Towards a contingent anticipatory infant hearing test using eye-tracking

Iris-Corinna Schwarz[1], Atena Nazem[1], Sofia Olsson[1], Ellen Marklund[1], Inger Uhlén[2]
[1] Department of Linguistics, Stockholm University, Sweden
[2] Department of Hearing and Balance, Karolinska Universitetssjukhuset, Sweden
iris@ling.su.se, athena.nazem@gmail.com, sool0517@student.su.se,
ellen@ling.su.se, inger.uhlen@karolinska.se

Abstract

Early identification of infant hearing impairment is imperative to prevent developmental language difficulties. The current diagnostic method is Visual Reinforcement Audiometry (VRA) in which infant response to sound is observed to establish hearing thresholds. Together with the Karolinska Institute, we are developing an observer-independent contingent anticipatory infant hearing test using eye-tracking to increase reliability and significance levels of the current clinical practice.

The present pilot study addresses in particular the first phase of the test in which the eye response is conditioned to occur at sound detection. The aim is to establish how well 6.5-month-olds associate the presence of sound to a certain location via a visual reward.

Introduction

Worldwide, more than 665 000 infants are estimated to be born with a significant hearing loss, and during the first year, the figures increase due to the occurrence of acquired hearing impairment (Olusanya, 2005). The earlier in infancy hearing impairment is discovered, the earlier measures can be undertaken to prevent communication difficulties and language delay (Lidén & Kankkunen, 1969).

In Sweden, detection of hearing difficulties has been nationwide included in the general screening procedures for newborns. Newborn hearing screening today includes commonly two steps: first, the otoacoustic emissions (OAE), and second, the auditory brainstem response (ABR). The otoacoustic emissions are the response of the outer hair cells of the cochlea to acoustic stimuli (Vohr & Maxon, 1996). It tests the physical cochlear components of perceiving an auditory event and gives a first indication on the working state of the hearing system (Kemp, 1978). If the hearing thresholds lie above 30 dB, no response will be indicated by OAE.

Infants who fail the newborn hearing screening are sometimes referred to the ABR. This procedure tests whether auditory information arrives at the cortex by measuring electroencephalography (EEG) at specific skull locations and requires sedation. A short latency is expected in the EEG-waveforms at the skull electrodes in response to a click stimulus (Davis, 1976). OAE and ABR are only testing the functionality of the hearing system.

If all infants were tested with the 2-stage method, about 23 % of the infants with permanent hearing loss at 9 months would still have passed ABR. When considering mild hearing loss, over 70% of infants would pass the screening procedure, yet in need of help (Johnson et al., 2005). This demonstrates the necessity of a hearing test that monitors behavioural responses to auditory stimulation and can establish hearing thresholds. In current clinical practice, the Visual Reinforcement Audiometry (VRA) fulfils this purpose.

Visual Reinforcement Audiometry

Originating in the Conditioned Orientation Reflex Audiometry (Suzuki & Ogiba, 1961), the VRA paradigm re-

sembles the Conditioned Head-Turn Procedure commonly used in infant speech perception studies (Werker, Polka, & Pegg, 1997), but does not incorporate the same level of observer objectivity. The child is seated in front of a panel with two loudspeakers on each side, combined with two screens to display reward pictures. The audiologist presents a sound stimulus on one of the loudspeakers and a correct turn to the side from the child is reinforced with picture presentation on the corresponding screen. The method is based on the assumption that, after a number of trials, the child becomes conditioned to associate sound presentation with picture display. Therefore, the head-turn towards the loudspeaker and/or screen at sound presentation can be interpreted as an indication of sound perception.

The problems associated with VRA are obvious: The audiologist is not blind to when a sound is presented. The parent also present in the test room may give subconscious indication of sound presence. The infant reaction is not always the defined head-turn an older child would present. Instead, it often leaves room for interpretation, ranging from slight body shivers to eye movement or even eye widening. There is no defined criterion as to when conditioning has been passed. Significance levels are low, since the same threshold level per frequency is tested at maximum two times in total. And yet this is the current clinical diagnostic tool to determine infant hearing thresholds.

Inspired by the improved experimental control of the Conditioned Head-Turn Procedure and yet incorporating the need for a behavioural measurement of infant hearing, we are developing a contingent anticipatory infant hearing test using eye-tracking.

The contingent anticipatory infant hearing test using eye-tracking

The first prototype was developed and coded in Tobii's Software Development Kit, based on Visual Basics (Mattson, 2009). A completed hearing test outputs a standard audiogram with hearing thresholds for both ears at the frequencies 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, providing a significance level for each threshold. This prototype required further refinement.

Palmgren & Sundberg developed a revised version of the program called eye-tracker-based VRA (2012) in which they managed to achieve anticipatory eye movement, however, unfortunately contingent to a constant time interval between fixation and sound presentation. Once this time interval was randomised, only few infants became conditioned.

The current complete version has been programmed in C# with all the features that the first prototype contained, but it proved to be too tedious to re-program just for the sake of testing different set-ups of the conditioning phase. Therefore we decided to implement parts of the complete hearing threshold test in E-Prime and Tobii Studio to log and record infant eye response to sound. For the current study, we wanted to improve the conditioning phase only as too few infant participants managed to associate sound detection with looking at a particular place on the screen.

As more minimum response levels are obtained with sound field testing compared to insert-earphone stimulus presentation, especially in the youngest infants (Day, Bamford, Parry, Sheperd, & Quigley, 2000), we decided on sound field testing using loudspeakers rather than headphones. Additionally, since the compliance to wear headphones or insert-earphones is low in infants, we reduce infant fussiness during testing.

Method

Participants

The participating families, randomly selected from the Swedish tax registry, lived in Greater Stockholm and had an infant at 6 months. They received an information letter and returned a con-

sent form upon which their lab visit was scheduled. Response rate was 9 %. In total, 12 infants (age 6 months +/- 2 week; 7 girls, 5 boys) participated in the study. All participants reported normal hearing screening results at birth and no known history of hearing difficulties.

Apparatus

The study was conducted in a test booth with an adjacent control room. The study set-up contained three directly linked stations, that is one eye-tracker, and two PCs. Sound and picture stimuli were presented via a PC (Windows XP) using the software E-Prime 2.0 (Psychology Software Tools, 2010), programmed in E-Studio version 2.0.8.90 using extensions for Tobii (Clearview). Eye movement was calibrated, recorded and analysed via another PC, using Tobii Studio Software version 3.2.0. The infants were seated in their parent's lap in front of a Tobii Eye-tracker T120 with a 17 inch-screen (1280 x 1024 pixels).

The Tobii eye-tracking system does not require head-mounted equipment, as near-infrared light is projected into both eyes and the position of the head is calculated by an algorithm. This makes Tobii eye-trackers particularly suitable for infant studies as eyes can be tracked while the head is free to move.

The sound stimulus was presented via two loudspeakers (NuForce S-1), located left and right of the eye-tracking monitor about 70 cm away from the infant head.

Stimuli

The sound stimulus that was used as a placeholder for the pool of frequency- and SPL-exemplars was a warble tone with a 1000 Hz base frequency, a modulation depth of 100 Hz and a rate of 1 phase per second. The warble tone was generated for 6 s (stereo, 44100 Hz, 16 Bit) with a left and a right channel only to be displayed at only one of the two loudspeakers at a time. Sound pressure level was measured as 83 DB at the source and 55 dB at infant position with about 70 cm distance to the loudspeakers.

The picture rewards were created in Adobe Flash Professional CC (version 13.1.0.226) and consists of smiling flowers in two different contrastive and bright colours (see Figure 1). The pictures are animated to move up and down on screen in phase with the warble tone within their target box (360 x 500 pixels).

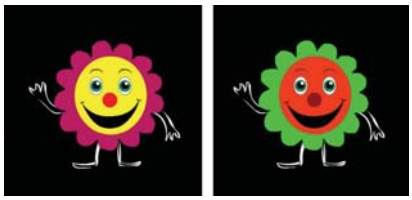

Figure 1. The reward pictures.

The fixation picture consisted of the same round window picture of a baby that was used for calibration. During Demonstration phase 1 and 2, the round frame was growing and shrinking to draw infant attention to the screen centre, whereas during test phase, it was reduced to a still picture.

Procedure

The infants sat in their parent's lap in the sound-attenuated test room at the Phonetic Lab at the Department of Linguistics at Stockholm University. Distance between infant head and eye-tracker was about 55-60 cm.

To calibrate the eye-tracker to the individual infant, 5-point manual infant calibration was used to capture the infant eye just when the infant was looking at the screen.

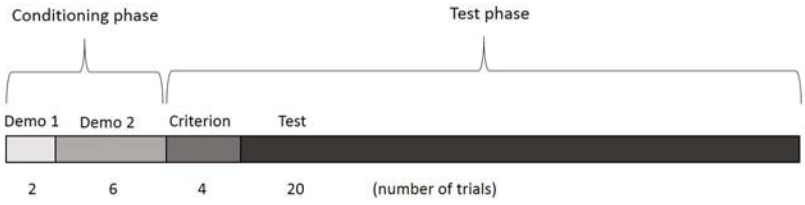

Figure 2. Overview over the test procedure: If the infant passes criterion phase, it will count towards establishing the hearing thresholds, i.e., adding four additional trials to the test phase.

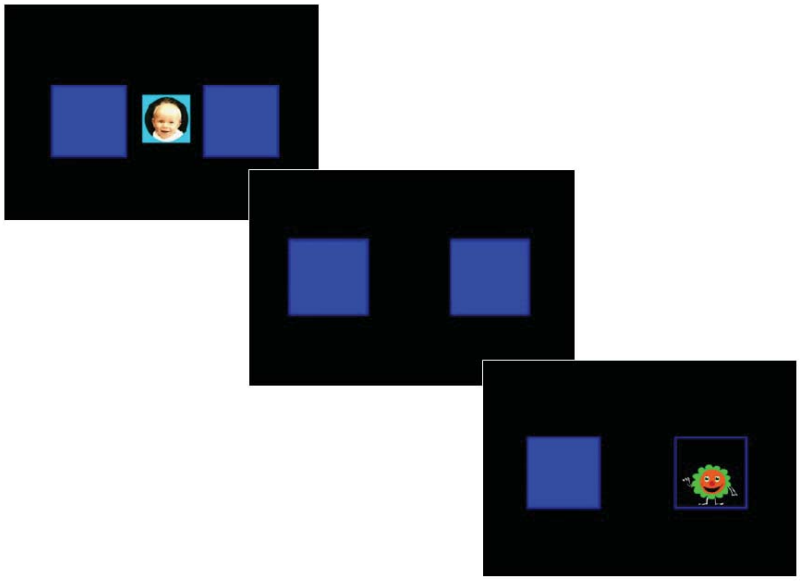

Figure 3. A typical trial with fixation phase, one-sided sound display during the decision window, and reward picture presentation if the correct side was fixated.

Instead of a growing and shrinking dot on the screen, a growing and shrinking round window with a baby face was used for calibration. Parents were not wearing headphones since no proper hearing test was conducted, the infant sound detection was not time-sensitive and parents were debriefed about the infant's actual task only after the test.

The test session contained several phases (see Figure 2). During demonstration 1, the infant is introduced to the task in 2 trials. After the fixation picture is displayed in the centre, the sound is presented while the reward is shown for 6 s first on one side, then on the other (see Figure 3). Sides are counterbalanced between participants. During demonstration 2, the infant follows 6 typical trials, 3 for each side, in randomised order. Criterion phase consists of 4 trials of which the infant has to

pass 3 trials. It is the first phase in which contingent feedback to infant fixation is active. A sound is only presented, if the fixation image is watched for 200 ms. The reward is only activated, if the correct box is fixated for at least 200 ms. The time window for this is 5.5 s; for the remaining 500 ms of the sound presentation, the reward will be shown in any case to remind and reinforce the formed association between sound and picture. The test phase contains 20 trials, 10 for each side. If the infant does not pass criterion, the test loops back to demonstration 2 and then to criterion phase again.

Each test session took about 10 min, depending on criterion phase outcome and potential demonstration phase repetitions.

Results

Of the 12 infants who participated, data of 6 had to be excluded from further processing due to inadequate calibration. Of the remaining 6, only 2 participants passed the criterion phase to move on to the test phase (see Table 1).

Table 1: Test performance of the 2 participants who passed criterion. Number of trials performed, number of correct side identification and percentage correct is presented per participant.

No.	Trials	Hits	Correct
3	17	9	53 %
6	24	5	21 %

None of the participants performed significantly above chance level in identifying the correct side, although they passed criterion for conditioning.

Table 2: First fixation duration in seconds towards target (T) and non-target (NT) on either side during criterion and test trials (R=right; L=left).

No.	TR	NTR	TL	NTL
3	1,63	3,43	0,56	1,84
6	0,64	1,4	1,44	0

When considering fixation behaviour, there is indication of the common right side bias. No matter whether target or non-target was situated on the right hand side, the duration of the initial fixation was much greater than for the left hand side (Table 2).

Discussion

As none of the participants who passed criterion phase completed the test phase with hits considerably above chance level, it can be assumed that the current set-up of the conditioning phase is not satisfactory. The criterion 3 out of 4 correct could be set too low or the infants could need reminder demonstration trials later during test phase as they may forget. Keeping infant attention was also an issue, especially after a repeated demonstration phase 2 and therefore a prolonged test time. A variety of sound stimuli as a real hearing threshold test would continue and a several different reward pictures could offer a solution to that. It was decided to be as rigorous as possible with the current set-up and not to vary either sounds or pictures in order to build and strengthen the association as much as possible. Of course there is a fine line between strengthened relationship and boredom, and this set-up's internal consistency may have crossed it.

Conclusions

The current study aimed to further develop the conditioning phase of a contingent anticipatory eye-tracker-based infant hearing test. While it is undisputed that such an automated and objective hearing threshold test for infants is bitterly needed, we cannot yet claim to have developed a fully-functioning test. The present results on the improvement of the conditioning phase look promising and give directions for further development, but more steps need to be taken until we have arrived at a successful contingent anticipatory eye-tracker-based hearing test for infants.

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