Development of Adaptive Communication Skills in Infants of Blind Parents

Nataşa Ganea[1], Kristelle Hudry[2,3], Angélina Vernetti[1], Leslie Tucker[1], Tony Charman[4], Mark H. Johnson[1], and Atsushi Senju[1]

[1]Centre for Brain and Cognitive Development, Birkbeck, University of London, Malet Street, London WC1E 7HX, UK

[2]Victorian Autism Specific Early Learning and Care Centre, La Trobe University, Australia

[3]Olga Tennison Autism Research Centre, School of Psychology and Public Health, La Trobe University, Australia

[4]Department of Psychology, Institute of Psychiatry, Psychology & Neuroscience, King's College London, UK

Correspondence concerning this article should be addressed to Atsushi Senju, Centre for Brain and Cognitive Development, Birkbeck, University of London, Malet Street, London WC1E 7HX, United Kingdom. E-mail: a.senju@bbk.ac.uk

Abstract

A fundamental question about the development of communication behaviour in early life is how infants acquire adaptive communication behaviour that is well-suited to their individual social environment, and how the experience of parent-child communication affects this development. The current study investigated how infants develop communication skills when their parents are visually impaired and cannot see their infants' eye gaze. We analysed 6-minute video-recordings of naturalistic interaction between 14 sighted infants of blind parents (SIBP) with a) their blind parent and b) a sighted experimenter. Data coded from these interactions were compared to those from 28 age-matched sighted infants of sighted parents (Controls). Each infant completed two visits, at 6-10 months and 12-16 months of age. Within each interaction sample, we coded the function (initiation or response) and form (face gaze, vocalisation, or action) of each infant communication behaviour. When interacting with their parents, SIBP made relatively more communicative responses than initiations, and used more face gaze and fewer actions to communicate, than did Controls. When interacting with a sighted experimenter, by contrast, SIBP made slightly (but significantly) more communicative initiations than Controls, but otherwise used similar forms of communication. The differential communication behaviour by infants of blind vs. sighted parents was already apparent by 6-10 months of age, and was specific to communication with the parent. These results highlight the flexibility in the early development of human communication behaviour, which enables infants to optimise their communicative bids and methods to their unique social environment.

Keywords: development, communication, interaction, infants, blind parents

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Communication is a cognitive skill manifest through complex social behaviour that consists of sending information to and receiving information from another (Jaswal & Fernald, 2002), and forms a fundamental part of human social interaction and social learning. From very early in postnatal development, infants use a wide range of channels to communicate with adults. Infants detect and preferentially look at faces that make eye contact (Farroni, Csibra, Simion, & Johnson, 2002), recognise and respond to their mother's voice (DeCasper & Fifer, 1980), and use information about their own goal directed actions to detect goals in others' actions (Sommerville, Woodward, & Needham, 2005). All of these channels allow infants to receive communicative information from, and send signals to, adults from the first days of life.

Research has demonstrated that infants actively exploit these channels to initiate and respond to communication with adults. A clear example of infants' initiation of communication is in their object directed action which has been shown to attract parents' attention, with parents being more likely to follow their infants' interest and explore the objects themselves as well as to use more referential language (Tamis-LeMonda, Kuchirko, & Tafuro, 2013). By contrast, infants respond to adults' communicative acts by looking toward them and attending to their actions. This behaviour is thought to set the foundation for referential communication (Bakeman & Adamson, 1984), and has been found to be reduced in 12-month-old infants who are later diagnosed with Autism Spectrum Disorder (ASD; Wan et al., 2013), a condition characterised by core social-communication impairment, alongside behavioural inflexibility.

Reciprocal sensitivity to each partner's vocalisations is also reported within parent-child interactions, from infancy. For example, from at least five and a half months of age, infants respond contingently to their mothers' vocalisations (Bornstein, Putnick, Cote, Haynes,

& Suwalsky, 2015) and, in turn, infants' vocalisations engage the parents who are more likely to vocalise back to the infants (Goldstein & West, 1999; Gros-Louis, West, & King, 2016). This research points to the fact that infants' communication behaviour is closely linked to that of their communicative partners, and that infants play an active role when communicating with adults.

A fundamental question about the development of communication behaviour is how infants acquire these skills, and how the experience of parent-child communication affects their development. The study of sighted infants of blind parents (SIBP) provides an intriguing opportunity for elucidating typical developmental processes, because this group of infants will not experience immediate responses from parents that are contingent upon visual modes of communication – such as eye contact, or gestures/actions which involve no physical contact – because their parents cannot see them. Given the major role that forms of communication specific to the visual channel – such as eye gaze (Corkum & Moore, 1995) and gestures (Csibra, 2003) – play in the typical development of early parent-infant communication, and the broad downstream effects of an altered developmental experience for children with congenital visual impairment (e.g., Tadic et al., 2009), it is crucial to investigate the development of communication skills among SIBP.

To date, only a handful of studies have reported on the communication skills of SIBP, possibly due to the difficulty in accessing the target population. Early qualitative research, often involving in-depth follow up of a small sample, has consistently reported that parental visual impairment has very little impact on the overall quality of parent-child communication which seems to be adaptable via different channels, such as through auditory and tactile communication behaviours. In the first single case study of a sighted infant of two blind parents, Adamson, Als, Tronick, and Brazelton (1977) found that the infant looked less at her mother – who also showed less modulation of her own facial expressions – but was very engaged with her father – whose actions she followed closely. When questioned about his ability to monitor his infant's attention, the father reported that he used the direction of her breath as a cue to judge whether or not she was looking at him. By contrast, the mother reported that she tended to rely more on touch to monitor her infant's attention, which proved distracting for the infant, especially during feeding.

Another qualitative study of four SIBP (Collis & Bryant, 1981) similarly indicated that blind parents relied more on language and touch to engage with their children. In particular, these parents exploited distinctive sounds made by objects in the room to monitor their child's location and, during periods of silence, they checked in verbally by calling the child's name, making remarks or comments about the child, or asking the child to bring them an object. Each of these behaviours provided opportunities to locate the child but also to engage in interaction when the child responded. Rattray and Zeedyk (2005) quantified the communication behaviour of five parent-child dyads affected by visual impairment on behalf of either the parent *and/or* the child and reported that all dyads relied on touch, vocalisation and facial orientation to maintain communicative interaction.

Recently, efforts have been made to quantify the communication behaviour of SIBP, including studies comparing groups of SIBP with control groups of infants with sighted parents (hereafter, Controls). Senju et al. (2013) reported the first such study, looking at the forms of communication used by a small number of SIBP (n = 5) during free play interaction with their blind parent. Similar to the qualitative/single case study reports presented above, Senju et al. found no differences in the overall quantity of communication behaviour between SIBP and Controls. However, SIBP vocalised more than Controls, and tended to look less at their parents, although this latter difference did not reach statistical significance. Chiesa, Galati, and Schmidt (2015) also recently compared the communication behaviours of seven SIBP (aged from 6 months to 3 years) to those of seven age- and gender-matched Controls, replicating Senju et al.'s finding that SIBP looked less frequently at their parents and vocalised more during interaction than did Controls. These studies corroborate the earlier qualitative accounts, suggesting a typical range of overall communication behaviours among SIBP, compared to Controls, albeit with possible differences in the specific channels of communication used by SIBP for interaction with their blind caregivers.

There are at least two contrasting theoretical viewpoints that can account for the suggestion that interacting with a blind parent may influence certain aspects of communication behaviour in infants, without broadly impairing development in this domain. The affective learning model (Dawson, Webb, & McPartland, 2005; Grelotti, Gauthier, & Schultz, 2002) emphasises the role of the reward value of communication behaviour that could emerge as a result of extensive exposure to the co-occurrence of communication behaviour and a wide variety of positive experiences through social interaction and communication. From this position, SIBP could fail to develop the usual expertise and interest in adults' gaze because their own use and processing of gaze is not reciprocated by their blind parent, and therefore does not become rewarding. (This is compared to auditory or tactile forms of communication which should be reciprocated equally – or to even greater extent – among SIBP and their parents, than among Control dyads). Alternatively, the interactive specialisation model (Johnson, 2011) assumes that infants are born with widespread connections between cortical and subcortical regions of the brain (Elman et al., 1996) and that input from subcortical routes interacts with architectural biases to form specialised networks for social cognition. This model of developing brain functions predicts that SIBP could develop different forms of specialised communication behaviours, optimised to fit adaptively with the unique input and contingent responses provided by their blind parents.

In light of these perspectives, the current study aimed to compare communicative behaviours across matched groups of SIBP and Control infants, elicited during naturalistic social interaction scenarios – parent-child interaction (PCI), and interaction between the child and an unfamiliar sighted adult (i.e., stranger-child interaction, SCI). The affective learning viewpoint would predict that the differences in communication behaviour between SIBP and Controls should not be limited to PCI but generalise to SCI, because communication behaviour is based on the passively-learned reward value of such behaviour, primarily through interaction with the blind primary caregiver. By contrast, the interactive specialisation model would predict that the communication behaviour of SIBP could manifest differently between PCI and SCI conditions, because this has developed as an active adaptation to optimise communication with the blind primary caregiver, which should generate different dynamics of interaction when they communicate with other sighted adults.

To quantify infant communication behaviours, we adopted a coding scheme initially developed by Clifford, Hudry, Brown, Pasco, and Charman (2010), whereby each identified child communication act is assigned a code for function (i.e., initiation vs. response) and one or more forms (i.e., face gaze, vocalisation, and gesture/action). In this way, we captured both the *pragmatic context* in which successful communication behaviours occurred (i.e., the function of communication acts), and the specific ways in which the infants communicated with their social partners (i.e., the form/s used to convey communication acts). Both of these aspects of communication were coded, as similar *forms* of communication (e.g., looking at the partner whilst vocalizing) could denote either a communication episode that the infant initiated (e.g., when seeking help from the partner to get an object that is out of reach), or one occurring in response to the adult (e.g., labelling an object held up by the adult). To capture any developmental changes in communication, we included a prospective follow-up within our design which allowed us to investigate the patterns of communication behaviour between groups and across communication contexts, during the latter half of the first year of life and the first half of the second year of life.

Methods

Design and Participants

We employed a 2 Group (SIBP vs. Control) x 2 Time-point x 2 Communication context (PCI vs. SCI) mixed between-within subjects design, with infants filmed playing with their mothers (PCI) and with an unfamiliar, sighted female researcher (SCI) at each visit. These data represent secondary analysis of a dataset already reported by Senju et al. (2015), a subsample of which (n = 5 SIBP) have previously been reported by Senju et al. (2013). The procedure was approved by the Research Ethics Committee of Department of Psychological Sciences, Birkbeck, University of London (project title: Cognitive development of sighted infants of blind parents, protocol number: 7842).

Our SIBP group comprised 14 parent-infant dyads, recruited via charities and parental support groups relevant to blind adults, and personal contacts. These dyads included sighted infants (seven female) – aged 6-10 months at Time 1 ($M = 8.85$, $SD = 1.10$) and 12-16 months at Time 2 ($M = 14.28$, $SD = 0.88$), with mean between-visit interval of 5.43 months ($SD = 1.47$) – and blind parents (all mothers) who were the infants' primary caregivers. Although the specific cause of the mothers' visual impairment varied, all had experienced sight loss for more than 15 years and could not detect their infants' eye gaze from a distance of ~50 cm, based on their self-report (see Supplementary Material for details about the mothers' visual impairment and the family structure). Four additional recruited SIBP dyads were excluded from this study, as they did not attend assessments at both Time-points. All SIBP had undergone routine eye-checks at or soon after birth and the parents were not aware of any sight problems in the infants, with the exception of one SIBP who was diagnosed with retinoblastoma soon after birth. This infant had undergone therapy for this condition prior to study participation, by which time (i.e. infant age 8 months old) the retinoblastoma was in remission (and remained at so Time 2) and the family had been told that infant's vision had not been affected.

Data for Control participants were made available via the *British Autism Study of Infant Siblings* Network *(BASIS:* www.basisnetwork.org.uk; e.g., Elsabbagh et al., 2012; Bedford et al., 2012; Elsabbagh et al., 2014), which shared video-recordings for 28 sighted typically developing infants (17 females) of sighted parents (all mothers). Again, data were available across two Time-points, when infants were aged 6-10 months (M = 8.32, SD = 0.92) and 12-16 months (M = 14.69, SD = 1.01), with mean between-visit interval 6.37 months (SD = 0.77).

Interaction Sampling and Coding Procedure. For the PCI sample, parent-child dyads were seated on a picnic mat in the assessment room, and provided with a small set of age-appropriate toys. Mothers were asked to play with their children as they would usually do at home, making use of the toys if desired. The experimenter left the dyad to play alone for 10 minutes, capturing footage via a remote video recording system. The SCI sample was drawn from video footage of infants interacting with a sighted, unfamiliar female researcher (one of six members of our research centre) within a semi-structured play-based assessment; the Autism Observation Scale for Infants (AOSI, Bryson, Zwaigenbaum, McDermott, Rombough, and Brian, 2008). Developed as a standardized behaviour sample from which to observe social-communication and other behaviours in 6- to 18-month-olds at risk of developing ASD, the AOSI includes presses to elicit specific infant behaviours (e.g., the ability to track moving objects, to imitate actions, to respond to name call, etc.) and two 3-5 minute periods during which the examiner engages the child in free play with standard age-appropriate toys. The aim of these free play periods was to observe infant's referential behaviour, spontaneous vocalisations, and spontaneous actions directed at the toys or at the adult. We therefore used the AOSI free-play periods as naturalistic samples from which to code infant communicative behaviour with an unfamiliar, sighted adult. Experimenters were aware of the infants' group membership, but naive to the current study hypotheses. When interacting with an infant, the experimenter did not use a script but she prompted the infant to explore the toys provided, and responded to the infant's vocalisations and behaviours directed at her.

The toys used in the SCI were different from those used in the PCI, as was the set-up with infants seated on the floor with their parents for PCI, and on their parents' lap across the table from the experimenter for the SCI. For each of the PCI and SCI, the set-up and available toys were identical for all participants.

We coded infants' communicative acts during the first 6 minutes of each interaction sample – PCI free-play with the blind or sighted parent, and SCI free-play with the unfamiliar sighted examiner – using aspects of the social-communication coding protocol of Clifford et al. (2010). Each infant communication act was assigned a specific function (i.e., initiation or response) and one or more forms (i.e., vocalisation, action, and face gaze; see average scores in Appendix Table 1). An act was classified as an *initiation* if the infant's communication behaviour was not in direct response to a preceding adult behaviour, and as a *response* when it followed on from something the adult had just said or done. The *form* of each act was classified as a *vocalisation* when either a non-verbal vocalisation, word approximation, or speech was used, as an *action* when there was some communicative movement of an object (e.g., holding something up to show it) or communicative use of the infant's own body (e.g., reaching towards an object), and as *face gaze* when the infant looked toward the adult's face or made a three-point gaze shift between the adult's face and an object. Other more specific communicative forms were coded (e.g., pointing, giving/showing, head nodding/shaking, and following gaze), but these presented infrequently during the interaction samples for infants of this age and so were excluded from further analyses. Behaviour combinations such as a vocalisation accompanied by face gaze were coded as having only one communicative function but multiple communicative forms.

PCI coding from video footage commenced when the researcher left the parent and child to play alone and continued for 6 minutes. SCI coding from video footage commenced when the researcher placed the free-play toys on the table in front of the infant, and ended after 6 minutes (pausing when the researcher removed the toys at the end of the first AOSI free-play episode, and resuming when she returned these to the table for the second AOSI free-play episode).

To standardize the rates of communicative function codes across participants, we calculated an initiation-response index (IRI) by subtracting the number of responses from the number of initiations coded for each infant, and dividing this by the total number of communication acts. Hence, positive IRI values represent relatively more initiations and negative IRI values represent relatively more responses among an infant's total communication acts. Similarly, the number of vocalisations, actions, and instances of face gaze were divided by the total number of infant communicative acts to obtain proportion measures of each communicative form (e.g. proportion vocalisations = number vocalisations/total communicative acts). As the communicative forms were not independent of one another, their sum could exceed 1. Total Communication acts, IRI, and proportions of Vocalisations, Actions and Face Gaze were then included in our key analyses.

Evaluation of Inter-Rater Agreement. Footage was coded by one of two raters, neither of whom was aware of the infants' group status or age, or the study hypotheses. Inter-rater reliability was established by having both raters code a subset of clips, selected unsystematically, representing both the SIBP (n = 13 clips) and control groups (n = 30 clips) across both PCI (n = 27) and SCI (n = 16) contexts. Two-way mixed intra-class correlation coefficients ($ICC_{2,2}$ with *absolute* agreement*; see* Trevethan, 2016) were used to evaluate inter-rater agreement across the key measures (see Results for a description of the measures). ICCs were adequate to excellent (Fleiss, 1986) for all the measures except for the Initiation-Response Index: Total Communication = .82 ($ICC_{2,1}$ with *absolute* agreement); Initiation-Response Index = .62; Proportion Vocalisations = .91; Proportion Actions = .72; Proportion Face Gaze = .87. The lower reliability score for the Initiation-Response Index may have been due to the fact that with very young infants it was more difficult to judge when they initiated communication than when they responded to the parent ($ICC_{2,1}$ scores for Initiations = .45, and Responses = .77). $ICC_{2,1}$ scores for the raw number of communicative forms are reported in the Supplementary Information. Note that the form of the ICC model changes for $ICC_{2,2,}$ to $ICC_{2,1}$ because the total number of communication acts and the raw number of communication forms were single measures, that were not averaged prior to the analysis.

Results

We conducted a series of three-way ANOVAs – with Group varying between participants and Communication context and Time-point varying within participants.

The three-way ANOVA on total communication showed main effects of Communication context ($F(1, 40) = 76.81$, $p < .001$, $\eta_p^2 = .66$) and Time-point ($F(1, 40) = 36.36$, $p < .001$, $\eta_p^2 = .48$), as infants communicated more often during SCI ($M = 33.35$, $SD = 8.14$) than PCI ($M = 18.08$, $SD = 6.97$), and more often at Time 2 ($M = 30.56$, $SD = 6.68$) than at Time 1 ($M = 20.87$, $SD = 7.55$). The latter main effect was qualified by a significant Time-point x Group interaction term ($F(1, 40) = 4.81$, $p = .034$, $\eta_p^2 = .11$) such that Controls used significantly more total communication acts at Time 2 ($M = 31.84$, $SD = 7.07$) than Time 1 ($M = 20.05$, $SD = 6.65$), $t(27) = 7.96$, $p < .001$, $d_z = 1.50$, whereas the differences in total communication acts between time points did not reach significance in SIBP (Time 2: *M*

= 28.00, *SD* = 5.13; Time 1: *M* = 22.5, *SD* = 9.13), $t(13) = 1.98$, $p = .07$. The significance level for these post-hoc tests and the ones reported hereafter was lowered to $p = .025$ after applying Bonferroni correction for multiple comparisons. Only those comparisons where $p < .025$ were reported as significant. Crucially, neither the main effect of Group ($F(1, 40) = .15$, $p = .70$), nor the Communication context x Group ($F(1, 40) < .001$, $p = .98$), nor the three-way interaction term ($F(1, 40) = .65$, $p = .43$) reached significance.

[Figure 1 about here]

The mean IRI composite score was negative, overall, suggesting that the majority of infant communication functions were *responses* rather than initiations to the adult partners (see Figure 2). However, results of the three-way ANOVA showed that IRI was modulated significantly by Group membership and Communication context. That is, there were significant main effects of Group ($F(1, 40) = 11.03$, $p = .002$, $\eta_p^2 = .22$) and Communication context ($F(1, 40) = 131.01$, $p < .001$, $\eta_p^2 = .77$). These effects were qualified, however, by a significant Group x Communication context interaction term ($F(1, 40) = 36.37$, $p < .001$, $\eta_p^2 = .48$). Observed power was 90 % for the significant main effect of group, 99 % for the significant main effect of communication context and 99 % for the significant interaction. Follow-up analyses revealed that Controls (*M* = -.07, *SD* = .31) initiated relatively more than SIBP (*M* = -.52, *SD* = .18) during PCI, $t(40) = 5.07$, $p < .001$, $d_s = 1.77$. Indeed, IRI of Controls during PCI was very close to zero, implying a more balanced initiation and responses in this condition. By contrast, SIBP (*M* = -.78, *SD* = .15) initiated relatively more than Controls (*M* = -.90, *SD* = .10) during SCI, $t(19.28) = 2.86$, $p = .01$, $d_s = .94$. No other main effects or interactions reached significance (Time-point effect, $F(1, 40) = .108$, $p = .74$; Group x Time-point, $F(1, 40) = .001$, $p = .98$; Communication context x Time-point, $F(1, 40) = .78$, $p = .38$; three-way interaction , $F(1, 40) = .39$, $p = .54$).

[Figure 2 about here]

For vocalisation, there was a significant main effect of Communication context ($F(1, 40) = 96.51$, $p < .001$, $\eta_p^2 = .71$), with relatively more vocalisation during PCI ($M = .56$, $SD = .19$) than SCI ($M = .26$, $SD = .12$; see Figure 3). This was qualified by a significant Time-point x Communication context interaction term ($F(1, 40) = 7.95$, $p = .007$, $\eta_p^2 = .17$). Observed power was 99 % for the significant main effect of Communication context and 80 % for the significant interaction. Follow-up analyses revealed that infants' vocalisations increased between Time 1 ($M = .20$, $SD = .16$) and Time 2 ($M = .32$, $SD = .19$) during SCI, $t(41) = 3.02$, $p = .004$, $d_z = .48$, but not during PCI, $t(41) = .61$, $p = .55$ ($M_{Time1} = .58$, $SD_{Time1} = .25$; $M_{Time2} = .55$, $SD_{Time2} = .25$). No other main effects or interactions reached significance (Group effect, $F(1, 40) < .001$, $p = .99$; Time-point effect, $F(1, 40) = 2.57$, $p = .12$; Group x Communication context, $F(1, 40) = 1.74$, $p = .19$; Group x Time-point, $F(1, 40) = 1.69$, $p = .20$; three-way interaction , $F(1, 40) = .45$, $p = .51$).

[Figure 3 about here]

A significant main effect of Communication context for proportion of actions ($F(1, 40) = 87.74$, $p < .001$, $\eta_p^2 = .69$) reflected infants' greater use of communicative actions during PCI ($M = .48$, $SD = .17$) compared to SCI ($M = .21$, $SD = .08$; see Figure 4). This effect was qualified, however, by a significant Group x Communication context interaction term ($F(1, 40) = 10.04$, $p = .003$, $\eta_p^2 = .20$). Observed power was 99 % for the significant main effect of Communication context and 87 % for the significant interaction. Follow-up analyses revealed that, during PCI, SIBP ($M = .38$, $SD = .13$) used relatively fewer actions than Controls ($M = .52$, $SD = .17$), $t(40) = 2.72$, $p = .01$, $d_s = .93$, whereas there was no such between-group difference during SCI (SIBP: $M = .22$, $SD = .08$; Control: $M = .20$, $SD = .08$), $t(40) = .93$, $p = .36$. No other main effects or interactions reached significance (Group effect, $F(1, 40) = 3.28$, $p = .08$; Time-point effect, $F(1, 40) = .009$, $p = .93$; Group x Time-point, $F(1,

40) = .80, p = .38; Communication context x Time-point, $F(1, 40) = .03$, $p = .86$; three-way interaction, $F(1, 40) = 1.84$, $p = .18$).

[Figure 4 about here]

Finally, for proportion of face gaze, there were significant main effects of Group (F(1, 40) = 4.60, $p = .038$, $\eta_p^2 = .10$), Communication context (F(1, 40) = 235.11, $p < .001$, $\eta_p^2 = .86$), and Time-point ($F(1, 40) = 12.73$, $p < .001$, $\eta_p^2 = .24$). Observed power was 54 % for the significant main effect of group, 99 % for the significant main effect of Communication context and 93 % for the significant main effect of time. These were such that SIBP used more face gaze ($M = .60$, $SD = .09$) than Controls ($M = .52$, $SD = .11$), and all infants used more face gaze during SCI ($M = .77$, $SD = .08$) than PCI ($M = .33$, $SD = .18$), and at Time 1 ($M = .59$, $SD = .14$) compared to Time 2 ($M = .51$, $SD = .13$; see Figure 5). The Communication Context x Group interaction approached significance, F(1, 40) = 3.622, $p = .06$, $\eta_p^2 = .08$, indicating marginally higher face gaze by SIBP ($M = .41$, $SD = .15$) compared to Controls ($M = .29$, $SD = .18$) during PCI, $t(40) = -2.28$, $p = .028$, $d_s = .73$, compared to similar face gaze by infants in each Group during SCI, $t(40) = -.76$, $p = .45$ ($M_{Control} = .76$, $SD_{Control} = .09$; $M_{SIBP} = .78$, $SD_{SIBP} = .07$). No other main effects or interactions reached significance (Group x Time-point, $F(1, 40) = .82$, $p = .37$; Communication context x Time-point, $F(1, 40) = .50$, $p = .49$; three-way interaction, $F(1, 40) = .08$, $p = .78$).

[Figure 5 about here]

Discussion

This study represents a unique investigation of the communication behaviour of SIBP, adopting a prospective follow-up design to examine interaction with both a blind parent and a sighted unfamiliar adult. We examined various aspects of infant communicative behaviour – including both the function of communication acts and various forms of signalling these to the partner (i.e., via vocalisation, action and face gaze) – and found significant interactions between child group and social partner for some of these. Specifically, when they interacted with their blind parents, compared to Control infants interacting with their own sighted parents, SIBP showed marked differences in both the function and the form of communication including using relatively more responses than initiations, and fewer communicative actions. By contrast, during interaction with a sighted unfamiliar adult, SIBP initiated relatively more than Controls, with both groups using similar levels of communicative actions. A similar trend was observed for face gaze, where SIBP showed more face gaze than Controls during interaction with their parents, but with no between-group differences during interaction with a sighted stranger. Interestingly, both groups used similar levels of vocalisations, and vocalised more during the interaction with the parent than with a sighted stranger, and more at Time 2 than at Time 1. The results suggest that SIBP are flexibly and adaptively switching the style of their communication when with blind parents vs. a sighted experimenter. This is consistent with the prediction derived from the interactive specialisation model (Johnson, 2011), which hypothesises that infants develop optimised communication behaviour adaptive to the given communicative context. By contrast, it is inconsistent with the prediction derived from the affective learning viewpoint, which hypothesises that infants learn the reward value of communication behaviour through interaction with parents/carers and generalise this to other communicative contexts.

The directions of group differences in both the function and the form of communication are also informative, and somewhat counterintuitive. As for communicative function, SIBP responded more toward their parents than did Controls, but initiated relatively more (or rather, responded relatively less) toward the sighted experimenter than did Controls. This might suggest that SIBP have acquired skills to more effectively (or frequently) initiate communication to compensate for their parents' difficulty to notice visual form of communication. It may also be that this between-group difference during parent-child interaction simply reflects a stronger tendency for initiated communication by *blind* (compared to sighted) parents – hence eliciting relatively more responses by their infants. However, this latter interpretation cannot account for the group differences also observed in communicative functions during the SCI condition (i.e. SIBP initiated relatively more than Controls), in which both groups of infants were communicating with unfamiliar sighted adults.

As for the form of communication, SIBP used fewer communicative actions than Controls, only when interacting with their parents, suggesting that SIBP also flexibly change the channels of communication depending on their communicative partner. It seems rational not to use actions – such as showing or reaching for an object – when these cues are less likely to be picked up by their blind parents. However, these results also showed that SIBP used a similar amount of these actions when they interacted with sighted communicative partner, suggesting that they can still use this channel of communication when it is efficient. In addition, overall higher use of face gaze by SIBP – particularly during interaction with their blind parents – may seem inconsistent with a previous study (Chiesa et al., 2015) which found shorter overall face gaze in SIBP. Possibly, this discrepancy is due to the adoption of different coding schemes. We coded the frequency of each form used in successful communication events, whereas Chiesa et al. coded the total frequency of each behaviour during an observation period regardless of whether or not behaviours lead to successful communicative exchanges. Thus, it is possible that SIBP overall spend less time attending to parents' faces, but efficiently respond to parental communicative bids with face gaze.

Methodological differences between studies may also explain the apparent contradiction between the results of the current study and those of our recently reported eye tracking studies (Senju et al., 2015). Senju et al. (2015) found that SIBP and Controls differ in terms of their gaze following behaviour and face scanning pattern. Specifically, when presented with video clips of a female actress which looks directly towards the infant and then gazes at one of two objects in front of her, SIBP and Controls follow equally frequently the gaze of actress to the object, but SIBP look for a shorter period of time at the gazed-at object that Controls do. On the other hand, when watching a silent video of a dynamic female face, SIBP look more at the mouth than at the eyes area, whereas Controls show the opposite face-scanning pattern, looking more at the eyes than at the mouth. The findings reported in the current paper, in contrast, are based on successful communication bids between infants and adults, and quantify different forms of communication among which is the proportion of looks to the adult's face, irrespective of the part of the face attended to. In fact, given the interaction set-up in the current study, it would be very difficult for us to report which part of the adults' face infants gazed at when communicating. We therefore cannot rule out that the face scanning pattern observed in the SIBP group by Senju et al. (2015) is specific to certain communication partners. Interestingly, Senju et al. (2015) found that SIBP and Controls spent similar periods of time gazing to the dynamic female face. In the current study, we did not find a group difference in the proportion of face gaze in the SCI, but we did find a group difference in the PCI suggesting that SIBP infants are adaptively changing their face scanning behaviour depending on whom they are interacting with. However, due to the low observed power for this statistical analysis, this result should be interpreted with caution. Further sufficiently powered follow-up researches will be informative to explore this interesting trend of the use of face gaze during communication in SIBP.

The longitudinal design of the study allowed us to also analyse developmental change from the latter half of the first year to the first half of the second year of the infants' lives. The results showed almost no group differences in the developmental trajectory of functional communication or the forms used to signal these, with the exception of a main effect of reduced face gaze, and a specific increase in vocalisations toward a stranger, over time. Crucially, all of the between-group differences we observed showed stability across Time 1 and Time 2 behaviour samples, suggesting that SIBP acquired this partner-specific characteristic mode of communication early, and at least by 6 to 10 months of age.

Limitations in the current study arise from the difficulty in recruiting this hard-to-reach population and conducting assessments in a controlled environment. Firstly, we could not fully match the communicative context between PCI and SCI, mainly because the video footage for SCI were taken from another semi-structured behavioural assessment which might have contributed to some of the observed main effects of Communication Context for the function and form of infant communication behaviours. Thus, interpretation of these main effects needs to be treated with caution. However, this does not confound our observed between-group differences, as both groups of infants participated in the same communicative context for each of PCI and SCI. Secondly, we did not code the adults' communication behaviour and cannot definitively say whether this was the same or different across groups. This could have affected the proportion of initiations and responses made by the infants, but it is less likely to have altered the proportions of forms of infant communication acts. Thirdly, the reliability coefficient for the Initiation-Response Index (IRI), one of the measures on which we find differences between groups across both communication contexts, can be classified only as fair to good (Fleiss, 1986). This was mainly due to the fact that the IRI was computed as a function of raw number of Initiations and Responses, and that two raters found it more difficult to judge Initiations than Responses in young infants (see the *Method*s section). In light of this fact, efforts should be made in future work to improve reliability on the function of communication acts in young infants either through better camera angle and higher video quality, or through double coding and consensus among raters on all the video clips coded. Fourthly, despite being the largest sample reported for a study of this kind to date, power remains limited to detect small, but potentially developmentally important effects as statistically significant. Further replication studies, and/or follow-up studies with larger samples will be beneficial to test the robustness of the findings reported here, especially to further examine the effect of variability in social experience within the SIBP group (see Supplementary Information for further analyses and discussions). Finally, we do not yet know whether the current findings are specific to SIBP or common to other populations who experience different forms of parent-child interaction, such as hearing infants of deaf parents. Future studies with more variable target populations will help us understand the specificity and generalizability of the unique communication behaviour found in SIBP.

To conclude, the current research is the first to demonstrate that SIBP flexibly change their communication behaviours when interacting with their blind parents vs. sighted unfamiliar adults. Such a capacity could relate to the advanced overall development reported in this population during the first year of life (Senju et al., 2015). The results highlight the plasticity inherent in the early development of human communicative skill, which enables infants to optimise their communication behaviours within the individual social environment.

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Figures

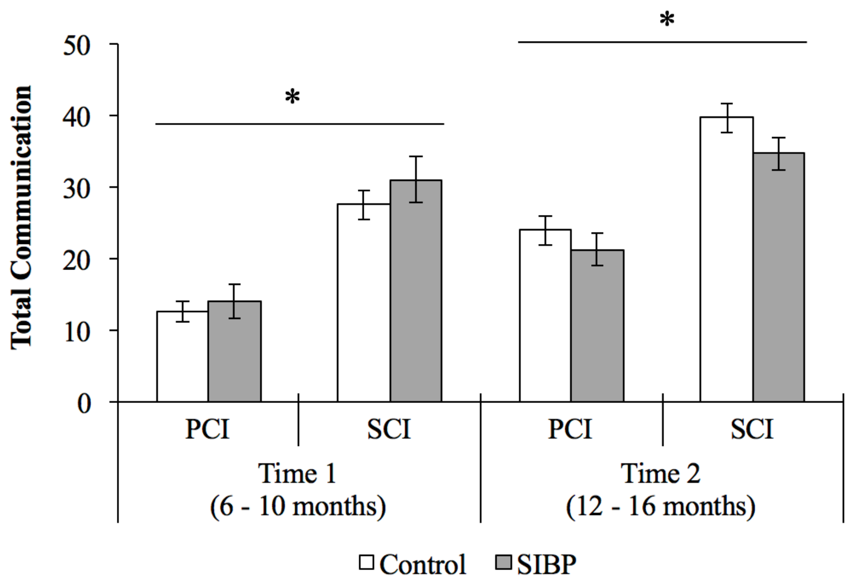

Figure 1. Total number of communication acts across groups, communication contexts, and time-points. Error bars: *SE*. * indicates $p < .05$.

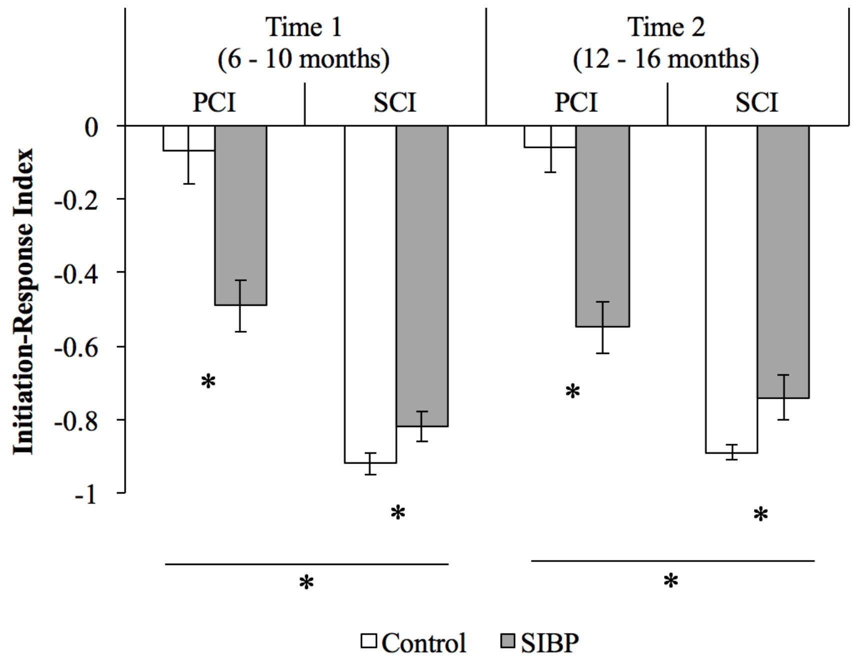

Figure 2. Initiation-response index (i.e. IRI = (initiations - responses)/(initiations + responses)) across groups, communication contexts, and time-points. Negative values indicate more responses than initiations. Error bars: *SE*. * indicates $p < .05$.

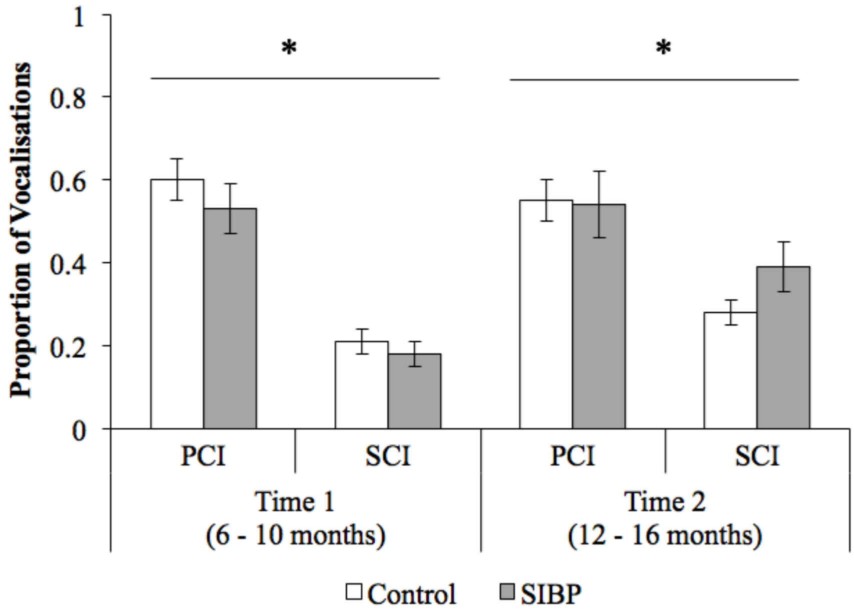

Figure 3. Proportion of vocalisations (i.e. number of vocalisations/total communication) across groups, communication contexts, and time-points. Error bars: *SE*. * indicates $p < .05$ and † indicates $p < .1$.

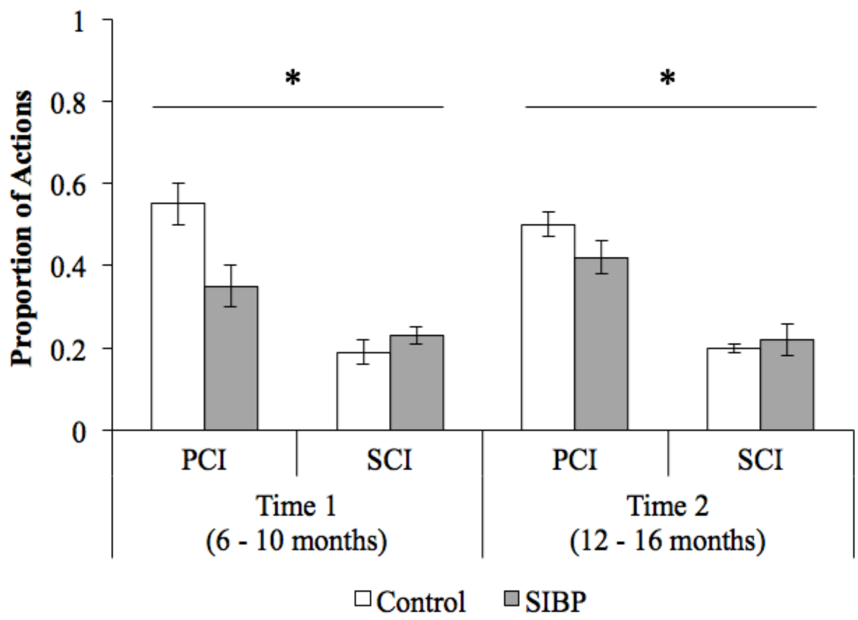

Figure 4. Proportion of action (i.e. number of actions/total communication) across groups, communication contexts, and time-points. Error bars: *SE*. * indicates $p < .05$.

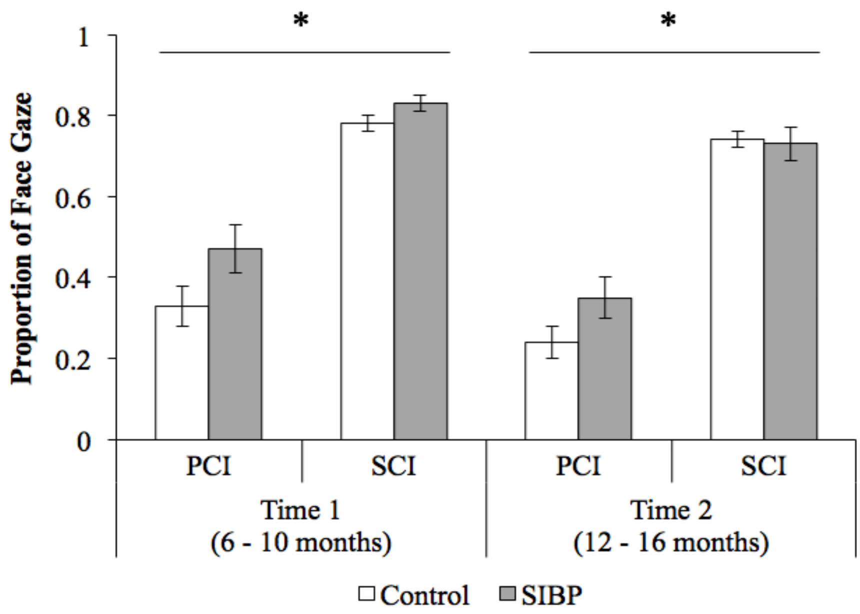

Figure 5. Proportion of face gaze (i.e. number of face gazes/total communication) across groups, communication contexts, and time-points. Error bars: *SE*. * indicates $p < .05$ and † indicates $p < .1$.

Table 1

Mean (standard deviation) number of initiations, responses, vocalisations, actions, and face gazes across groups, time-points, and communication contexts.

	Initiations				Responses				Vocalisations				Actions				Face Gazes			
	Time 1		Time 2		Time 1		Time 2		Time 1		Time 2		Time 1		Time 2		Time 1		Time 2	
Group	**PCI**	**SCI**	**PCI**	**SCI**	**PCI**	**SCI**	**PCI**	**SCI**	**PCI**	**SCI**	**PCI**	**SCI**	**PCI**	**SCI**	**PCI**	**SCI**	**PCI**	**SCI**	**PCI**	**SCI**
CTRL	5.61 (3.71)	.93 (1.51)	10.43 (4.60)	1.96 (1.50)	7.00 (4.97)	26.57 (11.02)	13.57 (8.13)	37.71 (10.99)	7.29 (5.32)	5.39 (4.69)	13.46 (8.27)	11.57 (8.29)	6.43 (4.37)	5.61 (4.71)	12.04 (6.53)	8.04 (3.76)	4.57 (4.64)	21.57 (9.29)	5.86 (4.41)	29.29 (9.38)
SIBP	3.36 (2.34)	3.14 (3.11)	5.14 (4.02)	4.43 (3.74)	10.64 (7.29)	27.86 (10.61)	16.07 (6.26)	30.29 (8.72)	6.93 (3.45)	6.64 (5.76)	13.00 (9.77)	13.43 (8.51)	5.64 (5.17)	7.21 (4.28)	9.07 (5.03)	8.00 (5.53)	6.57 (5.23)	25.36 (8.75)	7.71 (5.01)	25.36 (8.43)