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Brief report

fNIRS reveals enhanced brain activation to female (versus male) infant directed speech (relative to adult directed speech) in Young Human Infants

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ABSTRACT

We hypothesized an association between auditory stimulus structure and activity in the brain that underlies infant auditory preference. In a within-infant design, we assessed brain activity to female and male infant directed relative to adult directed speech in 4-month-old infants using fNIRS. Results are compatible with the hypothesis that enhanced frontal brain activation, specifically in prefrontal cortex that is involved in emotion and reward, is evoked selectively by infant directed speech produced by female voices and may serve as a neuronal substrate for attention to and preference for "motherese" displayed by infants.

1. Introduction

Infants do not command adequate skills to fully comprehend speech, but infants still respond to speech directed to them. Indeed, adults commonly speak to infants in a special register called "Infant Directed Speech" (IDS; also known as "baby talk") that is distinguished from Adult Directed Speech (ADS). IDS has unique vocal and acoustic characteristics and is thought to promote attention, cognition, and social interaction. In this fNIRS study, we examined and compared brain responses in infants' left and right frontal cortical hemispheres to female versus male voices speaking in IDS and ADS. In the next sections, we briefly review studies that describe differences between IDS and ADS, motherese versus fatherese, infant preferences for IDS, fNIRS, and hemispheric development in infancy.

1.1. IDS-ADS

Compared to ADS, IDS has higher pitch (f0), a larger pitch range (f0 range), slower tempo (longer phoneme duration), and more rhythm (Fernald et al., 1989; Kaplan, Goldstein, Huckeby, Owren, & Cooper, 1995; Soderstrom, 2007; Song, Demuth, & Morgan, 2010). IDS can be found in a wide variety of languages, such as English, German, Italian, Japanese, Korean, Sri Lankan Tamil,

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Tagalog, and Thai (Inoue, Nakagawa, Kondou, Koga, & Shinohara, 2011; Narayan & McDermott, 2016; Sulpizio et al., 2017), even if cross-language comparisons show IDS is subject to some cross-linguistic adaptations (Fernald et al., 1989). The exaggerated acoustics of IDS are thought to make it more attractive to infant listeners than ADS (Fernald & Kuhl, 1987; Kitamura & Lam, 2009; Papoušek, Papoušek, & Symmes, 1991; Trainor, Austin, & Desjardins, 2000): Young infants, even newborns, prefer listening to IDS over ADS (Cooper & Aslin, 1990; Fernald, 1985; Pegg, Werker, & McLeod, 1992; Werker & McLeod, 1989). IDS is also believed to aid infant language learning by facilitating speech segmentation (Thiessen, Hill, & Saffran, 2005) and amplifying lexical and grammatical structure (Fernald & Mazzie, 1991; Nelson, Hirsh-Pasek, Jusczyk, & Cassidy, 1989). Infants whose mothers use such exaggerations in speech show correspondingly better speech discrimination (Liu, Kuhl, & Tsao, 2003). Finally, IDS emerges in the vocal expression of emotion and is a likely pathway to emotional bonding (Saint-Georges et al., 2013; Trainor et al., 2000). Infants use IDS as a cue to select appropriate social partners, attending preferentially to an interlocutor who uses IDS (Schachner & Hannon, 2011). Thus, IDS stands at the core of the infant's perceptual, linguistic, emotional, and social development.

1.2. Motherese versus fatherese

Two principal vocal properties are intensity (loudness) and frequency (pitch). The larynx (voice box which holds the vocal folds) is more descended in males, so when the vocal folds generate a sound wave (via vibration), the wavelength is longer (because it has further to travel along the vocal tract), generating lower pitch. In general, male voices (MV) fall at an octave lower than female voices (FV). In consequence, mothers speaking in IDS ("motherese") and fathers speaking in IDS ("fatherese") share several features, albeit with some differences. Gergely, Faragó, Galambos, and Topál (2017) noted that mothers exaggerate vowels more than do fathers when speaking to infants, and the pitch characteristics of motherese are stable across infant development (see also Amano, Nakatani, & Kondo, 2006). Additionally, reading and conversing in fatherese involves different patterns of prosodic modification from motherese (Shute & Wheldall, 1989). Others have reported that motherese also utilizes a wider pitch ($f0$) range than fatherese (Fernald et al., 1989; but see Warren-Leubecker & Bohannon, 1984).

Mothers and fathers also vary in caregiving behaviors (Murry, Simons, Simons, & Gibbons, 2013; Pleck, 2010). Because mothers' and fathers' parenting separately predict children's language and cognitive skills (Tamis-LeMonda, Shannon, Cabrera, & Lamb, 2004), motherese and fatherese could have independent effects on child development. However, mothers are more frequently the primary caregiver and principal socializer of infants (Bornstein, 2015; Greenfield, Suzuki, & Rothstein-Fisch, 2006). Moreover, Johnson, Caskey, Rand, Tucker, and Vohr (2014) found that female adults respond to infant vocalizations more than do male adults. Differences between female-infant and male-infant interactions underscore that females may provide vocal cues, sociality, and language input different from males.

For their part, infants respond to IDS differently depending on the gender of the speaker. Niwano and Sugai (2003) reported that infants respond at a greater rate to motherese than fatherese. Infants become familiar with their mother's voice while in utero and hear vocalizations from their mothers most frequently. Not surprisingly, infants prefer their own mothers' IDS (Fernald, 1985; Grieser & Kuhl, 1988), and newborns prefer female voices (their mothers and strangers) over male voices (their fathers and strangers), suggesting that prenatal experience might also influence voice preferences (Brazelton, 1978; DeCasper & Prescott, 1984). Furthermore, infants show advantages in matching female faces to voices in contrast to matching male faces to voices (Richoz et al., 2017). Thus, the infant brain may respond differently to IDS vocalized by females and males.

1.3. Infant preferences

What is the basis of infants' preference for IDS, especially when produced by a female voice? The present study attempts to answer the question why infant attention to IDS exceeds infant attention to ADS. One hypothesis suggests that attention in infants is mediated by the amount of excitation of neural tissue in the brain (Bornstein, 1978; Haith, 1980). It has long been recognized that neurons, and neuronal network aggregations, respond preferentially to different specific types of stimulation (Hubel & Wiesel, 1962). When the appropriate stimulus or "trigger feature" for a given neuron or network is presented in its receptive field, the rate of neural electrical activity increases. Stimuli that deviate from the neuron's preferred feature structure produce lower rates of neural firing or may even inhibit neuronal excitation from its spontaneous level. This relation between specific stimulation and central nervous system activity is today unchallenged.

1.4. fNIRS

Advances in behavioral testing techniques have permitted strong inferences about infant perception (Bornstein, Arterberry, & Lamb, 2014). However, the neural underpinnings of infants' developing capacities have remained elusive, in large measure because of limited methods available to study brain development in human infants. Functional near-infrared spectroscopy (fNIRS) is a viable tool for measuring brain activation in awake, engaged infants (Jobsis, 1977). fNIRS is noninvasive and nonionizing and so is safe to use with infants repeatedly and for extended periods of time. fNIRS also has good temporal resolution: Brain signals can be routinely observed with a temporal sampling resolution up to 0.01 s. Furthermore, behavioral measures of infant looking time and head turning may show similar responses to different stimuli, whereas neuroimaging data may reveal different patterns of cortical responses to those same stimuli, suggesting that stimuli are actually perceived or processed differently, such as with mobile objects and checkerboard patterns in infants as young as 3 months old (Watanabe, Yagishita, & Kikyo, 2008). fNIRS neuroimaging technology can also localize function in the brain. A longitudinal fNIRS study revealed that localized patterns of activation in the temporal and frontal