



“Mom called me!” Behavioral and prefrontal responses of infants to self-names spoken by their mothers



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ABSTRACT

Development of a sense of self is a fundamental process needed for human social interaction. Although functional neuroimaging studies have revealed the importance of medial prefrontal cortex (mPFC) in self-referencing, how this function develops in infancy remains poorly understood. To determine the cerebral basis underlying processing of self-related stimuli, we used behavioral measures and functional multi-channel near-infrared spectroscopy (fNIRS) to measure prefrontal cortical responses in 6-month-old infants hearing their own names. We also investigated the influence of a mother's voice on name perception in infants — an ability that plays a crucial role in the recognition of social signals. Experiment 1 measured the behavioral preferences of infants for their own names and for other names, spoken either by their mothers or by strangers. Results showed that infants significantly preferred their own name to other names, regardless of speaker type. Experiment 2 examined hemodynamic responses to the same four conditions in the prefrontal cortex. Compared with other names, hearing their own names, especially when spoken by their mother, elicited greater activity in the infant's dorsal mPFC. Furthermore, the magnitude of the cerebral response correlated with the degree of behavioral preference only when involving their mother's voice. These findings suggest that, particularly in the context of their mothers' voice, the dorsal mPFC of infants is already sensitive to social signals related to self at 6 months. At the same time, familiarity and affection related processing are also discussed as possible factors modulating dorsal mPFC activation at this age.

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Introduction

Humans develop their communication skills from birth through interaction with others. To detect messages conveyed by others intended for interaction, one must understand signals directed at the self. Humans are extremely sensitive to ostensive signals like name calling that indicate someone's communicative intention toward them (Csibra, 2010). An infant's name is usually spoken in infant-directed speech ('motherese') by caregivers and gradually becomes an ostensive signal. Infants learn their own name as an auditory signal about the self and can recognize names at around 4.5 months of age (Mandel et al., 1995). From this age, infants will selectively turn their head when their name is called, showing that they interpret their own name as a vocative.

The underlying mechanism behind name recognition is thought to be “mentalizing” — a term that refers to an automatic cognitive process that underlies our ability to attribute intentions to ourselves or to others

(Amodio and Frith, 2006). This involves understanding communicative intentions toward ourselves by interpreting audio signals as our names. The brain regions that adults employ in processing these communicative signals are localized specifically in the right medial prefrontal cortex (mPFC) and the left temporal pole (Kampe et al., 2003). Recently, Grossmann et al. (2010) examined whether 5-month-old infants are sensitive to eye contact and their own names as communicative signals by measuring PFC responses using functional near-infrared spectroscopy (fNIRS). They showed that infants automatically process communicative signals directed at them, as the left dorsal prefrontal cortex was activated in response to their own names. Although this difference in localization patterns between 5-month-old infants and adults may be due to changes during development, supportive evidence is sparse, particularly for infants. The present study aims to reveal further details of the neural mechanism underlying early name recognition by focusing on prefrontal activation, particularly the mPFC, and the effect of speaker familiarity. In their daily lives, infants usually hear their names spoken by principal caregivers (e.g. mothers), and these familiar voices might have a large impact on developmentally early processing of social signals toward self. However, the influence of familiar voices on infant name recognition has not been explored in previous studies. Thus, our

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study has an additive effect on the recognition of one's own name as an ostensive signal. Namely, we examine whether mother's voice would enhance the association between names and self.

Each infants' response to their own name influences social-communicative development. Previous studies have focused on the role of an infant's own name in early language acquisition, including object learning. Because infants focus their attention in response to hearing their own names they may be more likely to associate events with their labels. For example, 6-month-old infants recognize words that follow their own name, but not words that follow other names (Bortfeld et al., 2005). Using event-related potentials (ERP), Parise et al. (2010) showed that ERP amplitude following the Nc peak was larger for objects preceded by the infant's own name. This suggests that infants use their own name as a social cue to focus their attention on events, and suggests that infants can easily absorb a great deal of information by effectively responding to their own name.

As many behavioral studies have shown, establishment of the mother–infant bond is also crucial for social-communicative development. An experiment using a measure of sucking behavior showed that at birth neonates already prefer their own mother's voice to that of a stranger (DeCasper and Fifer, 1980). Infants at 3.5 months of age can only recognize their mothers' facial expressions, while they can only recognize facial expressions of other people four months later (Montague and Walker-Andrews, 2002). Barker and Newman (2004) showed that word learning in 6- to 8-month-old infants was facilitated when words were spoken by the infant's own mother. These studies suggest that mothers play a crucial role in infant acquisition of basic social-communicative abilities in the first year of life.

Indeed, mothers spend a large amount of time with their infants, thus, it is assumed that the mother contributes to their infant's neurological development. Using fNIRS, Minagawa-Kawai et al. (2009) measured cerebral responses in infants to video-clips that showed their own mothers and unfamiliar mothers engaged in smiling behavior, and found that infants about 1 year in age showed activation in the anterior part of the orbitofrontal cortex (OFC) specifically when watching their own mothers' smiles. This suggests that infant prefrontal cortex might play a role in regulating and encoding affective cues from the primary caregiver. Using ERP, Purhonen et al. (2005) found that the mother's voice has special importance and enhances involuntary attention; this indicates a clear memory template of the own mother's voice at a very early age. Furthermore, it has been shown that the mother's voice elicits stronger activations in the anterior prefrontal cortex and the left posterior temporal region than an unknown voice, suggesting that the mother's voice plays a role in the early shaping of the human auditory system (Dehaene-Lambertz et al., 2009). As shown by these studies, the mother's voice has a strong impact on both behavioral and neural responses in young infants. A previous study using ERP in adult humans showed that a participant's own name elicited larger response amplitudes in the late phase of novelty P3 in the fronto-parietal region when the name was produced by a familiar voice than when it was produced by an unfamiliar voice (Holeckova et al., 2006). This indicates that familiar voices may induce deeper processing of self-related stimuli than unfamiliar voices even in infants. Hence, it is likely that an infant's name being called by the mother plays a special role in the development of the mechanism of mentalizing, and this should be studied by assessing the brain of the infant.

As discussed above, principal caregivers play a crucial role in the social-communicative development of infants. Although a previous behavioral study has shown that infants recognize their own name called by strangers as a familiar word form (Mandel et al., 1995), it has not yet been shown whether mothers' voices affect the ability of their infants to recognize communicative signals directed at the self. Furthermore, only a few infant studies have assessed behavioral and neurophysiological responses simultaneously. Using both approaches provides rich information on the interpretation of neural basis about behaviors (Seth et al., 2008). Therefore, the present study aimed to assess the responses

of 6-month-old infants to names (theirs or others), spoken by women (their mothers or strangers), using both behavioral and neuroimaging measures. In Experiment 1, we examined infant behavioral responses to names called by either mothers or strangers using a modified head-turn preference procedure. In Experiment 2, we used fNIRS to examine changes in infant cerebral activation patterns in response to hearing names spoken in different voices. To this end, we measured activation in frontal brain regions that have been implicated in similar studies using adults. These regions include part of the medial prefrontal area, which is crucial for processing self-related stimuli. We expected to find higher levels of activation in the prefrontal brain regions in response to one's own name (self-name) than to others (other-names). Furthermore, we predicted that a self-name spoken by one's own mother is the most effective self-referencing stimulus for activating the mPFC.

Experiment 1

Using a modified head-turn preference paradigm, we investigated whether mothers' voices or strangers' voices differentially affect how infants respond to hearing their names (Nelson et al., 1995). Previous studies have suggested that infants can perceptually discriminate between self-names and other-names at 4.5 months of age. However, no studies have been performed to assess whether the mother's voice affects the recognition of self-name as a familiar word form in infants. In this experiment, we investigated self-name recognition in infants by varying speaker familiarity. We hypothesized that infants would show a preference for self-names over other-names, and that they would show more preference to self-names when spoken by their own mother than when spoken by strangers.

Materials and methods

Participants

Seventeen 6-month-old infants (10 boys and 7 girls; mean age, 181.5 ± 22.8 days) and their mothers participated in the experiment. Three participants were excluded from final analysis because of fussiness ($n = 2$) and technical failure ($n = 1$). All infants were screened for typical cognitive functioning using the Kyoto Scale of Psychological Development (KSPD) (Ikuzawa et al., 2002) at the time of the experiment and all infants had been full term at birth and had no history of serious illnesses or disorders in both Experiments 1 and 2. The study was approved by the ethics committee of Keio University, Faculty of Literature (No. 11047). Informed consent was obtained from the parents prior to the study. On the basis of our interaction with the mothers and the results of KSPD, all mothers were regarded to be healthy with no cognitive deficits.

Stimuli

Audio recordings of the infants' first names spoken by their mothers were used as stimuli. The mothers' voices were recorded (PMD671, Marantz) before the behavioral study. We checked in advance what kind of names infants usually hear such as infants' sibling names and chose a name for other names condition. Mothers were instructed to say the name of their own child and those of the other infants using infant-directed speech. The experimenter demonstrated an example utterance before the recording. The audio stimuli were digitized at a sampling rate of 44.1 kHz and a resolution of 16 bits. All infant names were controlled to have the same number mora which is a sub-syllabic structure serving a basic unit in Japanese (e.g. Ma-sa-hi-ro, 4 morae; Ryo-o-he-i, 4 morae). The auditory stimuli comprised four conditions: self-name/mother's voice, self-name/stranger's voice, other-name/mother's voice, and other-name/stranger's voice. The name stimuli of each condition consisted of 40 s which included repeated one name with an inter-stimulus interval (ISI) of 500 ms and the number of one name was in each stimuli. Stimuli used in the self-name condition for

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