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Pupillometry in Six-Month-Old Infants

Jean-Rémy Hochmann*

1. Introduction

Studying infants is challenging. Young infants cannot be told what to attend to, and cannot give explicit answers to our questions. Researchers must therefore place infants in situations where their spontaneous reactions will inform theoretical questions. In addition to this constrain, which explains the numerous connections between infant and animal research, infant experiments are strictly limited in duration. Experiments on speech perception rarely exceed ten minutes, due to infants' short attention span. Success of infant studies therefore require well-thought theoretical questions, which can be answered by innovative experimental setups. The advances in methodology have paved the way for advances in our understanding of speech perception and infant cognition as a whole. The use of high amplitude non-nutritive sucking made it possible to study speech perception in neonates and very young infants in the early 70s (Eimas et al., 1971). Subsequent research has mainly focused on looking behavior in habituation, familiarization (Jusczyk & Aslin, 1995; Maye et al. 2002) or conditioning paradigms (Hochmann et al., 2011; Kuhl et al., 1992; Werker & Tees, 1984). Habituation studies using non-nutritive sucking or looking time paradigms are the most frequent in the field of infant speech perception. A caveat of these techniques, however, is that they require to bore (in technical terms *to habituate*) infants before we present the crucial test trials. This may sometimes result in the rejection of many kids that will start being fussy when they are bored. More recently, the use of electrophysiological measures (Dehaene-Lambertz & Dehaene, 1994; Peña et al., 2008) and brain imaging techniques (Benavides-Varela et al., 2011, 2012; Gervain et al., 2008; Dehaene-Lambertz et al., 2006; Peña et al., 2003) has often avoided this caveat, but they require expensive equipment and specialized technical competence.

In this paper, we present the use of pupillometry, a novel technique to study speech perception in young infants. Numerous studies have shown that adults' pupil diameter is sensitive to increase in attention and cognitive load (Beatty,

* Department of Psychology, Harvard University, William James Hall, 33 Kirkland Street, Cambridge, MA 02138, USA. E-mail: jr.hochmann@gmail.com

1982). In particular, in a an oddball paradigm, adults exhibit pupil dilation for the deviant stimulus relative to the standard stimulus (Qiyuan et al., 1985). We asked whether this technique can be extended to infant studies. We presented fourteen 6-month-old infants with sequences of four syllables, while a cartoon character was presented on a computer screen to attract infants' attention. A Tobii eyetracker T60 recorded infants' gaze position and measured their pupil diameters. In 75% of trials, infants heard the same syllable repeated four times (e.g., *ba ba ba ba*). The fourth syllale was different in 25% of trials (*ba ba ba di*).

2. Material and Methods

2.1. Participants

Fourteen American infants (5 months 25 days to 7 months 0 day; mean 6 months 13 days) were included in the analysis. Three other infants were tested but rejected for not providing sufficient data (see analysis).

2.2. Procedure

This experiment aimed at validating pupillometry as a reliable tool to study infants' speech perception. Infants were tested in an oddball paradigm. Standard trials (75%) consisted of the same syllable repeated four times (e.g., '*ba-ba-ba-ba'*); deviant trials (25%) consisted of the standard syllable repeated three times and a fourth different syllable (e.g., '*ba-ba-ba-di'*). Each syllable was generated by the MBROLA artificial speech synthetizer with the French voice database FR4, a phoneme duration of 120 ms and a pitch of 200 Hz. Half of our participants were tested with /ba/ as a standard syllable, and /di/ as a deviant. The other half of our participants were tested with /di/ as a standard and /ba/ as a deviant. Pupil diameters were measured by a Tobii eyetracker T60. Infants were tested in a dark room, where the computer screen constituted the only light source. During each trial, infants saw the same video showing a cartoon character for 5 seconds. Luminance was thus constant within and across trials.

2.3. Analysis

We defined an area of interest (512 x 280 pi) corresponding to the surface of the video played on the screen to attract infants' attention. Trials when infants looked away from the area of interest or pupil diameter information was not available for more than 25% of the total trial duration were rejected. Infants with less than 24 good trials were not included in the final analysis (N = 3).

Pupil diameter was averaged for all good trials and both pupils, for each condition separately. We computed the variation of the pupil diameter (VPD) in reaction to the fourth syllable relative to a baseline of 50 samples (833 ms) taken before the onset of the fourth syllable of each trial. The VPD was averaged in two successive time windows (0-800 ms; 800-1600 ms) following the fourth syllable onset. We ran a 2x2 ANOVA with Condition (standard/deviant) and Time Window as within-subject factors.

2.4. Results

Each infants contributed on average 35 trials (26 standard and 9 deviant). A 2x2 ANOVA with Condition (standard/deviant) and Time Window (0-800 ms; 800-1600 ms) as within-subject factors revealed a main effect of Time Window; $F(1, 13) = 35.95$; $P < .001$. The main effect of Condition was not significant; $F(1,13) = 3.06$; $P > .10$. Most importantly, there was a significant interaction of Condition and Time Window; $F(1, 13) = 7.19$; $P = .019$, showing that the increase of diameter in the second relative to the first time window was larger for the deviant than for the standard condition (Figure 1).

3. Discussion

Infants' pupil diameter increased when a deviant stimulus was presented in an oddball paradigm. The effect was observed to start about 800 ms after the presentation of the stimulus. The paradigm that we used is similar to that used in Event-Related Potential studies (Endress et al., 2007; Hochmann, 2010). It does not require habituation, nor a high number of trials. In contrast to Event-Related Potential studies, however, it does not require expensive equipment but only an eyetracker, and does not require complex processing of the data. The demonstration that pupillometry can be used with young infants opens new possibilities to study infant speech perception and speech representation. Our paradigm can easily be adapted to study categorization and abstract structure generalization. Current work in our lab is now investigating whether this can be used with even younger infants. Preleminary results suggest it is the case, thus providing a technique usable with participants from early infancy to adulthood.

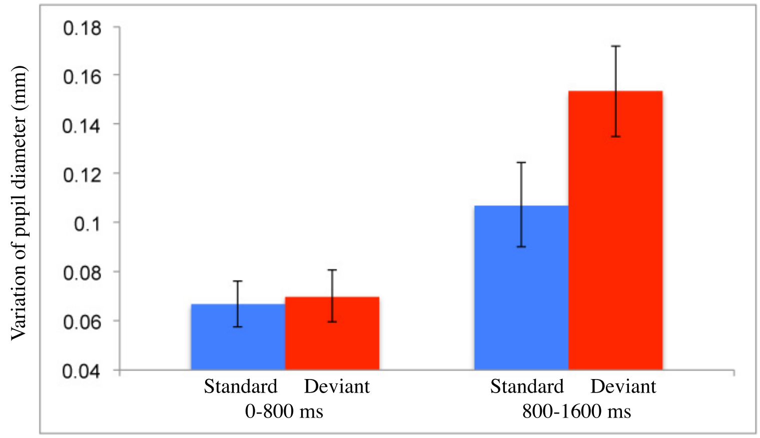

Figure 1 – Variation of pupil diamter with respect to the baseline.

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