponsor, Dr. Laura-Ann Petitto, a cognitive neuroscientist, has equipped me with the necessary theoretical background, inspiration, and support needed to conduct my proposed research study. The proposed training plan outlines a series of scholarly and research development activities including moving manuscripts to publication, refining our integrated fNIRS+eye tracking technologies, and gaining in-depth training in neuroscience data analysis, MATLAB and Homer programming, and multilevel modeling statistics. Completion of my training plan will present me with an outstanding set of skills to become an independent educational/cognitive neuroscientist and contribute to the fields of the neurobiology of language acquisition, developmental cognitive science, and applied visual language-based educational research.

B. Positions and Honors

ACTIVITY/ OCCUPATION	START DATE (mm/yy)	ENDING DATE (mm/yy)	FIELD	INSTITUTION/ COMPANY	SUPERVISOR/ EMPLOYER
Medical Student Program Assistant	08/04	03/05	Academic Administration	Moores UCSD Cancer Center, San Diego	Dr. Melanie Nakaji, Program Director
Federal Consultant	03/05	09/06	Federal Disability Law	Bayfirst Solutions, LLC, Washington, DC	Robert Rice, President
Volunteer Teacher	09/06	06/07	Bilingual Education	Rohana Special School, Sri Lanka	N.D. Abeygunawardena Principal
K-12 Substitute Teacher	12/07	06/08	Bilingual Education	California School for the Deaf, Fremont	Dr. Laura Peterson, Director of Instruction
Graduate Research Assistant	06/09	08/10	Psychology, Linguistics	Laboratory for Language & Cognitive Neuroscien., San Diego	Dr. Karen Emmorey, Lab Director
Graduate Research Assistant	06/09	08/10	Linguistics, Psychology	Padden Lab, University of California, San Diego	Dr. Carol Padden, Lab Director
Elementary Classroom Teacher	08/10	06/12	ASL/English Bilingual Ed.	P.S. 347 ASL & English Lower School, NYC	David Bowell, Principal
Graduate Research Assistant	08/12	--	Cognitive Neuroscience, Psychology, Linguistics, Bilingualism, Reading	Brain & Language Laboratory for Neuroimaging (BL2), Gallaudet Univ., DC	Dr. Laura-Ann Petitto, Scientific Director

Academic and Professional Honors

Neuroscience Scholars Program, Society for Neuroscience, 2015-2017
NSF National Scholar, Broadening the Participation of Deaf Students in Sign Language, 2015
NSF Science of Learning Center Travel Fellow, University of Hong Kong, 2015
Elizabeth Bates Graduate Research Award, University of California San Diego, 2014
Selected NSF National Scholar, Broadening the Participation of Deaf Students in Sign Language, 2013
VL2 Student Travel Grant (*7 separate awards*), Gallaudet University, 2012-2015
VL2 Student Training Grant, Gallaudet University, 2012
NSF Science of Learning Center VL2 Student-Scholar, 2012 to present
Graduate Student Travel Fund, Gallaudet University, 2012
Student Scholarship Award, California Educators of the Deaf, 2009
Graduated with Highest Honors, RIT, 2004
Outstanding Graduate Award, RIT, 2004

Memberships: NSF's Visual Language and Visual Learning (VL2) Student Network; Society for the Neurobiology of Language (SNL); Society for Research on Child Development (SRCD); Sign Language Linguistics Society; Society for Neuroscience

C. Contributions to Science

I. fNIRS Neuroimaging & fNIRS + Eye Tracking Integration: The integration of functional Near Infrared Spectroscopy (fNIRS) and eye tracking technologies is a powerful innovation in developmental cognitive neuroscience research as it permits us to associate the development and growth of brain sites and systems with infants' behavioral development, here, higher cognitive attention to visual stimuli. It advances our ability to answer new scientific questions about the dimensions of infant sensitivity to various parts of language, both signed and spoken, and the multiple levels of reading processing (phonological, orthographic) in children and adults. I was the lead graduate student and personally handled all aspects of this integration, which required months of technological and programming work. To arrive at this point, I received extensive training in Tobii eye tracking methodologies, data collection, and data analysis, and performed a pilot study with infants to test

my capabilities for running an eye tracking study. I also became certified in fNIRS neuroimaging via BL2's certification program developed in 2006-2012 via NIH R01 and R21 grants (Petitto, PI) and supported the training of other research assistants in this certification program. The yoked fNIRS-eye-tracking setup has been successfully tested in children and adults with minimal increases in in-laboratory time (~3 minutes). We ran a formal study of visual attention, language experience, and reading development in 4-year-old and 7-year-old children. Data analysis was successful and we discovered important trends in visual attention changes—with associated activation of neural sites for language—based on children's early language experiences that also influence how they process and read text. This same setup will be used for the proposed F31 study to associate the timing and location of neural sites and systems implicated in rhythmic-temporal processing and infants' looking behavior. I have also participated in fNIRS-only neuroimaging studies of phonological, semantic, and syntactic processing in deaf bilinguals (+/- early visual language exposure), and recently analyzed and presented novel fNIRS results at the Society for Neuroscience meeting in October 2015.

Abstracts:

Petitto, L.A., Stone, A., Andriola, D., & Langdon, C. (2015, October). *Age of sign-speech bilingual language exposure and syntactic processing in deaf individuals with cochlear implants using functional near infrared spectroscopy*. Society for Neuroscience, Chicago, IL.

Petitto, L.A., Langdon, C., & Stone, A. (2015, March). Early sign language experience and visual attention in young deaf readers: an eye tracking and fNIRS investigation. In K. MacDonald & A. Fernald (Chairs), *New Approaches to Understanding Human Language: Insights from Neuroimaging and Behavioral Studies of Visual Language Learning*. Symposium at Society for Research on Child Development (SRCD), Philadelphia, PA.

II. Relationship of Visual Sign Phonology, Language, and Reading in Deaf Children and Adults: A key BL2 theoretical advancement has been the conceptualization of how deaf children use an abstract level of phonological processing (key to this is sensitivity to rhythmic-temporal patterning at the core of human language phonological organization) in order to acquire language. Using this same mechanism, they are also able to segment, categorize, and integrate multiple visual cues (sign language, orthographic patterning, fingerspelling, speechreading) as a gateway to reading mastery in English. We call this integration *visual sign phonology* (VSP). I have participated in planning, collecting and analyzing data from multiple BL2 neuroscience research studies (including the study cited above) linked to this theme. In addition, I created stimuli and ran a pilot study with infants during my PhD program's required summer lab rotation at the UCSD Infant Vision Lab (PI: Bosworth). This work focused on infant perception of sonority levels in fingerspelling, revealing differences in sensitivity to phonetic contrasts based on language experience. Finally, I performed a secondary analysis of a large VL2 dataset showing that deaf adults' fingerspelling fluency is a strong predictor of reading fluency, again illustrating the contribution of visual sign phonology to reading success. We have published, submitted, and/or are preparing papers discussing all of the above. My scientific research will focus on further developing the VSP model with Dr. Petitto and testing the hypotheses that follow from this proposed model.

Publications:

Stone, A., Kartheiser, G., Hauser, P.C., Petitto, L.A., & Allen, T.E. (2015). Fingerspelling as a novel gateway into reading fluency in deaf bilinguals. *PLoS ONE, 10*(10):e0139610.

Petitto, L.A., Langdon, C., Cochran, C., Andriola, D., Stone, A., & Kartheiser, G. (Under 2nd review). *Visual sign phonology: Insights into human reading from a natural soundless phonology.* WIREs.

Williams, J., Stone, A., & Newman, S.D. (Submitted). *Modality-independent mechanisms for language production: Phonological neighborhood structure impacts sign language production.* Cognitive Psychology.

Stone, A., Petitto, L.A., & Bosworth, R. (In preparation). *Sonority values modulate infants' attraction to sign language.*

III. Bilingual Sign-Print Reading Materials for Deaf Children: A key priority in the Educational Neuroscience discipline is the principled two-way communication between cognitive neuroscientists and society, including teachers and parents. As a kindergarten teacher, I saw a dearth of bilingual reading materials for signing deaf and hearing children, so I created the *world's first* ASL-English bilingual ebook, named "Pointy Three" which has been downloaded 2,500 times. After joining Gallaudet University, I was invited to be part of the National Science Foundation Science of Learning Visual Language and Visual Learning (VL2)'s storybook app development team and participated in the writing, planning, and dissemination of fiction and non-fiction apps.

In keeping with two-way communication between science and society, I have given workshops (too numerous to list here) to educators on the value of sign-print bilingual materials and how they may create their own materials. I have also explored, from a scholarly perspective, the evolution of these products, their usability and efficacy, and how we can expand access on a worldwide level for all deaf children, resulting in my first peer-reviewed publication in *Critical Inquiry in Language Studies*. Also, in BL2, we explore the design of these products using a cognitive neuroscience lens, asking whether early visual language experience changes how children use these products. This is an important example of how science and society can interact to create long-lasting changes in educational opportunities for deaf and hearing children, and I (in my role as educational-cognitive neuroscientist) intend to retain close ties to educators and educational researchers, using their questions and concerns to drive development of new hypotheses and research studies.

Publications:

Stone, A. (2014). New directions in ASL-English bilingual ebooks. *Critical Inquiry in Language Studies, 11*(3).

Stone, A. (2012). *Pointy three* [Electronic book]. (ASL & English children's book). Retrieved from iTunes Store.

Abstracts:

Mirus, G., Malzkuhn, M., Stone, A., & An, J-S. (2015, July). *Sign language bilingual ebooks for children*. 17th World Congress of World Federation of the Deaf, Istanbul, Turkey.

Horejes, T. & Stone, A. (2009, April). *Critical policy issues in deaf education: Linguistic modalities, curriculum, and instructional strategies.* Presented at American Educational Research Association (AERA), San Diego.

D. Scholastic Performance

YEAR	SCIENCE COURSE TITLE	GRADE	YEAR	OTHER COURSE TITLE	GRADE
	Rochester Institute of Technology	B.S.		Rochester Institute of Technology	B.S.
2000	Introduction to Psychology	A	2000	Foundations of Communication	B
2000	Survey of Computer Science	A	2000	First Year Enrichment	B
2000	Calculus III	B	2000	Fine Arts: Visual Arts	A
2000	Human Biology I	A	2000	Interpersonal Communication	B
2000	Human Biology I Lab	A	2000	Computer Applications in Commun.	A
2001	Human Biology II	A	2000	Theatre Practicum	A
2001	Human Biology II Lab	A	2001	Political Ideologies	A
2002	Computer Science I	B	2001	Visual Communication	A
2002	Quantitative Research Methods	A	2001	Persuasion	A
2003	Qualitative Research Methods	A	2001	Principles of Marketing	B
2004	Abnormal Psychology	A	2001	Written Argument	A
	University of California San Diego	M.A.	2001	International Relations	A
2008	Cognitive Development & Educ.	A	2001	Theatre Practicum	A
	Gallaudet University	Ph.D.	2001	Survey of International Business	A
2012	Educational Statistics I	A	2001	Technical Writing	C
2012	Research Credit: Dr. Marlon Kuntze	A	2001	Mass Communication	B
2013	Advanced Research Design I	A	2001	Effective Speaking	A
2013	Research Credit: Dr. Marlon Kuntze	A	2001	Social Sciences Independent Study	A
2013	Educational Neuroscience Prosem.	P	2002	Politics in China	A
2013	Foundations I Educational Neurosci	A	2002	Argument & Discourse	A
2013	Proseminar I Educational Neurosci	A	2002	Small Group Communication	A
2013	New Directions in Neuroethics	A	2002	Professional Writing	A
2013	Psychology Statistics I	A	2002	Social Sciences Independent Study	A
2014	First & Second Language Acquisition	A	2002	Senior Seminar	A
2014	Foundations II Educational Neurosci	A	2002	Creative Writing: Prose Fiction	B
2014	Proseminar II Educational Neurosci	A	2002	Government and Politics of Africa	A
2014	Contemporary Mthds in Neuroimagin	A	2002	Theories of Communication	A
2014	Psychology Statistics II	A	2002	Introduction to Philosophy	A
2014	Data Visualization	A	2002	Freedom of Expression	A

YEAR	SCIENCE COURSE TITLE	GRADE
2014	Summer Lab Rotation I	A
2014	Neuroanatomy & Neuropsychology	A
2014	EduNeuro GuidedStudies I: Translati	A
2015	EduNeuro GuidedStudiesII:Researc	A
2015	Analysis of Variance (ANOVA)	A

S = Satisfactory; full credit
P = Pass; full credit

YEAR	OTHER COURSE TITLE	GRADE
2002	Wines of the World	A
2003	The Evolving English Language	A
2003	20th Century American Diplomacy	B
2003	Intercultural Communication	A
2003	Cultural Change	A
2003	Rhetoric & Discourse	A
2003	Public Relations	A
2003	Strategy in Global Environments	C
2003	Marketing in Global Environments	B
2003	Foods of the World	A
2004	Senior Thesis in Communication	A
2004	Wines of the World II	A
	University of California, San Diego	M.A.
2008	Language, Culture, & Education	A
2008	Biling. Ed. History, Politics, & Theory	A
2008	Intro. To Teaching & Learning I	A
2008	Intro. To Teaching & Learning II	A
2008	Practicum in Teaching & Learning I	S
2008	Practicum in Teaching & Learning II	S
2008	Voices: Deaf People in America	A
2008	Edu. Research Practicum	S
2008	Intro. Teaching & Learning Resources	A
2008	Technology: Teaching & Learning	A
2008	Teaching English Language Learners	A
2008	ASL & English Bilingual Education I	A
2008	Innovative Instructional Practices I	A
2009	ASL & English Bilingual Education II	A
2009	Innovative Instructional Practices II	A
2009	Elementary Teaching Practicum	S
2009	ASL & English Bilingual Education III	A
2009	Innovative Instructional Practices III	A
2009	Elementary Teaching Practicum	S
2009	Inclusive Educational Practices	A
2009	Research: ASL/English Bilingual Ed I	A
2009	Equitable Educational Practices	A
2010	Research: ASL/English Bilingual Ed II	A
2010	Research Practicum	S
2010	Research ASL/English Bilingual Ed III	A
2010	Deaf Specialist Teaching Practicum	S
2010	M.A. Thesis	A
	Gallaudet University	Ph.D.
2012	Seminar in Scholarly Discourse	P
2012	Proseminar I: Critical Pedagogy	A
2013	Proseminar II: Critical Pedagogy	A
2013	Critical Studies in Language & Culture	A
2014	Education Policy & Politics	A
2015	Sign Language Planning & Advocacy	A

BIOGRAPHICAL SKETCH

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED FIVE PAGES.**

NAME: Laura-Ann Petitto

eRA COMMONS USER NAME (credential, e.g., agency login): lapetitto

POSITION TITLE: Co-Principal Investigator & Science Director, National Science Foundation & Gallaudet University's Science of Learning Center, Visual Language & Visual Learning (VL2). Cognitive Neuroscientist & Scientific Director, Brain & Language Laboratory for Neuroimaging (BL2), Gallaudet University. Full Professor, Department of Psychology, Gallaudet University. Affiliated Full Professor, Department of Psychology, Georgetown University; Sin Wai-Kin Distinguished Visiting Professor, University of Hong Kong

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Ramapo College	BS Honors	05/1975	Theoretical Psychology
New York University	Master's	11/1978	Rehab. Counseling Psychology
Harvard University	Master's	06/1981	Human Dev. & Psychology
Harvard University	Doctorate	03/1984	Human Dev. & Psychology
MacArthur Postdoc Award *Salk Institute & UCSD*	Post-Doc	12/1984	Psycholinguistics (Bellugi & Bates)

A. Personal Statement

I am a Developmental Cognitive Neuroscientist with four decades of scientific study of cross-species studies of language, cross-modal studies of language, studies of reading, and bilingualism, using among the world's leading brain imaging technologies. Presently, I use functional Near-Infrared Spectroscopy (fNIRS—Hitachi ETG 4000), which I have helped to pioneer by advancing its imaging capacity and analyses, in infants, children and adults. My research is concerned with uncovering the biological and genetic mechanisms and environmental factors that together determine how our species acquires language, as well as how language is organized and processed in the human brain. In addition to fNIRS neuroimaging, in my nearly 20 years as a Research Scientist in the Department of Neurology and Neurosurgery at the Montreal Neurological Institute & Hospital with Drs. Brenda Milner, Michael Petrides, and Robert Zatorre (while a professor in McGill's Department of Psychology), I have used many innovative approaches to studying the adult brain and language, including (i) Cognitive Neuroscience investigations of the neural substrates underlying monolingual and bilingual adult language processing, with MRI, fMRI, and PET structural and neuroimaging technologies, on which I have outstanding expertise; fMRI studies continued while I was a professor at Dartmouth and the University of Toronto. My research has further included (ii) infant studies of motoric constraints and patterning of human language production using OPTOTRAK motion analyses (which I also built to be functionally equivalent to a "speech spectrogram" recording F_o, etc., but, here, for sign, inventing a "sign spectrogram"); (iii) language and reading acquisition studies (including fNIRS brain imaging studies) of young monolingual and bilingual children, as well as basic studies of how signed languages are acquired in early life, as well as their neural representation, including American Sign Language (ASL) and Langue des Signes Québécoise (LSQ), (iv) genetic analyses to identify polymorphisms in candidate genes associated with monolingual and bilingual language development and adult language processing in typical and atypical populations, and (v) cross-species analyses of the extent to which chimpanzees can (and cannot) master aspects of human language. See: www.gallaudet.edu/petitto

B. Positions and Honors

Positions and Employment

1978-1978 Lecturer, New York Society for the Deaf (Course: "Introduction to Linguistics")

1981-1983	Undergraduate Lecturer/Psychology Tutor, Harvard University, Department of Psychology
1983-1984	The John D. and Catherine T. MacArthur Foundation, Post-Doctoral Fellow, The Salk Institute for Biological Studies, Neurolingiustics Laboratory/Dr. Ursula Bellugi, and UCSD/Dr. Elizabeth Bates
1983-1989	Assistant Professor, McGill University, Department of Psychology; Director of Cognitive Neuroscience Laboratory for Language, Sign, & Cognition
1989-1999	Associate Professor, McGill University, Department of Psychology; Director of Cognitive Neuroscience Laboratory for Language, Sign, & Cognition
1999-2001	Full Professor, McGill University, Department of Psychology; Senior Scientist & Director of Cognitive Neuroscience Laboratory for Language, Sign, & Cognition
2001-2007	Full Professor, Dartmouth College, Dept. of Psychological & Brain Sciences, and Department of Educational Neuroscience and Human Development; also, The John Wentworth Endowed Chair; Senior Scientist & Director of Cognitive Neuroscience Laboratory for Language, Bilingualism & Child Development; Founder and Chairman: Department of Educational Neuroscience and Human Development
2004-2006	Co-PI National Science Foundation's first/original cohort of its Science of Learning Centers, "Center for Cognitive and Educational Neuroscience," Dartmouth College
2007-2011	Full Professor, University of Toronto, Department of Psychology; Senior Scientist & Director of Genes, Mind & fNIRS Brain Imaging Laboratory for Language, Bilingualism and Child Development
2011-present	Full Professor, Department of Psychology, Gallaudet University Co-Principal Investigator and Science Director: National Science Foundation and Gallaudet University's Science of Learning Center, Visual Language and Visual Learning (VL2) Cognitive Neuroscientist/Scientific Director and Founder: Brain and Language Laboratory for Neuroimaging (BL2) Co-Founder of Gallaudet's Ph.D. Program in Educational Neuroscience (PEN) Chair of Steering Committee: Ph.D. Program in Educational Neuroscience
2011-present	Affiliated Full Professor: Department of Psychology, Georgetown University
2015-2018	Sin Wai-Kin Distinguished Visiting Professor in the Humanities, University of Hong Kong

<u>Other Experience and Professional Memberships</u>

1973-1976	Project Coordinator & Primary Teacher of "Project Nim Chimpsky"(and lived w/chimpanzee; language-training project), Columbia University
1983-1993	Research Scientist, Department of Neurology and Neurosurgery, Montreal Neurological Institute, McGill University
1993-2001	Research Scientist, McDonnell-Pew Centre for Cognitive Neuroscience, Brain Imaging Center; Department of Neurology and Neurosurgery, Montreal Neurological Institute, McGill U.
1993-	Member, Society for Research in Child Development
1999-	Member, Society for Neuroscience
2001-	Member, American Association for the Advancement of Science
2002-2007	Chairman of Department, Dartmouth College. Creator and design of entirely new department: Dept. of Educational Neuroscience and Human Development. Co-Creator of new discipline (coined name of discipline).
2004-	Charter Member, Society for Language Development (SLD) and the new international journal, "Journal of Language and Learning Development"
2004-	Charter Member, International Mind, Brain, and Education Society (IMBES). Charter member of the new society. Founding Member of the new discipline "Educational Neuroscience" (aka "Mind, Brain, and Education").

Honors

1983-1984	The John D. and Catherine T. MacArthur Foundation. Postdoctoral Fellowship (awarded to "the top 10 doctoral students in the United States")
1985-1995	Natural Sciences and Engineering Research Council of Canada (like NSF), 10 year University Research Fellow (like the U.S. "Career Development Award")
1988-	APA "Young Psychologist Award" & traveling fellow to Sydney, Australia, APA Meeting
1988-	APA "Young Scientist Award" Division 7/Boyd R. McCandless "for outstanding early career contributions to, and achievements in, Developmental Psychology."
1991-1992	Center for Advanced Studies in the Behavioral Sciences, Invited Center Fellow
1997	Boys Town Medical Center Public achievement award "in recognition of international contributions on behalf of Deaf children and their families."
1998	John Simon Guggenheim Foundation Award for "unusually distinguished achievement in the past and exceptional promise for future accomplishments," in Neuroscience.
2004	Université de Montréal Honorary Diploma, Faculty of Medicine: "The Justine and Yves Sergeant International Prize in Cognitive Neuroscience" Quebec, Canada, June 2004.
2004	Phi Beta Kappa Society. Inducted as Honorary member for outstanding teaching and scholarship. Dartmouth College, Hanover, N.H. Conferred in June 2005.
2004	Honorary Master's Degree, Dartmouth College, Hanover, NH
2005	Carnegie Institution Award and Distinguished Invited Lecture
2009	Association for Psychological Science. Elected APS Fellow for life.
2009	American Association for the Advancement of Science. Elected AAAS Fellow for life.

C. Contributions to Science

I. Cognitive Neuroscience Investigations of the Neural Tissue and Systems in Language Acquisition in Monolinguals and Bilingual Infants. My research points towards a common neural foundation for how all young human children acquire language, be it signed or spoken, and towards the existence of select tissue in the human brain that helps young babies learn language, for example, the Superior Temporal Gyrus (STG)—tissue vital for young babies' phonological segmentation and categorization of the linguistic stream around them. I have advanced the hypothesis that this brain tissue is not neurally set to sound but instead to specific rhythmic-temporal patterns in maximal contrast –crucially, in ~1.5 Hertz temporal bursts – which are uniquely part of language phonetic-syllabic structure, which corroborated my earlier infant manual babbling discoveries (see Section II below) and moving beyond "where" language processing occurs in the human brain to explain the nature of its underlying neural basis.

Petitto, L.A., Berens, M.S., Kovelman, I., Dubins, M.H., Jasinska, K. and Shalinksy, M. (2012). The "Perceptual Wedge Hypothesis" as the basis for bilingual babies phonetic processing advantage: New insights from fNIRS brain imaging. *Brain and Language, 121*(2), 142-155.

Shalinsky, M.H., Kovelman, I., Berens, M.S., & **Petitto, L.A.** (2009). Exploring Cognitive Functions in Babies, Children & Adults with Near Infrared Spectroscopy. *Journal of Visualized Experiments, 29*.

Petitto, L.A. (2007). Cortical images of early language and phonetic development using Near Infrared Spectroscopy. In K. Fischer & A. Battro (Eds.), *The Educated Brain*. England: Cambridge University Press, pp. 213-232.

Petitto, L.A. & Dunbar, K. (2004). New findings from educational neuroscience on bilingual brains, scientific brains, and the educated mind. In K. Fischer & T. Katzir (Eds.), *Building Usable Knowledge in Mind, Brain, & Education*. England: Cambridge University Press.

II. Developmental Milestones in Signed and Spoken Language Acquisition in Monolinguals and Bilinguals Infants. My scientific achievements have included the discovery of babbling on the hands in Deaf children exposed to signed languages (manual Babbling), the maturational timing of bilingual children's achievement of the classic language milestones, and the similarities and differences between all children's early gestures and early language (first words, pronouns). Taken together, these discoveries forced a reconceptualization of the nature of human language by decoupling Speech and Language, and suggested a common, biological basis for all language learning, independent of modality, and tied to temporal-rhythmic, phonetic-syllabic patterning.

Baker, S.A., Golinkoff, R. M., & **Petitto, L.A**. (2006). New insights into old puzzles from infants' categorical discrimination of soundless phonetic units. *Language Learning and Development, 2*(3), 147-162.

Petitto, L.A., Holowka, S., Sergio, L. E., & Ostry, D. (2001). Language rhythms in baby hand movements. *Nature, 413*, 35-36.

Petitto, L.A., Katerelos, M., Levy, B., Gauna, K., Tétrault, K., & Ferraro, V. (2001). Bilingual signed and spoken language acquisition from birth: Implications for mechanisms underlying early bilingual language acquisition. *Journal of Child Language, 28*(2), 453-496.

Petitto, L.A., & Marentette, P. (1991). Babbling in the manual mode: Evidence for the ontogeny of language. *Science, 251*, 1483-1496.

III. Educational Neuroscience Investigations of Reading in Monolinguals and Bilingual Children. I am also known for my discoveries about reading and the "reading brain," by studying monolingual and bilingual children when they first begin to read, achieve skilled reading, and how monolingual an bilingual adults read and process language. A key finding has been that age of bilingual exposure (AoE) is a powerful predictor of reading outcomes in children and that bilingual education may even ameliorate the impact of low socioeconomic status in American schools by increasing the likelihood of reading success in children.

Stone, A., Kartheiser, G., Hauser, P.C., **Petitto, L.A.,** & Allen, T.E. (2015). Fingerspelling as a novel gateway into reading fluency in deaf bilinguals. PLoS ONE 10(10):e0139610

Jasińska, K. & **Petitto, L.A.** (2014). Development of Neural Systems for Reading in the Monolingual and Bilingual Brain: New Insights from functional Near Infrared Spectroscopy Neuroimaging. *Developmental Neuropsychology, 39*(6).

Jasińska, K. & **Petitto, L.A.** (2013). How Age of Bilingual Exposure Can Change the Neural Systems for Language in the Developing Brain: A functional Near Infrared Spectroscopy Investigation of Syntactic Processing in Monolingual and Bilingual Children. *Developmental Cognitive Neuroscience, 6*, 87-101.

Kovelman, I., Berens, M. & **Petitto, L.A.** (2013). Should Bilingual children learn reading in two languages at the same time or in sequence? Evidence of a bilingual reading advantage in children in bilingual schools from monolingual English-only homes. *Bilingual Research Journal, 36*, 35-60.

IV. Cognitive Neuroscience Investigations of the Neural Substrates Underlying Monolingual and Bilingual Adult Language Processing. Following from my infant studies, we have repeatedly found, in adults, that the same brain tissue recruitment is used when processing the same parts of language regardless of whether the language is signed or spoken, and to the key role of the STG as a site of phonological processing. These findings further suggest that all human languages, independent of modality, share the same biological underpinnings.

Kovelman, I., Shalinsky, M. H., Berens, M., & **Petitto, L. A.** (2014). Words in Bilingual Brain: fNIRS Brain Imaging Investigation of Lexical Repetition in Sign-Speech Bimodal Bilinguals. *Frontiers in Neuroscience, 8*(606).

Kovelman, I., Shalinsky, M.H., White, K. S., Schmitt, S.N., Berens, M.S., Paymer, N., & **Petitto, L.A.** (2009). Dual language use in sign-speech bimodal bilinguals: fNIRS brain-imaging evidence. *Brain & Language, 109*, 112-123.

Kovelman, I., Baker, S.A., & **Petitto, L.A**. (2008). Bilingual and Monolingual brains compared: An fMRI investigation of syntactic processing and a possible "neural signature" of bilingualism. *Journal of Cognitive Neuroscience, 20*(1), 153-169.

Petitto, L.A., Zatorre, R., Gauna, K., Nikelski, E.J., Dostie, D., & Evans, A. (2000). Speech-like cerebral activity in profoundly deaf people processing signed languages: Implications for the neural basis of human language. *Proceedings of the National Academy of Sciences, 97*(25), 13961-13966.

V. Cross-Species Analyses of the Extent to which Chimpanzees Can and Cannot Master Aspects of Human Language. My first contributions to science were my discoveries involving animal language and communication in chimpanzees, following from my roles as primary teacher and project coordinator of "Project Nim Chimpsky." My discoveries pointed towards a natural biological endowment of language for humans only, giving us all unique insights into the essence of being human.

Seidenberg, M.S., & **Petitto, L.A**. (1981). Ape signing: Problems of method and interpretations. *Annals of the New York Academy of Science, 364*, 115-130.

Terrace, H.S., **Petitto, L.A**., Sanders, R.J., & Bever, T.G. (1979). Can an ape create a sentence? *Science, 206*, 891-902.

Petitto, L.A., & Seidenberg, M.S. (1979). On the evidence for linguistic abilities in signing apes. *Brain and Language, 8*, 72-88.

Seidenberg, M.S., & **Petitto, L.A**. (1979). Signing behavior in apes: A critical review. *Cognition, 7,* 177-215.

For a full list of publications please see http://www.gallaudet.edu/petitto

D. Research Support

NOTE: Petitto has 32 years of *uninterrupted competitive Federal funding* spanning Canada and the United States governmental granting agencies (1984-2015). In addition, she has had private foundation funding (e.g., W.M. Keck Foundation, Dana Foundation, Spencer Foundation).

Ongoing Research Support

• *IIS-1547178, Petitto (PI)* — *2015-present*
INSPIRE: The RAVE Revolution for Children with Minimal Language Experience During Sensitive Periods of Brain and Language Development. With Co-PIs Co-PIs Malzkuhn (MoCap/Gallaudet), Merla/Thermal IR (U. Chieti, Italy), Scassellati/Robotics (Yale), Traum/Avatars (USC).

• *W.M. Keck Foundation, Petitto (PI)* — *2015-present*
Seeing the Rhythmic-Temporal Beats of Human Language. Goal: Create a revolutionary learning tool that provides the core components of language's rhythmic-temporal phonological patterning to babies during critical periods of early brain development, with Co-PIs Traum/Avatar (USC), Scassellati/Robotics (Yale), Merla/Thermal IR (U. Chieti, Italy).

• *F31 DC014230, Kartheiser (PI/Trainee), Petitto (Sponsor)* — *2014-present*
NIDCD Kirchstein Predoctoral Fellowship: Neuroplasticity of Spatial Working Memory in Signed Language Processing

• *IIS-1343948, Petitto (PI)* — *2013-present*
National Science Foundation Avatar & Robotics Signing Creatures Workshop

• *SBE-1041725, Petitto (Co-PI)* — *2013-present*
National Science Foundation, Science of Learning Center, Visual Language and Visual Learning, at Gallaudet University, Washington, DC

• *R01 HD04585503, Petitto (PI)* — *2006-2013*
NICHD: Neuroimaging and Behavioral Studies of Bilingual Reading. Goal: Understand reading in bilingual children and adults. This research involves both standardized behavioral measures and state-of-the art neuroimaging measures (fMRI and NIRS).

• *R21 HD50558, Petitto (PI)* — *2006-2012*
NICHD: Infants' Neural Basis for Language Using New NIRS. Goal: Understand, using NIRS neuroimaging technology, the neural mechanisms that enable human infants to rapidly acquire the phonetic inventory of their language.

• *Canadian Foundation for Innovation Major National Award (CFI), Petitto (PI)* — *2008-2012*
Brain, Behaviour, Genes: New Knowledge Form Innovative Studies of Language and Reading in Monolingual and Bilingual Children Leads to Optimal Pathways to Remediation

• *Ontario Research Fund for Research Infrastructure Funding (ORF), Pettito (PI)* — *2008-2012*
Brain, Behaviour, Genes: New Knowledge Form Innovative Studies of Language and Reading in Monolingual and Bilingual Children Leads to Optimal Pathways to Remediation

Completed Research Support

• *Gazzaniga, Petitto, Dunbar, Grafton, Heatherton (Co-PIs)* — *2004-2006*
National Science Foundation's *Science of Learning Center*, "Center for Cognitive and Educational Neuroscience," Dartmouth College. Petitto: Major role in scientific design and vision creator, center design/functions, new discipline Educational Neuroscience, major author of submitted grant (total that was to be funded = $50 million).

• *Gazzaniga (PI); Petitto (Co-PI), Dunbar (Co-PI)* — *2004-2007*
Dana Foundation, Arts Education and Its Impact on the Brain and Enhanced Learning In Other Knowledge Domains. Petitto: Major role in scientific design/creator of vision, major author of the submitted grant (Total awarded = $1.8 million.) The goal of Petitto's research in the Consortium was to understand the impact of early intensive education in the Arts on individuals *other* content learning and cognitive processing.

SECTION II – SPONSOR AND CO-SPONSOR INFORMATION

A. Research Support Available

Funding	PI	Funding Source	Dates	Award Amount	Title
[[NSF IIS-1547178	Petitto	NSF Information and Intelligent Systems	2015-2018	$1,000,000	"INSPIRE: The RAVE Revolution for Children with Minimal Language Experience During Sensitive Periods of Brain and Language Development"]]
W.M. Keck Foundation	Petitto	W.M. Keck Foundation	2015-2018	$900,000	"Seeing the Rhythmic-Temporal Beats of Human Language"
NSF SBE-1041725	Petitto	NSF Social Behavioral and Economic Sciences	2013-present	$50,000 (Sub-Award grant written by Petitto)	"The impact of early visual language experience on visual attention and visual sign phonology processing in young deaf emergent readers using early-reading Apps: A combined Eye Tracking and fNIRS brain imaging investigation."
NSF SBE-1041725	Petitto Co-PI: NSF Science of Learning Center Grant, Visual Language and Visual Learning, VL2	NSF Social Behavioral and Economic Sciences	2011-2017	$2,500,000, plus (see Title note)	Petitto Center Leadership and major author of NSF Center's Strategic and Implementation Plan, and Annual Reports on which the Center won $2,500,000, in addition to a $1 million unsolicited Center merit increase (i.e., Year 10 was restored to the Center, which is a year that was previously lost by the Center prior to Petitto's arrival as Co-PI). Petitto's Brain and Language Laboratory for Neuroimaging, BL2, a major "Resource Hub" of the Center, receives infrastructure funds from this Center grant from which her students benefit.

Dr. Petitto was also PI of the NIH R01 HD04585503 ("Neuroimaging and Behavioral Studies of Bilingual Reading," 2006-2013, $4,445,803) and the NIH R21 HD50558 (Infants' Neural Basis for Language Using New NIRS, 2006-2012, $439,725). Dr. Petitto is also the Co-PI of the SBE-1041725 Federal grant for the NSF Science of Learning Center, "Visual Language and Visual Learning, VL2" (one of 6 in the nation), 2011-2016, $2,500,000 and serves as the Center's Co-PI as well as its Science Director. Dr. Petitto has had 32 years of *un-interrupted competitive Federal funding* spanning Canada and the United States governmental granting agencies (1984-2015) and was the recipient of among the country of Canada's most honored grant-scientific scholar awards, including The Canadian Foundation for Innovation. In addition, she has had private foundation funding (e.g., Dana Foundation $1,800,000, Co-PI with cognitive neuroscientist Michael Gazzaniga, 2004-2007 and the Spencer Foundation, Petitto, PI, $250,000, 2000-2003.) Dr. Petitto also was the leading/main author and Co-PI with Michael Gazzaniga on the Dartmouth College NSF Science of Learning Grant, "Center for Cognitive and Educational Neuroscience," T=$2,500,000, 2004-2006, during which time Dr. Petitto was among the first founders in the United States of the new discipline *Educational Neuroscience*. Prior to this, Dr. Petitto's grants include those with renowned Montreal Neurological Institute (MNI) cognitive neuroscientists Brenda Milner, Michael Petridies, Robert Zatorre, Medical Research Council of Canada, and she was Co-PI on multiple MNI Center grants with the above team, including The McDonnell-Pew Center Grant in Cognitive Neuroscience (while Dr. Petitto was Professor at McGill University, Montreal) and most recently she was winner of the prestigious and significant "Canadian Foundation for Innovation" grant (2 continuous funding cycles in a row) with matching funds from the Ontario Research Fund (also 2 continuous funding cycles in a row).

B. Sponsor's Previous Fellows/Trainees-Petitto's student sponsorship spans 30 years and includes many hundreds of students/trainees. Here, please find only the past 6 years of only *advanced* student training:

1. Kaja Jasinska, Ph.D., Petitto's PhD student. Now a Postdoctoral Fellow, Haskins Laboratories/Yale University with Dr. Ken Pugh

2. Ioulia Kovelman, Ph.D., Petitto's PhD student. Now an Assistant Professor, Language & Literacy Lab, University of Michigan
3. Lynne Williams, Ph.D., Petitto's Postdoctoral Fellow, Rotman Research Institute, University of Toronto
4. Melody Berens, Ph.D., Petitto's Postdoctoral Fellow, Assistant Research Scientist, Center for the Advanced Study of Language, University of Maryland
5. Katherine S. White, Ph.D., Petitto's Postdoctoral Fellow, Assistant Professor, University of Waterloo
6. Art Kaso, Ph.D. Petitto's Postdoctoral Fellow and fNIRS brain imaging Physicist, University of Toronto
7. Mark Shalinsky, Ph.D., Petitto's Postdoctoral Fellow, fNIRS brain imaging Physicist, University of Michigan
8. Sujin Yang, Ph.D., Petitto's Postdoctoral Fellow, University of Toronto

C. Training Plan, Environment, Research Facilities

Mr. Stone's Training Plan is composed of several distinct but interdependent goals that will equip him with the necessary experience to become an outstanding, independent educational-cognitive neuroscientist researching ground breaking questions of language acquisition, visual signed languages, and reading development in deaf and hearing populations. Gallaudet University, as the location of the Ph.D. in Educational Neuroscience program (PEN), my Brain and Language Laboratory for Neuroimaging (BL2), and the NSF Science of Learning Center, Visual Language & Visual Learning (VL2) are, together, the most ideal environment for Mr. Stone because altogether these entities provide the support that will allow him to carry out most successfully the training plan. Mr. Stone has full access to my BL2 laboratory and all of its computer and technical equipment, including most importantly our fNIRS optical topography neuroimaging system, Tobii eye tracking system, Infant Habituation Laboratory, and the state-of-the art Motion Capture system purchased with funds from the W.M. Keck Foundation grant that I recently won (Petitto, PI), which is in my BL2 lab's sister lab, Malzkuhn's Motion Light Lab (literally in adjacent joined lab spaces). Taken together, he will be able to carry out successfully his proposed research study.

BL2 and the NSF Center VL2 supports many researchers who are trained in language and cognitive measures for deaf infants and children, as well as researchers who are expert in many methodologies (behavioral, eye tracking, neuroimaging, motion capture) for use with infants, children, and adults, and in deaf and hearing populations. Mr. Stone has been successfully fNIRS-certificated, and will continue to be supported in advanced behavioral, eye tracking, and neuroimaging methodologies through the Ph.D. in Educational Neuroscience program and through the NSF-VL2 partnership agreements with Georgetown University, Stanford University, Yale University, San Diego State University, University of California San Diego, University of California Davis, University of New Mexico, Rochester Institute of Technology, the University of Hong Kong, and more. In particular, the Ph.D. in Educational Neuroscience program requires two summer cognitive neuroscience lab rotations; Mr. Stone has completed his first at the UCSD Infant Vision Lab (PI: Karen Dobkins and Rain Bosworth), where he gained invaluable training in infant testing and eye tracking methodologies, and [[recently completed his second lab rotation at the Hearing & Speech Sciences Laboratory (PI: Brendan Weekes and I-Fan Su) at the University of Hong Kong, where he gained basic training in EEG and data analysis as used for studies of dyslexia and communication disorders.]] Also, Gallaudet's consortium program provides access to neuroscience and advanced statistical training at the University of Maryland's Language Science Center and at Georgetown University, where I am an Affiliated Full Professor. Additionally, both our Ph.D. program in Educational Neuroscience and our NSF-VL2 Center provide unique training on responsible ethical conduct of research, including required Neuroethics training courses, with a special focus on working with deaf and hard of hearing populations, and other important professional issues. Further, Mr. Stone has continual contact with his graduate adviser (me), other mentors at Gallaudet University, and within the NSF-VL2 Center network and VL2's predoctoral trainees across a variety of disciplines, which foster interdisciplinary and synergistic collaboration. As NSF support of VL2 approaches a natural end, Gallaudet University is progressively taking over as VL2's main source of funding, permitting Mr. Stone's uninterrupted pursuit of his scientific and scholarly interests. His goals are as follows:

1. **To master design and administration of scientific studies in language perception and reading studies with neuroimaging technology (fNIRS), with eye tracking technology, and with infants and children**

Because Mr. Stone is interested in neural underpinnings of language and reading, especially infant sensitivity to rhythmic-temporal patterning, he will attain expertise in scientific investigation in these areas using a variety of technologies and approaches, all available at my laboratory. With respect to fNIRS neuroimaging, he has already successfully completed our fNIRS certification course. This intensive fNIRS certification program includes training in the neurophysiological principles of the world's modern neuroimaging methodologies, fNIRS neurophysiological measurement principles, contemporary brain imaging paradigms (including Block and Event design/experimental design in neuroimaging), statistical analysis techniques of brain imaging, ethical use of contemporary brain imaging systems (inclusive of fNIRS), the neuroethical issues associated with brain imaging, the ethical treatment of participants, ethical

treatment of data (confidentiality of data and strict confidentiality of data Archiving), safety issues, storage and neuroimaging equipment maintenance, and more. Mr. Stone will, in turn, teach incoming graduate students the basics of neuroimaging methodologies, ethical conduct in research, and how to operate the fNIRS system for neuroimaging studies in adults and children. With respect to eye tracking technology, he has worked for nearly two years with our BL2 team in establishing our new Eye Tracking Experimental Room, housing a Tobii X120 eye tracker, and trailblazing novel setups using touchscreens and iPads, as well as the innovative joining of our fNIRS brain imaging system with the Tobii Eye Tracking system (in conjunction with E-prime). He will continue to gain his extraordinary expertise in this area, with special attention to joint fNIRS brain imaging+eye tracking methodologies.

2. To deepen his expertise with functional Near Infrared Spectroscopy (fNIRS)

fNIRS technology is presently growing in use world-wide to assess cortical activity during cognitive tasks in both typical populations (including adults, children, and infants) as well as in persons with atypical cognitive disorders. fNIRS technology ideally lends itself to studies of higher cognition over other brain imaging technologies because it has both excellent temporal and spatial resolution, without the use of, for example, radiation, and without requiring research participants to be in an enclosed structure. [[Modern advances in 3-D head mapping and NIRS-SPM now permit systems and localization analyses of neural activity to the gyrus level, even in infants (Petitto, 2007, 2009; Petitto et al., 2012). fNIRS, in contrast to fMRI, also has the ability to track the time course of neural activity across hemispheres via measurements of both blood oxygenation and de-oxygenation, and a decade of studies consistently identifying STG activity in infants and adults (including fMRI/MRI and fNIRS neuroanatomical co-registration; Kovelman et al., 2008).]] With fNIRS, participants' cortical activity can be assessed while they are comfortably seated in an ordinary chair (adults and children) or even seated in mom's lap (infants). Notably, fNIRS is the only portable neuroimaging system (the size of a desktop computer), virtually silent, and can tolerate participants' subtle movement. This latter feature is particularly outstanding for the neural study of higher cortical functions, such as human language, which necessarily has as one of its key components the movement of the mouth in speech production or the hands in sign language. fNIRS is at the leading edge of current research in visual language and visual learners and have begun to revolutionize current theories about how deaf children learn to read.

Because Mr. Stone's research objectives include brain imaging with deaf infants, many who may have cochlear implants (which is wholly incompatible with MRI machines) and/or use sign language, as well as eye tracking investigations (again, currently incompatible with MRI), fNIRS is the most outstanding neuroimaging technology available to him. The rigorous BL2 fNIRS certification program has trained him in all aspects of NIRS technology, including responsible conduct of research and conducting fNIRS experiments.

3. To gain foundational knowledge of issues and controversies in Cognitive Neuroscience, Educational Neuroscience, and Child Development

New knowledge about how we learn, think, reason, acquire vast knowledge, and how we conceptualize our social, emotional, and moral worlds, has led to revolutionary insights into the developing child and the birth of an exciting multidisciplinary field called *Educational Neuroscience*. Educational Neuroscience focuses robustly on learning that is specifically at the heart of early child development and early schooling: language and bilingualism, reading and literacy, math and numeracy, science and critical thinking, and social-emotional cognition. Mr. Stone, with my guidance, will work on gaining an understanding how the rich multidisciplinary field of Educational Neuroscience can inform science and education (and educational policy) in principled ways, beyond what is currently offered through his Educational Neuroscience coursework due to his placement in my Brain and Language Laboratory for Neuroimaging (BL2), which explores Educational Neuroscience-related questions using unique methodologies focusing on learning, language and bilingualism, reading and literacy, and higher cognition. This training is enhanced by my deep expertise in Child Development and specifically how all infants, deaf and hearing, acquire language, be it signed or spoken, and be it one or many.

4. To further develop skills in programming and statistical analyses including multilevel modeling (MLM)

Part of the Ph.D. in Educational Neuroscience Program (PEN) is a strong focus on advanced statistics knowledge. First, an overview: studying deaf children and adults has its unique challenges due to the diversity of language and sensory experiences in this population. Research in this area is often marked by smaller sample sizes. Traditional statistical analyses often mask more nuanced details about how this population acquires language and literacy, and the impact of specialized intervention approaches such as cochlear implants or visual learning modules. Newer statistical approaches, such as multilevel modeling, may better capture the variance in this population and permit discovery of effect sizes even with smaller sample sizes. Through Gallaudet University's consortium program with other Washington, D.C.-area universities as part of his Ph.D. program, Mr. Stone will take advanced statistical modeling classes, including

multivariate analysis (MLM), at the University of Maryland at their Maryland Language Science Center [[and at George Washington University]]. However, in my lab, and through our collaborations with VL2 scientists and researchers, for example, Dr. Matthew Traxler at University of California, Davis, Mr. Stone has not only learned these skills but is learning how to *apply* them to BL2 data and support statistical analyses for our ongoing studies. These skills, combined with Mr. Stone's training in behavioral and neuroimaging technologies for fNIRS, will surely support his goals in becoming an independent educational neuroscientist.

In addition, administering fNIRS studying and analyzing their data requires a formidable set of programming skills across many platforms, including E-Prime, Python, and Matlab. He has already self-trained on the Python programming language and was able to successfully write customized fNIRS data pre-processing and group analysis scripts for one of our ongoing studies. He has outlined a plan to gain further expertise in programming in Matlab and Python, which will position him as an exceptionally strong neuroscientist and further enhance his ability to integrate collected fNIRS neuroimaging and Tobii eye tracking data for especially original data analysis and hypothesis testing.

5. To continue ethical conduct and ethical treatment training in all contexts of scientific inquiry and with special attention to emerging neuroethics, law, and social issues (NELSI)

Mr. Stone will also continue ethics training in order to become an independent and professional neuroscience researcher with practices that involve the highest research integrity possible. Research ethics is, not surprisingly, a large concern within the deaf community. To this end, he completed a required course in Neuroethics in his PhD program in Educational Neuroscience, and he will continue to participate in research ethics seminars targeted to researchers who work with deaf participants, for example, student-led efforts in our NSF-VL2 Center to recommend a set of appropriate research terminology to refer to different qualities within the deaf community (e.g., "hearing-impaired," "late signers," and so on).

6. To train in scientific leadership, mentorship, and dissemination/translation of scientific findings

Mr. Stone—owing to his former research experiences, public professional/conference presentations, and classroom teaching experience—has highly impressive public presentation abilities and has already delivered more than a dozen (15) invited conference and workshop presentations on the use of e-literacy technology in bilingual classrooms. In addition, he has recently published [[his *second* first-authored paper, an analysis on fingerspelling skill as an important predictor of reading fluency, in *PLoS ONE* (Stone et al., 2015). He also very recently presented a poster discussing fNIRS neuroimaging of syntactic processing in deaf bilinguals with/without early language exposure at the annual Society for Neuroscience.]] He now will need to harness those skills to explain Educational Neuroscience discipline and his research in more specialized academic/research settings (e.g., Society for Research on Child Development; Society for the Neurobiology of Language; American Educational Research Association), and he will continue to make community presentations on important findings from neuroscience that have considerable implications for deaf and hard of hearing populations. Our BL2 weekly seminars include time for lab members to practice their formal presentation skills for upcoming poster talks and conferences. Very recently, he presented our preliminary data from a BL2 integrated fNIRS neuroimaging+behavioral eye tracking investigation of visual attention, early language experience, and reading in young children at the Society for Research on Child Development (SRCD); his scientific presentation skills are quite exemplary. In addition, the NSF-VL2 Center student community regularly meets weekly (Fridays) for mentorship seminars, which also includes practice time for presentations. In addition, our NSF-VL2 Center is focused on the principled, two-way translation of our important scientific findings on the critical role of early visual language experiences in learning across the lifespan. Mr. Stone has already been a part of VL2's translation efforts, for example, participating in a student workshop on disseminating research findings on Twitter and translating science to "visual tweets." BL2 and VL2 will offer him many more opportunities like this to truly become not only an educational neuroscientist known for his innovative methodologies and scientific discoveries, but for his ability to share those findings with diverse sectors of society at large, including teachers, parents, and policymakers.

In summary, Mr. Stone's training plan is:

1. Master design and administration of behavioral tests in language and reading studies,
    a. With neuroimaging technology (fNIRS)
    b. With modern eye tracking technology
    c. With infants and children
2. Deepen his expertise in functional Near Infrared Spectroscopy (fNIRS)
3. Gain foundational knowledge of issues and controversies in Cognitive Neuroscience, Educational Neuroscience, and Child Development
4. Further develop skills in statistical analyses including multilevel modeling (MLM)

5. Continue critical training in Neuroethics throughout his PhD Program in Educational Neuroscience, ethical conduct and ethical treatment training in all contexts of scientific inquiry and with special attention to emerging neuroethics, law, and social issues (NELSI)
6. Training in scientific leadership, mentorship, and dissemination/translation of scientific findings

D. Number of Fellows/Trainees to be Supervised During the Fellowship

1. Adam Stone, predoctoral student (Gallaudet University) through 2017
2. Geo Kartheiser, predoctoral student & NIDCD F31 fellow (Gallaudet University) through 2017
3. Frank Fishburn, predoctoral student (Georgetown University) through 2016

E. Applicant's Qualifications

Adam Stone has outstanding potential for a truly transformative cognitive-educational neuroscience scientific career. He is the type of exceptional candidate that would truly benefit from F31 funding. He will use this wonderful funding to further his research scientific expertise and there is not a shadow of a doubt that he will bring all aspects of this F31 grant (indeed all that he does) to total scientific fruition.

Advancements to Science: Beyond certain completion of his work, it is also certain that Mr. Stone will advance breakthrough scientific discoveries for all of science regarding how young children learn language and reading. Most especially, Mr. Stone will advance revolutionary knowledge about how young deaf children gain entry into the English reading system via the extraordinary process of a Visual Sign Phonology—here involving among its most central features, the capacity to perceive, segment and categorize sign-phonetic syllabic units and fingerspelling. Answers to the puzzle of how young deaf children may best learn to read have eluded our research community for decades, a scientific puzzle that has also been identified as a looming educational priority. Mr. Stone's impressive prior teaching and research experiences, his present truly outstanding scientific performance in my Neuroimaging laboratory, and his future research trajectory, represent revolutionary scientific ideas and questions in contemporary Cognitive and Educational Neuroscience regarding reading in the human brain and human language. His future scientific findings will change the way we view the human reading process. Moreover, his scientific discoveries will shed new light on a level of language organization in visual signed languages that is homologous to sound phonology, specifically Visual Sign Phonology. By identifying its role in the development of reading, Mr. Stone will change the way we conceptualize human language and the nature of its levels of language organization.

Advancements to methods and technology in science—our scientific tools to explore new ideas: Adam Stone's proposed work is theoretically driven and employs cutting-edge behavioral, neuroimaging, and eye-gaze methodologies, brought together for the first time, to explore developmental mechanisms of language and reading. He has already pioneered the advancement of new experimental and technological combinations, hitherto unknown to science. Here, Stone's marriage of behavioral, fNIRS neuroimaging, and eye tracking technologies will change the face of child experimental science, opening new doors to the study of reading acquisition. For example, now, for the first time, Stone will be able to include diverse populations of deaf children who previously could *not* be studied in early life; indeed, his methods will remove these earlier study inclusion barriers. For example, he will be able to include deaf infants with Cochlear Implants who could not be studied before with traditional structural/functional neuroimaging technology due to the fundamental incompatibility of Cochlear Implants with fMRIs (around which, in turn, there is much unresolved scientific controversy regarding auditory brain tissue development with and/or without early sign language exposure).

Advancements to Translation: The translational impact of his work will also be revolutionary. His work has the potential to alter history regarding the education of all children's acquisition of reading and literacy, especially the young deaf visual learner. Here, his work will provide new insights into the role that Visual Sign Phonology and, specifically, the role that rhythmic-temporal patterning plays in early English language and English reading acquisition. He will yield new knowledge, and new learning insights, into which aspects of Visual Sign Phonology the child has peaked sensitivity to, and, crucially, when in development (what age). This, in turn, will provide direct educational insights into how to promote optimal reading success in the young visual learner.

Additional outstanding factors: The training proposed in this application is ideally suited to Mr. Stone's research questions and optimally complements my own expertise in the biological foundations of language acquisition, bilingualism, and reading. I am delighted to serve as Mr. Stone's sponsor for this F31 project and will continue to devote my time, expertise, and lab resources to his training. We will continue our regular interactions in our weekly Brain Seminar, our existing formal individual weekly meetings, in addition to all the informal learning interactions we have on a day-to-day level while in my laboratory. His remarkable academic record and scientific scholarship, in combination with his experiences in my neuroimaging lab as my F31 fellow, will allow him to develop a unique skill set that is *unmatched by any contemporary at the predoctoral level.* To help better situate this observation, he is among the top three most outstanding young cognitive neuroscientists whom I have met in my career.

In addition to his outstanding academic record, Mr. Stone comes to BL2 with an impressive professional and research background. It is truly a gift to have a deaf research scientist, who has *already* been a classroom teacher, investigating questions of learning and language in deaf children. Mr. Stone also comes to BL2 "ready" with his prior scientific research lab assistantships with top scientists in this field, including Dr. Carol Padden and Dr. Karen Emmorey. He has taken charge of our current BL2 fNIRS neuroimaging+eye tracking study that investigates effects of early visual language experience on visual attention and allocation and depth of processing for English text. He has contributed significantly to the development of the experimental design and stimuli, the writing of the IRB application, and he has taken a true leadership role in the formidable experimental and technical setup process involving the integration of the Tobii Eye Tracking system with the fNIRS brain imaging system. Beyond this, he is a brilliant participant in our theoretical discussions on the theory and core scientific questions at the heart of this study. Through my various interactions with Mr. Stone, I have found him to be creative, insightful—truly an original thinker—in addition to being hard-working, and extremely dedicated to his work. He has outstanding leadership qualities, and, at the same time, he is sensitive to the ideas of others. He is an individual who listens to the thoughts of others, and sensitively and gently guides his co-workers to achieve their very best. He drinks in knowledge, has a true passion to "know." To be sure, Adam Stone is admired and adored by his professors, colleagues, BL2 lab and VL2 peers spanning the nation.

Awarding this F31 fellowship will allow Mr. Stone to continue to develop his research strengths. He has, through sheer hard work, determination, and brilliant scientific insight forged the present research trajectory that looks at the role of rhythmic-temporal patterning (and its relation to the extraordinary existence of a Visual Sign Phonology) in language perception in deaf infants and possible factor in reading acquisition in deaf children. I cannot stress enough that this is a critical question that the best minds in this field have, so far, failed to answer. His ideas and work comes closest to identifying what is often known as "the missing link" between sign language and English reading ability. What is also impressive is that he comes to this field with his own personal experience as a deaf person, is an individual who has stunningly high literacy and scientific critical thinking and reasoning skills, and he has had teaching experience in elementary settings. It is critical that more researchers be trained who have his ability to bridge together diverse fields spanning cognitive neuroscience, linguistics, psychology, child development, and pedagogy. Mr. Stone can do this. He has the gumption, drive, intelligence, and commensurate scientific insights and abilities that it takes to become a successful, transformative scientist. I offer nothing less than my highest endorsement.

After much careful thought and consideration, I offer that Adam Stone is going to be science's shining star—one of those rare brilliant minds who makes scientific history and who becomes part of science history—and one certain to make lasting contributions to all society.

SELECTION OF SPONSOR AND INSTITUTION

When considering doctoral programs, I found Gallaudet University to be the best choice for me. Gallaudet University is home to among the nation's first pioneering Ph.D. programs in Educational Neuroscience (along with Harvard University, Columbia University, Vanderbilt University), is the only one in the metropolitan D.C. area, and is the only one that especially focuses on new discoveries about visual learners and on the unique training in the neuroplasticity of visually-guided learning processes underlying the development of attention, cognition, language, bilingualism, reading and literacy in the young deaf child. This Ph.D. program is interdisciplinary and draws on strengths from the Departments of Education, Psychology, Interpreting, Linguistics, and Hearing & Speech Language Sciences—all of which are already recognized as leaders in their fields with respect to working with deaf children and adults. For a scientific career working with this specific population and researching questions regarding visual language, there is no better place.

Gallaudet University is also host to the Petitto Brain & Language Laboratory for Neuroimaging (BL2), one of the few university laboratories with its own dedicated neuroimaging (fNIRS) and eye tracking equipment and which is already making new scientific findings on neuroplasticity in children and adults with cochlear implants and differing visual language experiences. In addition, Gallaudet is the headquarters of Visual Language and Visual Learning (VL2), one of the six NSF Science of Learning Centers, and the administrative home of the Ph.D. program in Educational Neuroscience. VL2 allows me with direct access to a vast network of leaders in neuroimaging laboratories at VL2's network of partnership universities across the nation; I am already taking advantage of this network by seeking out mentors at University of California San Diego and Rochester Institute of Technology to support me with this research proposal. Two other "resource hubs" also exist at Gallaudet: the Malzkuhn Motion Light Laboratory (ML2) focusing on cutting-edge motion capture, point-light, and educational product development, and the Allen Early Educational Longitudinal Lab (EL2), which holds a treasure trove of data regarding early deaf children's home, family, and school factors, permitting data analysis to discover predictors of later language and literacy success (e.g., I have a paper [[published]] about fingerspelling skill as a predictor of reading fluency, using EL2 data).

I selected Dr. Laura-Ann Petitto, a developmental cognitive neuroscientist widely known for her discoveries about the biological foundations of language, to be my advisor and sponsor because her research program matches my scholarly and research interests. Dr. Petitto is a very successful and prolific researcher in the area of cognitive neuroscience, especially identifying key brain structures underling early human *language acquisition* (e.g., her well-known discoveries that children exposed to sign languages also hit the human babbling acquisition milestone, and that all children—monolinguals and bilinguals, signing and speaking—hit the same language maturational milestones), *bilingualism* (highlighted by her discoveries about neural tissue and systems in monolinguals and bilinguals, "the bilingual brain"), and *reading* (highlighted by her 12 years of discoveries about the behavioral and neural tissue development that make possible bilingual and monolingual children and adults' reading success, "the reading brain"). She is further known for articulating a biologically plausible and testable theory about the human language acquisition process (especially answering the question, how does human language acquisition begin?). She has been fortunate to have received [[32]] years of consecutive and uninterrupted Federal funding, spanning both the USA and Canadian Federal funding agencies. She has won USA NICHD R01-HD045822, NICHD R21-HD50558, NSF SBE-1041725, [[and NSF IIS-1547178]] grants, W.M. Keck Foundation and Dana Foundation grants, and has won among the country of Canada's highest and most honored Federal funding awards, specifically "The Canadian Foundation for Innovation."

Dr. Petitto is an excellent adviser who has supported my research interests 110%, and has very thoughtfully and thoroughly helped design my plan of study for my Ph.D., ensuring I receive top-quality training in classical behavioral and modern neuroimaging methods, and demands only the best from me. She has given me opportunities to develop skills not only in research methodologies but also in project management, by giving me leadership of an eye tracking pilot study we are currently working on in BL2. She also has faith in my abilities to communicate clearly both written and verbally, and gave me the opportunity for complete management of a NSF-funded workshop ($38,000 budget) bringing together avatar, robotics, and visual language scientists to Gallaudet University to learn about visual language and learning tools (http://signingcreatures.weebly.com). Finally, she is fluent in American Sign Language (ASL), and is able to explore all questions of visual language with ease thanks to her decades of expertise in the Deaf community.

Dr. Laura-Ann Petitto's sponsorship is quite simply the keystone of my research training plan; my interests are ideally supported by her expertise in Developmental Cognitive Neuroscience, Psycholinguistics, and Child Development. I am confident her mentorship will provide me with training opportunities in order to become an independent, successful educational neuroscientist. There is no other person I can think of who is better suited, nor is there any other University or research location better suited for me to investigate questions of the neurobiology of human language acquisition and reading.

FACILITIES AND OTHER RESOURCES

I will be conducting my research into infant behavioral and neural sensitivity for phonological rhythmic-temporal patterning at the Petitto Brain & Language Laboratory for Neuroimaging (BL2) on the campus of Gallaudet University. The BL2 lab was established by Laura-Ann Petitto, a cognitive neuroscientist, when she was brought in to become the Co-PI and Science Director of the National Science Foundation's Science of Learning Center, Visual Language and Visual Learning (VL2), at Gallaudet University. Serving also as BL2's Scientific Director, Petitto's intimate ties with VL2 provide a powerfully beneficial, tangible and concrete, means for students in BL2 to garner deep intellectual enrichment from VL2. BL2 at Gallaudet is already recognized as an internationally known research center focused on uncovering the biological mechanisms and environmental factors that together determine how the human species acquires language, as well as how language is organized in the brain. It is notable for being one of the few neuroimaging centers in the world specialized towards investigating deafness and sign language, and even more so for having its very own, dedicated neuroimaging equipment. It is an outstanding, high-quality, and high-profile collaborative environment in which my research will be well supported because it aligns with the goals of BL2 in looking at biological language development. Specifically, my research looks at how infants demonstrate neural and behavioral sensitivity to either the frequency (timing) and/or the type (alternation of maximally contrasting phonetic units). In addition, BL2 primarily uses American Sign Language (ASL) as its language for science and methodology discussions, permitting greater rapport with the Gallaudet community and the greater deaf and hard of hearing community.

As above, one of BL2's strengths is in its affiliation with Visual Language & Visual Learning (VL2), one of six NSF Science of Learning Centers in the United States of America, headquartered at Gallaudet University. Founded in 2006, VL2 is composed of a large network of behavioral, eye-tracking, and neuroimaging laboratories at partnering R01 universities nationwide, all investigating questions of visual language and visual learning, including sensory and visual plasticity, language and cognition, and reading and literacy advantages of ASL/English bilingualism. As a NSF Science of Learning VL2 Student Scholar situated in BL2, I have direct access to this network of research leaders through weekly VL2 mentoring (via teleconferencing with VL2 Student Mentorship Leader, Dr. Peter Hauser, Rochester Institute of Technology), science meetings (for example, our weekly Brain Seminar in) and weekly student-run colloquia, termed "VL2 Student Network Lecture Series." All will support me throughout my training program and research project.

Laboratory: The BL2 complex is a multi-million dollar facility, which was built and completed in December 2011 in the then brand-new Sorenson Language and Communication Center on the campus of Gallaudet University. Designed by renowned San Francisco Architects specializing in "Deaf Space," and in direct consultation with Dr. Petitto regarding the specific needs of a modern, multi-functioning cognitive neuroscience laboratory, this extraordinary facility would be considered rare by any standards—and regarding any campus spanning the United States. BL2 is comprised of specialized laboratories, including a complex of separate (individual) minilabs for cognitive neurogenetics research, Tobii eye tracking studies of children and adult reading, a child development experimental room, psycholinguistic/behavioral testing chamber, a specially-designed fNIRS neuroimaging complex, with separate pilot/co-pilot control areas, a physicist's analysis room, and a waiting area and private entrance for participant confidentiality. Moreover, the fNIRS complex also houses Petitto's *Infant Habituation Laboratory*. Furthermore, the Tobii eye tracking system is also yoked to the fNIRS brain imaging system; indeed, all three yoked (fNIRS, eye tracking, habituation rig) together permits the world's most advanced experimental procedures for the study of higher cognition in infants to date. The facility also houses multiple observational chambers (e.g., for parents of child participants and for student training), a library in a center "courtyard" for informal meetings, an important teleconferencing room, offices for Dr. Petitto and BL2's full-time Administrative Assistant, and a specially designed research workstation for teams of students, thereby making possible a rich context for collaborative discovery as well as independent analyses. Most importantly, the lab contains an NIH-approved, HPPAA compliant, and entirely secure, data archiving facility, with electronic entry permitted only by Dr. Petitto and her administrative assistant. Finally, the entire complex can only be accessed through secure electronic entry by "cleared" individuals, which is reviewed every 6 months.

Digital Editing Studio: The 6x15 Digital Editing Studio houses two computers: two Dell XPS 730 with Intel Core 2 Quad 2.66 GHz processors, 4 GB RAM, 500 GB hard drives, 21" LCD monitors, running Windows 7. There is also a Sony Digital Handycam (MiniDV), DCR-VX2000. There are two windows – one two-way mirror and one one-way mirror, allowing observation from two adjacent rooms. This room is also frequently used to administer psychometric assessments (e.g., language and cognitive measurements). There are white curtains and shades to minimize distraction during assessment.

Digital Recording Studio & Child Development Experimental Room: The 10x15 Digital Recording Studio & Child Development Experimental Room consists of several pieces of child-size furniture and a large array of children's toys and books appropriate for different ages. It has large windows to allow in natural sunlight and a seating area with cushions. One wall contains a one-way mirror permitting observation from an adjacent room. This room serves both as a play area for visiting children and families, as well as a natural, child-friendly environment for naturalistic data collection,

behavioral tasks, and a place where parents and/or participants may read and evaluate the Participant Consent Form in a relaxed environment. It contains a JVC ProHD Digital Camera Recorder, GY-HM100U set on a tripod.

fNIRS Neuroimaging Room: The 10x20 fNIRS Neuroimaging Room contains a Hitachi ETG-4000 functional near infrared spectroscopy optical topography machine, configured for 24 and 48 channel measurements, with specially designed Infant as well as Adult probe sets. It also contains a Tobii X120 eye tracker, mounted to a 27" Samsung LCD TV via a VESA-compatible monitor mount. Additional equipment include a Serial Response Box, USB button controllers, stereo speakers, and microphones. Two desktop PCs are available for running E-Prime and Tobii Studio: two Dell XPS 8700 with Intel i7 4.0 GHz processor, 12 GB memory, and 1.5 TB hard drive and containing a Datapath Vision-AV/B video capture card. The two PCs contain specialized video connectivity cables and hardware to permit the integration of fNIRS and Tobii eye tracking technologies and collection of time-locked hemodynamic response, eye gaze, and behavioral data. There is also one iMac 21" with a Intel Core 2 Duo 3.06 GHz processor, 4 GB RAM, a 1 TB hard drive, running Mac OS X 10.6. Two laptops are also available as needed: a 17" Acer with Intel Core i5 2.67 GHz processor, 4 GB memory, and a 500 GB hard drive, running Windows 7; and a 15" IBM ThinkPad with Intel Pentium 1.59 GHz processor, 1 GB memory, and a 50 GB hard drive, running Windows XP. There is also another JVC ProHD Digital Camera Recorder, GY-HM100U set on a tripod for filming subjects during fNIRS recording. This controlled room requires an electronic key card to enter.

Student Analysis Workstations: The Student Analysis Workstation area is where doctoral, graduate, and undergraduate students do most of their work, and where I am placed. There are several computers in this room. There are three 27" iMacs with Intel Core i7 3.4 GHz processors, 8 GB memory, with 2 TB hard drives and 2 TB external hard drives each, all running OS X 10.7.5. There is also a Mac Pro with 6-Core Intel Xeon, 2 x 2.66 GHz processors, with 12 GB memory and 5 TB total storage (both internal and external), with a 27" Apple Cinema Display. There is one 21" iMac, Intel Core i5 2.5 GHz processor with 8 GB memory and a 500 GB hard drive. Finally, there is one 21" Dell LCD monitor available for hookup to a laptop. Innovative to the Student Analysis Station is that it houses students at multiple levels from different disciplines (e.g., Linguistics, Psychology, Educational Neuroscience, ASL & Deaf Studies, Information Technology), providing mentorship, discussion, and collaboration opportunities all in American Sign Language (ASL)

Cognitive Neurogenetics Room: The Cognitive Neurogenetics Room houses a ThemoScientific Forma FRGL404 4.6 cubic foot laboratory refrigerator for storing DNA samples that we collect from fNIRS participants. In addition, there is a Mac Pro with 6-Core Intel Xeon, 2 x 2.66 GHz processors, with 12 GB memory and 5 TB total storage (both internal and external), with a 27" Apple Cinema Display, containing the full set of Apple Creative Studio video and audio editing tools (Final Cut Pro X, Cinema, Motion, Color, Compressor) and MatLab. Also there is a HP Color Laserjet CP5225 four-color duplex laser printer.

Discovery/Video Teleconferencing Room: The Discovery/Video Teleconferencing Room is where the lab family meets daily for group discussions and updates, and where we are also able to meet remotely with our BL2 and VL2 collaborators nationwide. It houses a 27" iMac with a Intel Core i7 3.4 GHz processor, 8 GB memory, and a 2 TB hard drive, connected to a 50" Vizio LCD display.

Clinical: Not applicable

Animal: Not applicable

Computer: I will have access to more than a dozen computers (both Mac and PC) See above for detailed descriptions of computers. All analysis computers are networked to a secure, lab-administered server via our dedicated, private wireless network. All data collection computers are shielded from Internet exposure as to maintain subject confidentiality and data fidelity (we go beyond use of firewalls; they are simply not physically connected at all to an Ethernet outlet or wireless access point). Computers are equipped with standard software program (e.g., Microsoft Office, E-Prime, SPSS) needed for completing the research project.

Office: I am placed in the Student Analysis Workstation in BL2 and have access to all of BL2 and VL2.

Other: BL2 is located in the Sorenson Language and Communication Center, adjacent to Visual Language & Visual Learning (VL2). They have resources which all BL2 members may take advantage of, including a Xerox multipurpose high-quantity copier/scanner, a large format printer for posters, and administrative supplies. We also have access to computers containing advanced photo and illustration editing software (Adobe Creative Studio), a professional Video Recording Studio with green and blue chromakey backgrounds, and an Artist-in-Residence studio for creating illustrations and graphics. Also housed in the same building, literally next door to BL2, is the Malzkuhn Motion Light Laboratory (ML2), a "sister" laboratory to BL2 and one of Gallaudet University's "resource hubs," containing eight state-of-the-art Vicon T160 Series 16 megapixel 120fps motion capture cameras and associated hardware and rendering software, permitting the quick and easy creation of point-light scene stimuli, avatar-based signing animations, and other 3D-based scenes. BL2 and ML2 have worked together since 2011 developing visual stimuli for scientific studies and for education and research translational materials.

EQUIPMENT

My research environment at the Petitto Brain & Language Laboratory for Neuroimaging (BL2) provides all the necessary equipment for conducting behavioral, eye-tracking, and functional neuroimaging testing. BL2 has a dedicated fNIRS and Eyetracking Laboratory, containing a Hitachi ETG-4000 functional near infrared spectroscopy optical topography machine, configured for 24 and 48 channel measurements, with specially designed Infant as well as Adult probe sets. It also contains a Tobii X120 eye tracker, mounted to a 27" Samsung LCD TV via a VESA-compatible monitor mount. Additional equipment include a Serial Response Box, USB button controllers, stereo speakers, and microphones. Two desktop PCs are available for running E-Prime and Tobii Studio: two Dell XPS 8700 with Intel i7 4.0 GHz processor, 12 GB memory, and 1.5 TB hard drive and containing a Datapath Vision-AV/B video capture card. There is also one iMac 21" with a Intel Core 2 Duo 3.06 GHz processor, 4 GB RAM, a 1 TB hard drive, running Mac OS X 10.6. Two laptops are also available as needed: a 17" Acer with Intel Core i5 2.67 GHz processor, 4 GB memory, and a 500 GB hard drive, running Windows 7; and a 15" IBM ThinkPad with Intel Pentium 1.59 GHz processor, 1 GB memory, and a 50 GB hard drive, running Windows XP. There is also another JVC ProHD Digital Camera Recorder, GY-HM100U set on a tripod for filming subjects during fNIRS recording. This controlled room requires an electronic key card to enter.

The two technologies (fNIRS ETG-4000 and Tobii eye tracker) are easily yoked together or disassembled apart. When they are integrated (e.g., in this proposed study), they are connected with E-Prime which presents the stimulus on the 27" LCD TV, collects time-locked behavioral and timing data, and transmits time stamps to the ETG-4000 for hemodynamic data recording, and also is connected to Tobii Studio which collected time-locked eye gaze data and captures the video output from E-Prime via a dedicated video capture card (Macguire et al., 2012). This integrated setup has already been used in studies of reading, visual language, and sign language perception in children and adults and data analysis has been successfully performed and presented (Petitto, Langdon, & Stone, 2015).

Especially critical for creating a child-friendly environment for young participants, BL2 also has a Digital Recording Studio & Child Development Experimental Room, consisting of several pieces of child-size furniture and a large array of children's toys and children's books appropriate for different ages. It has large windows to allow in natural sunlight and a seating area with cushions. One wall contains an one-way mirror permitting observation from an adjacent room. This room serves both as a play area for visiting children and families, as well as a natural, child-friendly environment for naturalistic data collection and behavioral tasks.

There are more than a dozen available modern computers in BL2 available for my use. I also have full access to Xerox, scanning, and faxing machines and a large-format printer in VL2. Notably, I also have full access to the Motion Light Laboratory (ML2) which contains a full contingent of state-of-the-art Vicon T160 Series 16 megapixel 120fps motion capture camera hardware and rendering software, permitting the quick and easy creation of point-light scene stimuli, avatar-based signing animations, and other 3D-based scenes. This MoCap system is the same one that Dr. Petitto proposed and was awarded in her Keck Foundation grant as PI (see Petitto Biosketch). The MoCap is presently housed in ML2, directed by Melissa Malzkuhn (a Keck Grant Co-PI) and a "sister" laboratory to Dr. Petitto's BL2. Petitto, her students (including myself), and Malzkuhn have worked collaboratively on many projects since 2011 to generate visual stimuli (using other point light-generating equipment) for lab studies and translational products, including 3-D generated signing scenes using point-lights as key spatial coordinates.

RESPECTIVE CONTRIBUTIONS

[[My research objectives focus on the neural bases of language in deaf and hearing infants. I am fortunate to work with my advisor, Dr. Petitto, whose laboratory and funding cover this same topic, permitting me to receive top-notch training in the theoretical areas in which I seek to excel, and to conduct this proposed study. Dr. Petitto has supported me in conceptualizing and designing this proposed study. However, as a deaf neuroscience student scholar, I also bring unique life experiences and knowledge to Dr. Petitto's research program in the form of perspectives on neuroplasticity in the human brain and the impact of experience-dependent changes to neural structure and processing.]]

Specifically, I developed my research proposal and training plan with the guidance of my sponsor, Dr. Laura-Ann Petitto. I developed the specific aims of the current research study during the first year of my doctoral program; the broad goal of identifying the timing and type of rhythmic-temporal patterning to which all babies are sensitive to, using sign language as a lens, was motivated by my research experience in the Petitto Brain & Language Laboratory for Neuroimaging (BL2) and in other language-related laboratories, my involvement with Visual Language and Visual Learning (VL2), a NSF Science of Learning Center, and my professional teaching experience.

I further developed the experimental design of my study through regular conversations with my sponsor, Dr. Petitto, with graduate and doctoral students in BL2 and VL2, and with VL2 researchers Dr. Peter Hauser at Rochester Institute of Technology and Dr. Rain Bosworth at University of California, San Diego. I wrote the research proposal and training plan and, based on constructive feedback from Dr. Petitto and colleagues, revised the materials. Specifically, Dr. Petitto provided feedback on topics including background, hypotheses, participant selection, experimental design, and scientific theory/translational impact. [[I also gained valuable feedback on my study design and stimuli via my second cognitive neuroscience laboratory rotation at the University of Hong Kong's Hearing and Speech Sciences Laboratory, and via discussions with Dr. Guinevere Eden at Georgetown University (presently an instructor in the PEN program).]]

In accomplishing the proposed research, I will be responsible for recruiting and evaluating participants, refining the yoked neuroimaging and eye tracking technologies and programming the study in Tobii Studio and E-Prime, collecting and analyzing data, and interpreting results. I will consult with Dr. Petitto and mentors on a regular basis throughout the course of this training program, and, with input from Dr. Petitto, develop presentations and publications reporting my findings.

RESPONSIBLE CONDUCT OF RESEARCH

KEY: (a) Conflict of interest – personal, professional, and financial; (b) Human subjects policies; (c) Mentor/mentee responsibilities and relationships; (d) Collaborative research including collaborations with industry; (e) Peer Review; (f) Data acquisition and laboratory tools—management, sharing, and ownership; (g) Research misconduct and policies for handing misconduct; (h) Responsible authorship and publication; (i) The scientist as a responsible member of society, contemporary ethical issues in biomedical research, and the environmental and societal impacts of scientific research.

	Format	**Topic**	**Faculty**	**Duration**	**Frequency**
Completed					
VL2 Student Retreat 2012, 2013, 2014, [[2015]]	*Discussion*	*d, h, i*	*Peter Hauser, Erin Wilkinson*	*1.5h*	*Once*
CITI: Conflicts of Interest (Feb 2013; [[Dec 2015]])	*Reading*	*a, b, d, f, g, h, i*	*Laura-Ann Petitto*	*1.5h*	*Once*
CITI: Social and Behavioral Research (Feb 2013; [[Dec 2015]])	*Reading*	*a, b, d, f, g, h, i*	*Laura-Ann Petitto*	*4.5h*	*Once*
PEN 703: Foundations of Educational Neuroscience I	*Reading, Lecture, Discussion*	*a, b, c, e, f, g, h, i*	*Clifton Langdon*	*3.0h*	*Weekly (15 weeks)*
PEN 705: Contemporary Issues in Neuroethics	*Reading, Lecture, Discussion*	*a, b, d, g, i*	*James Giordano*	*3.0h*	*Weekly (15 weeks)*
PEN 704: Foundations of Educational Neuroscience II	*Reading, Lecture, Discussion*	*a, b, c, e, f, g, h, i*	*Peter Hauser*	*3.0h*	*Weekly (15 weeks)*
PEN 895: Contemporary Methods Neuroimaging	*Reading, Lecture, Discussion*	*b, f, g, i*	*Clifton Langdon*	*1.0h*	*Weekly (15 weeks)*
PEN 801: Two-Way Translation	*Reading, Lecture, Discussion*	*a, b, f, g, h, i*	*Melissa Herzig*	*3.0h*	*Weekly (15 weeks)*
PEN 802: Research	*Reading, Lecture, Discussion*	*a, b, f, g, h, i*	*Ted Supalla*	*3.0h*	*Weekly (15 weeks)*
Planned Seminars					
Informal Ethics Instruction (e.g., Brain Lab Seminar)	Discussion	a, b, c, d, e, f, g, h, i	Laura-Ann Petitto, Clifton Langdon	1.5h	Weekly
CITI: Biomedical Research	Reading	a, b, d, f, g, h, i	Laura-Ann Petitto	4.5h	Once
The VL2 Meeting, Retreats, & Workshops	Discussion	a, c, d, e, f, g, h, i	Peter Hauser, VL2 Mentor Leaders	1.5h	Weekly & Yearly
Research Ethics for Research Programs	Lecture	b, d, f, g, h, i	Carlene Thumann-Prezioso	1.0h	Once
Responsible Conduct of Research (University of Maryland)	Lecture, Discussion	a, b, c, d, e, f, g, h, i	Jennifer de Simome	8.0h	Once

I have already undergone NIH-certified RCR training (CITI) in social and behavioral research. In addition, my NIH-approved (Petitto NICHD R01, R21) fNIRS certification course involved discussion of standards of ethical and safe usage of neuroimaging technologies. To date, I have completed more than 50 hours of RCR training and discussion, mainly owing to my Ph.D. program's unique course offerings (e.g., Contemporary Issues in Neuroethics, Dr. James Giordano, Neuroethics Studies Program Chair, Pellerino Center for Clinical Bioethics, Georgetown University). I also have participated in planning and facilitating ethics discussions sponsored by Visual Language and Visual Learning (VL2), a NSF Science of Learning Center, with more than 25 students nationwide. I will continue my ethics-based coursework as part of my Ph.D. program in Educational Neuroscience, participate in formal and informal ethics discussion in my lab and within the VL2 Center, and seek out individual seminars and workshops on responsible conduct of research, in consultation with my advisor and sponsor, Dr. Laura-Ann Petitto.

PROTECTION OF HUMAN SUBJECTS

The Institutional Review Board at Gallaudet University will review the following human subjects procedures for this project.

1. Risks to human subjects

Human participants involved and characteristics: The proposed research will involve 40 5-6 month old infants. This sample is divided equally between deaf and hearing infants. To minimize perceptual variability among infants, all infants will be full-term and healthy.

Source of materials: The data collected will include background questions about language use at home. Eye gaze, brain activity, and in-scanner behavioral data will be collected. Participant's identification numbers, videos, and other data will be stored apart from their identifying information. Only I, Dr. Petitto (sponsor), and designated key personnel in the Petitto Brain & Language Laboratory for Neuroimaging (BL2) will have access to participant's identifying information.

Potential risks: There are minimal risks associated with participation in this study. The eye tracking method is completely non-invasive; nothing is attached to or put onto the subject's body and eyes. The infrared light is not perceptible and there are no known risks associated with exposure to it. Subjects may become bored, bothered, or irritable during testing; in this case, we either take a break or cease testing. The caregiver is to stay with the child at all times. In addition, there is no risks associated with fNIRS because the light sources are not intense (less than 1 mw/cm2), are largely transparent to biological tissue (i.e., insufficient absorption to cause heating), and the light sources and photodectectors are placed on the surface of the skull using a comfortable runner's terrycloth headband; the sensor's very low-intensity light is less than natural sunlight and the equivalent of a small flashlight. The fNIRS unit is also behind a partition and the cords running from the headband to the machine will be bundled behind the participant's head. The possibility that the participant will yank on the cords is minimal. In the event that a participant does grab on one of the cords, the only result is that the cord will be damaged—there is no chance of the participant being shocked or injured. Power surge protectors will be used for both the computer and the fNIRS equipment. Additionally, the experimental stimulus is administered in the form of watching a video on a computer monitor in a comfortable setting and thus constitutes a relaxed atmosphere.

2. Adequacy of protection against risks

Recruitment and informed consent: We will recruit using multiple methods. We will recruit from the community: the Gallaudet University and the greater Washington, D.C. area via fliers, postings on community bulletins and in daycares and schools, webpages, and social media. We will also put ads in the local papers. Children and their parents will participate in a single visit lasting approximately thirty minutes, with in-scanner time around 7-8 minutes. We will also network with our collaborating labs at Washington, D.C. consortium universities (e.g., Georgetown, University of Maryland) to potentially share infant recruitment resources.

A brief description of the planned consent sequence appears here: After describing clearly the goals and methods of the study, parents will be asked if they would like to participate in the study (that is, "to consent") at this time, whereupon, if they agree, they will sign and date a formal consent form. All consent forms will be in a person's native language, All persons from whom we seek consent will be made to feel at ease and all interviews will be conducted entirely without direct or implicit pressure to participate; note that we will happily discontinue an interview the moment a potential participant shows any sign of not wanting to continue (i.e., not to participate in our study). To be sure, absolutely no pressure of any kind will be conveyed to a potential participant and, in addition, we will convey complete support and kindness to all potential participants who do not want to join in our study. Only highly trained personnel directly working on a specific study will conduct the recruitment and informed consent component of the proposed project. Additionally, if the experimenter feels that the participant is becoming agitated or uncomfortable during the testing, the experimenter will stop the testing session. This sensitivity to the participant is especially important when testing young infants, and we will indeed stop a testing session if a young participant appears agitated or uncomfortable even if its parent wishes to push on.

Protection against risks: There are minimal risks associated with participation in this study, mainly due to the use of low-power infrared light which is not perceptible to the human eye, is largely transparent to biological tissue, and is less intense than natural sunlight (see above for additional description of minimal fNIRS and eye tracking associated risks). The primary risks are fussiness, boredom, or irritation for the child and loss of confidentiality. The study will be stopped if the child withdraws assent, the parent withdraws consent, or if the examiner sees that the study should be stopped. Identifying information will be obtained only for purposes of initial recruitment and scheduling. All participant information and data will be stored in a locked room to which only highly qualified lab members has access. Confidentiality will be maintained by assigning participant numbers to identify participants in place of personal information; identifying information will be stored separately from de-identified information. Only Dr. Petitto, designated graduate students (not all lab assistants), and I will have access to the raw data.

3. Potential Benefits of the Proposed Research to Human Subjects and Others.

There are no direct benefits of participating in this study. Families will receive $20 per visit as compensation for their time. Their participation will help us learn more about young children's language and visual perception abilities. Potential advantages exit in the form of increased knowledge by discovering more about infant language acquisition and reading acquisition in deaf children. These findings will provide scientific "evidence-based" information vital to early childhood education for visual learners and for successful language learning and reading and will impact U.S. educational policy regarding early language remediation and teaching.

4. Importance of Knowledge to be Gained.

The results of this study may directly benefit teachers, clinicians, and parents by providing fundamental scientific ("evidence-based") information about the maturational development of human language, as well as their neural representation in the brain. We propose a study that uses innovative fNIRS and eye tracking technology, which permits us to evaluate highly scientific and neuroanatomical hypotheses about the brain tissues that are sensitive to rhythmic-temporal patterning and phonological acquisition in young infants in a manner hitherto not possible in science. This research will provide important answers to a decades-old question – what specific components of the language signal are babies sensitive to – and also inform more scientific questions about (a) the multiple factors that underlie early language acquisition and the specific type of processing tissue that underlie them, (b) the developmental trajectories of linguistic processing tissue, and (c) the peaked sensitivity that linguistic processing tissue has to certain kinds of linguistic input in early development. In addition, our eye tracking and fNIRS approach will also yield guidelines for principled use of eye tracking and neuroimaging in infants that ultimately can have important diagnostic, remediation and teaching utility and help identify normal and abnormal language development early in life.

INCLUSION OF CHILDREN

Because our question looks at early sensitivity to properties of rhythmic-temporal patterning, this study will require the participants of infants. This experiment involve **no greater than minimal risks.** The child will be included in the study only after we obtain an informed and written consent from the parents or guardians. The parents will be provided with a summary of our research goals, description of the study methods, and the gift and certificate that the infant will receive for participation. The parents or guardians will also be provided with Dr. Petitto's and my contact information should they need to discuss the study in more detail. Should the child refuse to participate or feel discomfort at any point during the study, or if the experimenter feels that the child is showing signs of discomfort or agitation, the testing will stop immediately and the child will be praised (the guardians will be thanked), and the child will receive the promised gift and certificate.

Rationale for selecting age ranges and inclusion criteria: The age ranges selected are based on developmental milestones that are standard in the field of child development and language acquisition. In order to accurately replicate prior language acquisition, rhythmic sensitivity, and visual perception studies, and to advance the field in terms of being able to measure early linguistic sensitivities, we have chosen to study infants 5-6 months based on key ages for demonstrating sensitivity to all phonetic features in all languages (Baker et al., 2006; Bosworth et al., 2013; Krentz & Corina, 2008; Petitto et al., 2012; Stone, Bosworth, & Petitto, 2015). All children who meet these age criteria, and who are full-term and healthy (as reported by parents) are eligible to participate. If a child is sick for a testing session, and the parent has not called to reschedule before the appointment, the experimenter will ask the parent to reschedule the testing session as a consideration for the child's comfort. There is no greater risk associated with testing a sick child, and we routinely do this to ensure that the infant be as comfortable as possible during the session.

Description of the investigative team's expertise with children: Dr. Petitto has had more than 40 years of research experience with infants, for which she is internationally known, and has been involved in the recruitment and running of most of all of her participants to date. She also has had extensive experience working across a wide range of methodologies (longitudinal/naturalistic, longitudinal/experimental, and large-scale experimental/cross-section) and technologies (including neuroimaging with children and adults). In addition, I am very experienced with infants having been a former elementary schoolteacher, and have performed a summer lab rotation at the Infant Vision Lab at UCSD (PI, Dr. Karen Dobkins) which has afforded me opportunities to conduct eye tracking sessions with many infants. The yoked fNIRS and eye tracking setup is also intimately familiar to me, as I designed and integrated the two technologies and was the lead graduate student on a project investigating visual attention and reading in young children using this setup. Finally, the Petitto Brain & Language Laboratory for Neuroimaging (BL2) are set up explicitly to be a comfortable, friendly environment for young children. It has an at-home feel thanks to the use of home furnishings and natural patterns (e.g., wood, rugs, gentle colors), and there is a bright and joyful Digital Recording Studio/Play Room designed for young participants.

INCLUSION OF WOMEN AND MINORITIES

Although this study is not clinical, but experimental, approximately half the participants in each age group will be female, to ensure that our findings generalize adequately across the population.

Infants from diverse racial and ethnic backgrounds will be actively recruited to participate in the proposed study. The Greater Washington, D.C. area is extraordinarily diverse. Efforts will be made to maximize the diversity of the sample. The Petitto Brain & Language Laboratory for Neuroimaging (BL2) has existing mechanisms in place to recruit a diverse sample of child participants. Fliers will be distributed to schools, libraries, coffee shops, and other community locations in diverse neighborhoods, and be posted to social media websites and neighborhood blogs. In addition, we will increase access to research opportunities for families with lower socioeconomic status by compensating for travel to/from Gallaudet University.

Planned Enrollment Report

This report format should NOT be used for collecting data from study participants.

Study Title: Neural Systems For Infant Sensitivity to Phonological Rhythmic-Temporal Patterning

Domestic/Foreign: Domestic

Comments: Participants are recruited from the Washington, D.C. area. Therefore, this table reflects the approximate ethnic and racial diversity in the area.

Racial Categories	Ethnic Categories				
	Not Hispanic or Latino		Hispanic or Latino		Total
	Female	Male	Female	Male	
American Indian/ Alaska Native	1	1	0	0	**2**
Asian	2	2	0	0	**4**
Native Hawaiian or Other Pacific Islander	0	0	0	0	**0**
Black or African American	4	4	2	2	**12**
White	5	5	4	4	**18**
More Than One Race	1	1	1	1	**4**
Total	**13**	**13**	**7**	**7**	**40**

LIST OF REFEREES

(in alphabetical order)

1. Thomas Allen, Ph.D.
   Gallaudet University
   Professor, Department of Education
   Program Director, Ph.D. in Educational Neuroscience Program
   Co-PI, Visual Language & Visual Learning, a NSF Science of Learning Center

2. Rain Bosworth, Ph.D.
   University of California, San Diego
   Assistant Research Scientist, Department of Psychology
   Infant Vision Lab

3. Ioulia Kovelman, Ph.D.
   University of Michigan
   Assistant Professor, Department of Psychology
   Director, Language and Literacy Lab

4. Carol Padden, Ph.D.
   University of California, San Diego
   Professor, Department of Communication
   Dean, Social Sciences, and Director, Padden Lab

5. Steven Pinker, Ph.D.
   Harvard University
   Professor, Department of Psychology

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December 12, 2015

To Whom It May Concern:

This letter certifies Adam Stone as being eligible for the Ruth L. Kirschstein National Research Service Awards for Individual Predoctoral Fellowships to Promote Diversity in Health-Related Research (F31). Mr. Stone has a disability (profound deafness).

Best,

Dr. Laura-Ann Petitto — Date
Full Professor, Gallaudet University
Scientific Director, Brain & Language Laboratory for Neuroimaging (BL2)
Science Director & Co-PI, Visual Language & Visual Learning, NSF Science of Learning Center

FORWARDED WITH THE CONCURRENCE OF GALLAUDET UNIVERSITY

Audrey Wineglass Foster — Date
Director, Office of Sponsored Programs
Gallaudet University

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