Multimodal communication in newly sighted children: An investigation of the relation between visual experience and pragmatic development

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Abstract

We investigated the relationship between visual experience and pragmatic development by testing the socio-communicative skills of a unique population: the Prakash children of India, who received treatment for congenital cataracts after years of visual deprivation. Using two different referential communication tasks, our study investigated Prakash' children ability to produce sufficiently informative referential expressions (e.g., 'the green pear' or 'the small plate') and pay attention to their interlocutor's face during the task (Experiment 1), as well as their ability to recognize a speaker's referential intent through non-verbal cues such as head turning and pointing (Experiment 2). Our results show that Prakash children have strong pragmatic skills, but do not look at their interlocutor's face as often as neurotypical children do. However, longitudinal analyses revealed an increase in face fixations, suggesting that over time, Prakash children come to utilize their improved visual skills for efficient referential communication.

Keywords: pragmatics, informativity, communicative intention, non-verbal cues, reference.

Introduction

Visual experience is of paramount importance for the development of early socio-communicative skills. Visual information obtained through head turning, gaze direction, pointing gestures and facial expressions helps children establish joint attention, which plays a crucial role in their language acquisition (Baldwin, 1995; Corkum & Moore, 1998; Carpenter et al., 1998; Tomasello, 2009). The effect of visual deprivation on the structural language skills of blind populations have been extensively investigated (e.g., Andersen et al., 1984; Landau & Gleitman, 2009; McConachie & Moore, 1994), yet the extent to which limited visual experience affects the development of language use (or *pragmatics*) is not as well understood.

It stands to reason that those communicative skills that depend on the visual modality would show more deficits in blind children than those skills that are primarily learnt through speech. Indeed, it has been observed that blind children's structural language skills are intact (Landau & Gleitman, 2009), whereas those areas of pragmatic development that require visual information (e.g., appropriately initiating conversations, understanding irony and sarcasm—which can be highly dependent on the visual context, or being sensitive to others' levels of interest and adjusting conversational topics accordingly) show the greatest deficits (Tadic et al., 2010). Crucially, these and other pragmatic abilities require careful monitoring of the conversational partner's facial expressions and gestures.

Delays in the early development of Theory of Mind (i.e. the capacity to represent other people's mental states, such as beliefs, desires, and intentions) as established through false-belief tasks (Wimmer & Perner, 1983) have also been attributed to blind children's lack of access to visual information—which is still necessary to pass false-belief

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tasks allegedly adapted for blind children (Pereira, 2014). However, advanced Theory of Mind development and understanding of non-literal language are largely unaffected by visual experience as they emerge mostly in the speech modality (Pijnacker et al., 2012). Further support for the claim that blind people eventually develop an effective Theory of Mind comes from the observation that the relevant brain regions are similarly localized and functionally specific in congenitally blind and sighted adults (Bedny et al., 2009).

Given the dominance of visual experience in the early emergence of joint attention and its effect on language acquisition, here we investigated a unique population for the study of socio-communicative development: newly sighted children who received treatment for congenital blindness (due to dense bilateral cataracts) during childhood. We will refer to these children as *Prakash children,* adopting the name of the organization that sought their treatment in India (Sinha & Held, 2012; Sinha, 2013). Investigating the socio-communicative abilities of Prakash children gives us a unique opportunity to understand how prolonged visual deprivation affects pragmatic development. In particular, our study focused on informativity and attention to faces in referential communication (Experiment 1) and the recognition of referential intent through non-verbal cues such as head turning and pointing (Experiment 2).

Multimodality in language acquisition

Gaze direction and pointing are the main non-verbal cues that adults use with sighted children to establish joint attention. Infants as young as 3 months can follow an adult's head turn (D'Entremont et al., 1997) and start following another's gaze by 12 months (Caron et al, 2002a, 2002b; Brooks & Meltzoff, 2002; Meltzoff & Brooks, 2007). Around the same age, infants also start reliably following pointing gestures to distal targets (Carpenter et al., 1998). By the age of one, sighted infants can therefore follow pointing and understand its communicative intent (Behne et al, 2005; Gliga & Csibra, 2009).

Highlighting the importance of multimodality for language acquisition, Brooks and Meltzoff (2005) report a strong correlation between gaze following behavior and later language development. Pointing has also been found to be a robust predictor of subsequent lexical and syntactic development in neurotypical children (Iverson & Goldin-Meadow, 2005; Tomasello et al., 2007; Goldin-Meadow, 2007; Brooks & Meltzoff, 2008; Rowe et al., 2008; for a meta-analysis, see Colonessi et al., 2010).

Since joint attention is primarily established through the visual modality, there is little research on how it emerges in blind children. To understand their interlocutor's focus of attention, blind children must rely on auditory and tactile information (Bigelow, 2003). According to an early study, blind infants do not engage in joint attention until around 21-30 months of age (Preisler, 1993), but more recent work has revealed that blind children show non-prototypical signs of engaging in joint attention (e.g., stilling their body, becoming quiet or leaning toward the object or activity in focus), which might not be recognized as such by their caregivers, hence the reports of delayed joint attention (Herrera, 2017).

Gesture production has also been studied in blind children to address a deep theoretical question: are gestures primarily produced for the benefit of the listener, or do they also serve a function for the speaker? Iverson et al. (1997, 2000) observed that blind children start producing gestures as early as sighted children, although there are differences in the context of use. For example, sighted children in Iverson et al. (2000) used deictic gestures more often than blind children to indicate the location of a referent, whereas blind children only pointed at objects in their peripersonal space and mostly relied on speech. Iverson and colleagues interpret these findings as evidence that directing the listener's attention is not the only function of gestures, since even blind children (who have never benefited from the gestures produced by their interlocutors) produce gestures themselves.

By studying multimodal communication in Prakash children, we aim to understand how newly sighted children learn to attend to visual information after years of visual deprivation. This population also gives us an unprecedented opportunity to investigate whether there is a critical age to start detecting communicative intent through non-verbal cues such as eye gaze and pointing.

Current study

Newly sighted individuals have offered researchers a unique opportunity to study the development of visual systems. Recent work from Project Prakash has shown that motion cues facilitate facial expression recognition in children with delayed sight onset (Gilad-Gutnick et al., 2019). Prakash children have also been shown to localize faces in complex scenes after surgery (Bouvrie & Sinha, 2007), and with increased visual experience, they have also demonstrated the capacity to distinguish faces from non-faces (Gandhi et al., 2017). Prakash children normally have varying degrees of visual acuity prior to surgery, including light perception and the ability to detect large movements. While the development of different visual capacities (e.g., face and object recognition, or shape discrimination) has been documented in newly sighted children, we were interested in how these children learn to use these visual capacities in their face-to-face communicative interaction.

Experiment 1 investigated Prakash children's ability to produce appropriate referential expressions, which requires monitoring the informativity demands of the situation to avoid ambiguity. For example, in a situation with more than one cup, an appropriate definite description should include a unique property of the referent (e.g., 'Pass me the blue cup' or 'the small cup'). Given Prakash children's limited experience with visual contrast, we wanted to investigate their ability to produce sufficiently informative descriptions in a simple referential communication game. We also used eye-tracking glasses to compare Prakash children's attention to their partner's face relative to neurotypical controls.

Experiment 2 investigated Prakash children's sensitivity to a speaker's referential intent through non-verbal cues. Head turning has been shown to facilitate gaze following in this population, providing an alternative pathway to the development of joint attention. (Rubio-Fernandez et al., 2022). Here we investigated whether newly sighted children begin to fixate more on the interlocutor's face as their visual experience increases over time, and whether they start relying on gaze as a referential cue when no other sensory information (e.g., head movement, voice direction or pointing) are available.

Experiment 1

Methods

Participants

Two cohorts of Prakash children were tested after receiving surgery for congenital cataracts. The first cohort included 8 children operated in January 2018 (ages: 6-13 years; M: 9.3) and the second cohort included 5 children treated in July 2018 (ages: 11-16 years; M: 12.4). Age- and gender-matched controls for each participant were recruited from schools for neurotypical children in Delhi (N=13).

Materials and Procedure

Materials included 10 sets of 2-3 toys, which differed by color and size, among other tactile properties (see Fig. 1). Participants were tested in pairs. One child in each pair wore SMI eye-tracking glasses. Participants were told that they were going to play a game where one child would be given a few toys to explore and had to choose their favorite one. At this point they were not allowed to say or indicate in any way which toy they had chosen. Instead, the first child had to pass the toys over to the other player and describe to them which toy was their favorite. The other player then had to identify which toy the first child had chosen based on their description. Guessing was discouraged and the first child was given up to two more chances to provide a sufficiently informative description if the other player was not able to identify the toy. Describing and understanding (i.e. speaker and listener) roles were counterbalanced across trials.

Figure 1, Left: Two participants playing the referential communication game in Experiment 1. Right: Pairs of toys from two trials in the game (small yellow pear vs large green pear, and large blue plate vs small orange plate).

Coding

Toy descriptions were transcribed and coded for informativity (i.e. whether the description was informative enough to identify the selected object), number of attempts required for successful communication and toy property used as a descriptor (i.e. color, size and/or other). Informativity was evaluated independently of the partner's ability to identify the target (since partners could make the wrong guess despite receiving an appropriate description).

The looking behavior of the child wearing eye-tracking glasses in each pair was also coded to calculate the ratio between number of fixations on the other child's face divided by the total duration of the task. Face fixations were counted separately for those trials where the child wearing the eye-tracking glasses was the speaker vs. the listener. Face fixation counts were coded manually from the processed eye-tracking videos.

Results

The Prakash children showed strong pragmatic skills, providing sufficiently informative descriptions on the first attempt in 80% of trials. Despite their relatively good performance, the results of a Fisher's Exact Test revealed a significant difference with the matched controls, who were close to ceiling at 98% (*p*. < .0001). Both groups showed a comparable preference for color adjectives (Prakash: 65% of trials; Controls: 69% of trials) relative to size adjectives (Prakash: 18%; Controls: 20%).

Regarding attention to faces, paired-samples t-tests were conducted on each participant's average face fixation rate vs their matched control's (see Fig. 2). Results revealed significantly lower face fixation rates in the Prakash group, both in the Speaker role ($t(8) = -2.38$, $p < .0446$) and the Listener role ($t(8) = -2.54$, $p < .0348$).

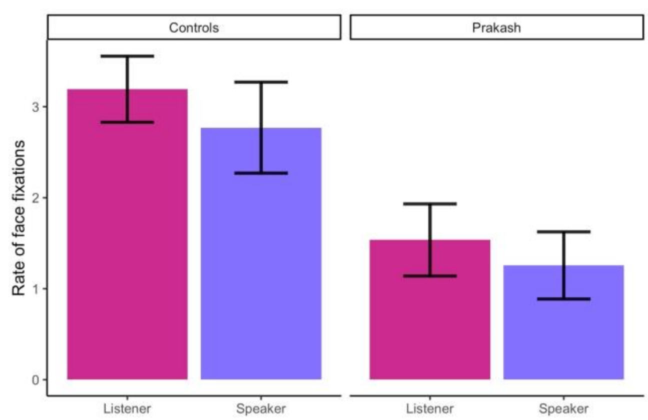

Figure 2: Mean rate of face fixations (i.e. # face fixations / task duration) for the Prakash children and their matched controls in Experiment 1, split by Speaker and Listener role.

The results of Experiment 1 confirmed that Prakash children are sensitive to the informativity demands of a simple referential communication game. However, the eye-tracking results suggested that they make fewer fixations on their interlocutor's face (corrected by the duration of the game) than their matched controls. Experiment 2 followed up on these results.

Experiment 2

Methods

Participants

Three groups of Prakash children were tested in our second experiment:

Prakash Group 1 included 7 children (ages: 6-13 years; M: 9.3) who received treatment in January 2018 and were tested on the task 10 months after surgery (10m Follow-up). The performance of Prakash Group 1 was compared to two sets of age- and gender-matched neurotypical controls: those who performed the task wearing blurred goggles (matching the visual acuity of the corresponding Prakash kid) and those who performed the task without blurred goggles.

Prakash Group 2 included 5 children (ages: 6-16 years; M: 11.3) who received treatment in July 2018 and were tested on the task before surgery (Pre-Op) and 1 year later (1y Follow-up). The performance of Prakash Group 2 was compared at these two testing points.

Silver Linings Group included five girls (ages: 8-18 years; M: 13.2) who performed the task five times at 2-week intervals in a boarding school for children with visual impairment in Delhi (which gave name to the group). All girls had been treated for congenital cataracts 1 to 10 years before the time of testing.

Materials and Procedure

We designed a task where children could make use of various perceptual cues to interpret an ambiguous instruction ('Could you give me that one?') to pick up one of three rolls of red tape placed on a table between the child and the Experimenter. Because the task was administered right after surgery (among earlier and later test points), the task was kept short (1 warm-up trial + 8 experimental trials, 2 per condition). The perceptual cues were Head direction + Voice direction (H_V, 2 cues) in Trials 1 and 2; Head direction + Pointing (H_P, 2 cues) in Trials 3 and 4; Head direction (H, 1 cue) in Trials 5 and 6, and Gaze direction (G, 1 cue) in Trials 7 and 8 (presented in that order for increasing difficulty). The Experimenter looked at the target object in all four conditions but, except for the first condition (where she turned her head towards the target while requesting it), she otherwise made the verbal request looking at the child *before* providing the disambiguating cue(s).

Testing sessions were recorded using video cameras and looks to the Experimenter's face were recorded using SMI eye-tracking glasses.

Coding

Participants' looking behavior was independently coded by two Research Assistants, who resolved any discrepancies by re-watching the recordings and coming to an agreement. The start and end of a trial were marked by the onset of the verbal request and the point at which the participant picked up a roll of tape, respectively. For the duration of each trial, it was calculated how long the Experimenter's face (or part thereof) remained in the participant's view. Face fixation coding therefore included video frames where only the lower half of the Experimenter's face was in view. This measure of face fixation is more conservative than using eye contact, but we settled on the more conservative measure because it was appropriate for this particular task since it allowed detecting the Experimenter's head direction in three out of four experimental conditions (i.e. all except Gaze only).

Results

Prakash Group 1. For data visualization, see Fig. 3 and Fig. 4. All data in Experiment 2 were analyzed with the lme4 package (Bates et al., 2015) from R (R Core Team, 2021). Using linear mixed effects regression, we modelled the outcome variable of Proportion of Face Fixation per trial with Number of Perceptual Cues (One, Two) and Group (January Cohort, Controls with Blur, Controls without Blur) as fixed effects and the maximal random effect structure by Participants and Items (Barr et al., 2013). The January Cohort and One Cue condition were coded as the reference levels.

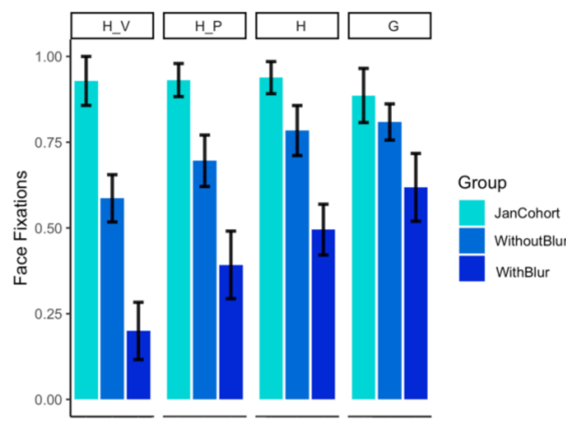

Figure 3: Mean proportion of face fixation per trial by group and cue type in Prakash Group 1 (10m Follow-up).

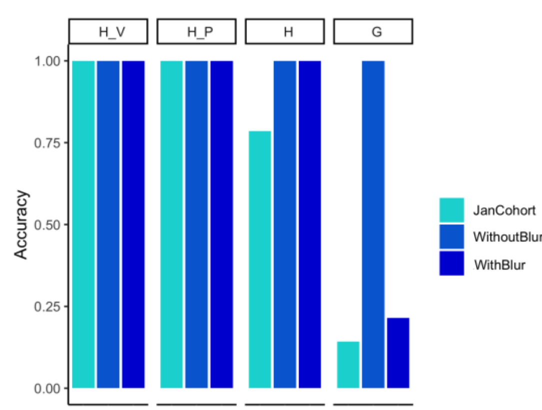

Figure 4: Mean accuracy rates by group and cue type in Prakash Group 1 (10m Follow-up).

Results revealed that the January Cohort made a higher proportion of face fixation (m=0.9211) than the Controls with Blur (m=0.42641; $p < .0144$) (for the full model output, see Table 1). In addition, the January Cohort made a higher proportion of face fixation with One Cue (m=0.9122) than the Controls with Blur with Two Cues (m=0.2961; $p < .001$). Lastly, the January Cohort made a higher proportion of face fixation with One Cue (m=0.9122) than the Controls without Blur with Two Cues (m=0.6411; $p < .0069$).

Table 1: Model output for the Prakash Group 1analysis

Fixed Effect	Coefficient	SE	P-value
Two Cues	.018	.053	.740
With Blur	-.355	.131	.014
Without Blur	-.116	.131	.389
Two Cues x With Blur	-.278	.063	.007
Two Cues x Without Blur	-.173	.063	.007

Prakash Group 2. For data visualization, see Fig. 5 and Fig. 6. Using linear mixed effects regression, we modelled the outcome variable of Proportion of Face Fixation per trial with Number of Perceptual Cues (One, Two) and Testing Run (Pre-Op, 1y Follow-up) as fixed effects and the maximal random effect structure by Participants and Items. Deviation coding was used for Cues (One=-.05, Two =.05) while Testing Run was entered as a scaled continuous predictor.

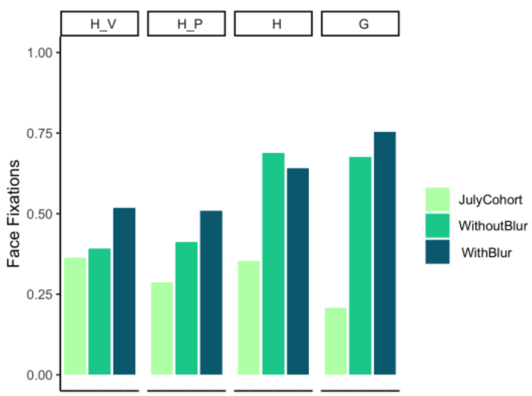

Figure 5: Mean proportion of face fixation per trial by group and cue type in Prakash Group 2 (1y Follow-up).

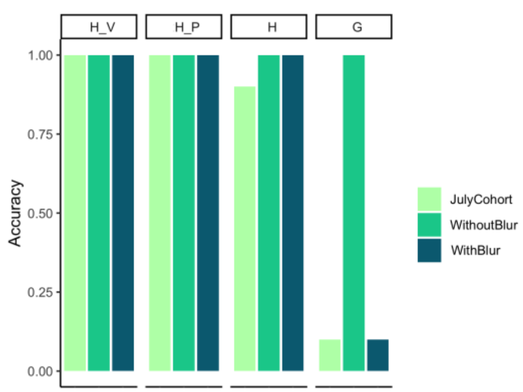

Figure 6: Mean accuracy rates by group and cue type in Prakash Group 2 (1y Follow-up).

Our results revealed that the July Cohort made a higher proportion of face fixations in the 1y Follow-up (m= 0.30296) than at Pre-Op (m= 0.2580; $p < .0013$) (see Fig. 7; for the full model output, see Table 2).

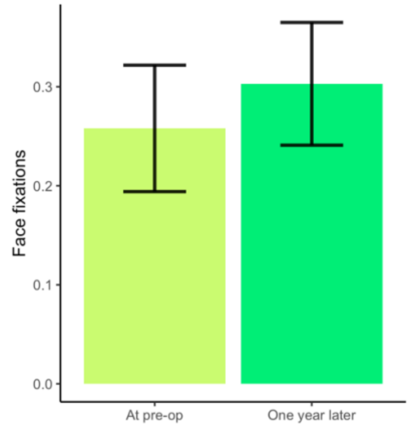

Figure 7: Mean proportion of face fixation per trial split by testing run for the Prakash Group 2.

Table 2: Model output for the Prakash Group 2 analysis

Fixed Effect	Coefficient	SE	P-value
Cues	-.019	.064	.773
Testing Run	.057	.017	.001
Cues x Testing Run	.033	.032	.307

Silver Linings Group. For data visualization, see Fig. 8. Using linear mixed effects regression, we modelled the outcome variable of Proportion of Face Fixation per trial with Number of Perceptual Cues (One, Two) and Testing Run (1-5) as fixed effects and the maximal random effect structure by Participants and Items. Deviation coding was used for Cues (One=-.05, Two =.05) while Testing Run was entered as a scaled continuous predictor.

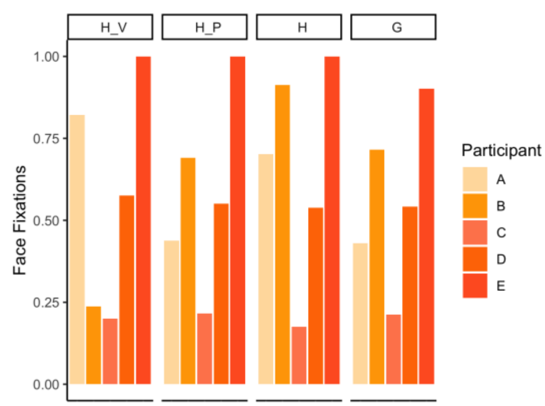

Figure 8: Mean proportion of face fixation per trial averaged across five testing runs and split by participant and cue type in the Silver Linings Group.

Our results revealed an overall increase in the proportion of face fixation per trial across Testing Runs (p < .001) (for the full model output, see Table 3; see also Fig. 9).

Table 3: Model output for the Silver Linings Group analysis

Fixed Effect	Coefficient	SE	P-value
Cues	-.032	.065	.646
Testing Run	.093	.021	<.001
Cues x Testing Run	.072	.041	.081

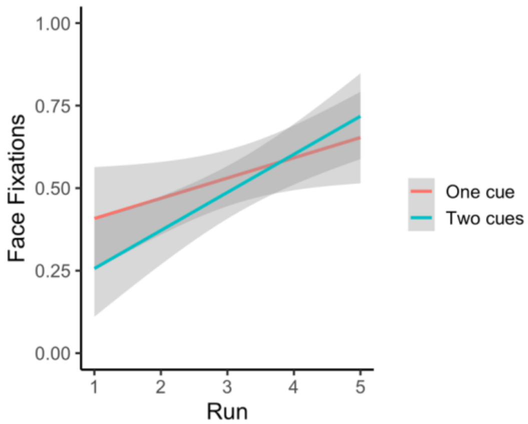

Figure 9: Mean proportion of face fixation per trial by testing run and number of cues for the Silver Linings Group.

Discussion

We investigated the relationship between visual experience and pragmatic development by testing the socio-communicative skills of a unique population: the Prakash children of India, who received treatment for congenital cataracts after years of visual deprivation.

The results of Experiment 1 showed that Prakash children have strong pragmatic skills, providing sufficiently informative descriptions of their toy of choice (i.e. descriptions that allowed their partner to uniquely identify the toy amongst competitors) in 80% of trials. However, despite this relatively good performance, Prakash children did worse than their age- and gender-matched neurotypical controls, who were at ceiling in this simple referential communication task. Interestingly, both groups showed a comparable preference for color adjectives over size adjectives, relying on the toys' visual contrast rather than their tactile contrast. These unexpected results highlight the importance of color for efficient referential communication (Rubio-Fernandez, 2021).

Experiment 1 also revealed that Prakash children fixate less on their interlocutor's face than their matched controls, both as speakers and listeners. This looking behavior was further investigated in a second experiment with three groups of Prakash children, who performed another referential communication task, this time testing their use of perceptual cues to understand the speaker's referential intent.

Prakash Group 1 was tested 10 months after surgery, and their performance on the task was compared to that of two control groups (with and without blurred goggles). Prakash Group 2 was tested before surgery and a year later, and their performance was compared at these two testing points to investigate possible developmental effects. Finally, the Silver Linings Group was tested five times at 2-week intervals several years after they had received treatment, with the aim of investigating possible training effects in their attention to faces.

The first group of Prakash children fixated more on the Experimenter's face than their matched controls, who increased their face fixations as the task got progressively difficult (going from two perceptual cues to only one). However, these looking patterns are not characteristic of all Prakash children in our sample (compare Fig. 3 and Fig. 5), who also show great individual variation (see Fig. 8). We hypothesize that the key difference between Prakash Group 1 and Prakash Group 2 is their visual acuity, with the former group having greater visual acuity than the latter even before surgery, potentially benefitting more from looking at their interlocutor's face as they could gather more visual information. We are planning to perform further analyses to test the linking hypothesis between attention to faces and visual acuity.

Interestingly, despite their different looking behavior, Prakash Groups 1 and 2 revealed comparable accuracy rates (i.e. selecting the correct roll of tape), only falling below chance level in the Gaze only condition (see Fig. 4 and Fig. 6). This pattern of results confirms that Prakash children are able to detect a speaker's referential intent from the non-verbal cues that they can perceive (i.e. head direction, voice direction—even when the message is ambiguous, and pointing gestures). These findings are in line with the results of a recent study using a computer-based task where Prakash children learned to follow an interlocutor's gaze direction from the head motion cues provided in earlier trials (Rubio-Fernandez et al., 2022).

Finally, the two longitudinal analyses we conducted in Experiment 2 revealed improvements in attention to faces, both when comparing performance before surgery and a year later for Prakash Group 2, and when training the girls at the Silver Linings school for 10 weeks. These results suggest that over time, Prakash children learn to make use of their newly acquired visual skills to look for cues on their interlocutor's face during referential communication.

We interpret our findings as evidence that there is no critical age after which blind and newly sighted children cannot come to utilize those communicative cues that they can rely on, showing great plasticity and adaptability in referential communication. Our results also highlight the importance of multimodal communication for the robust transmission of information, intention and emotion across different populations with varying perceptual profiles.

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