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Effects of transient auditory deprivation during critical periods on the development of auditory temporal processing

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ABSTRACT

Objectives: The central auditory pathway matures through sensory experiences and it is known that sensory experiences during periods called critical periods exert an important influence on brain development. The present study aimed to investigate whether temporary auditory deprivation during critical periods (CPs) could have a detrimental effect on the development of auditory temporal processing.
Materials and methods: Twelve neonatal rats were randomly assigned to control and study groups; Study group experienced temporary (18–20 days) auditory deprivation during CPs (Early deprivation study group). Outcome measures included changes in auditory brainstem response (ABR), gap prepulse inhibition of the acoustic startle reflex (GPIAS), and gap detection threshold (GDT). To further delineate the specific role of CPs in the outcome measures above, the same paradigm was applied in adult rats (Late deprivation group) and the findings were compared with those of the neonatal rats.
Results: Soon after the restoration of hearing, early deprivation study animals showed a significantly lower GPIAS at intermediate gap durations and a larger GDT than early deprivation controls, but these differences became insignificant after subsequent auditory inputs. Additionally, the ABR results showed significantly delayed latencies of waves IV, V, and interpeak latencies of wave I-III and wave I-V in study group. Late deprivation group didn't exhibit any deterioration in temporal processing following sensory deprivation.
Conclusion: Taken together, the present results suggest that transient auditory deprivation during CPs might cause reversible disruptions in the development of temporal processing.

1. Introduction

Language development is a basic aspect of human life that enables the communication of essential information. High spectral and temporal resolutions are necessary to achieve normal development of language and understanding of speech [1,2] and, in particular, the normal development of auditory temporal processing is crucial during childhood learning language [3]. Critical periods (CPs) are defined as developmental windows during which specific experiences have greater effects relative to other periods [4–6]. In other words, sensory experiences during a particular CP exert an important influence on brain development [7]. Auditory CPs can be viewed as periods in which the auditory cortex undergoes an extensive refinement to acquire an adult-like organisation, or when the absence of auditory experiences cannot be fully compensated for later in life [8,9]; thus, auditory CPs are an important factor to consider when investigating the development of language. It has been suggested that early age hearing loss, whether sensorineural or conductive, may alter the temporal properties of the auditory cortex [10,11]. Additionally, substance use during a CP may act as an abnormal stimulus. For example, nicotine exposure during early postnatal periods, including auditory CPs, impairs the normal development of auditory temporal processing [12]. However, the manner in which the experience of temporary sensory deprivation during an auditory CP affects the development of the central auditory
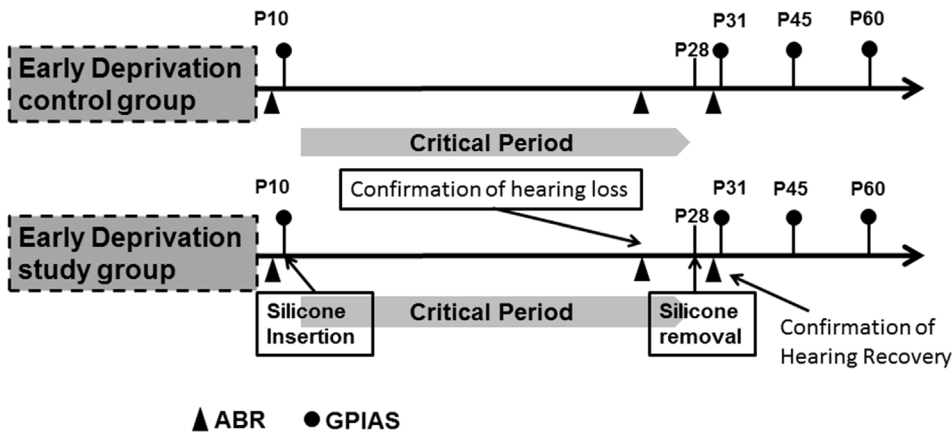
Fig. 1. Schematic schedule of the study. Auditory brainstem response (ABR) and gap PPI of the acoustic startle reflex (GPIAS) were assessed in both groups. Early deprivation study group underwent silicone insertion into the ear canals during critical periods.

nervous system has yet to be well elucidated.

Auditory temporal processing, or the temporal resolution of the auditory system, can be evaluated using the gap detection method because this technique has been established as a reliable behavioural measure of auditory temporal resolution across different species, including humans and rodents [13–16]. The gap detection method is widely used and previous studies have identified changes in gap detection according to age [17]. The prepulse inhibition (PPI) paradigm involving the acoustic startle reflex is one method utilised to assess gap detection; this characteristic emerges between postnatal days (P) 13 and 16 in the rat [18,19]. Many studies have used the gap PPI of the acoustic startle reflex (GPIAS) paradigm to assess temporal resolution in the rat [12,20]. Thus, the present study aimed to investigate the effects of transient auditory deprivation during auditory CPs on the development of auditory temporal processing in the rat using several outcome measures.

2. Materials and methods

2.1. Animals

The present study included 12 neonate Sprague-Dawley (SD) rat pups and eight adult SD rats (Nara Biotech; Seoul, Korea). The 12 neonate pups were randomly assigned to either the early deprivation control (n = 6) or early deprivation study (n = 6) group at P7. Additionally, to confirm the role that auditory deprivation during CPs plays in the development of auditory temporal processing, eight 6-week-old rats (that were assumed to have experienced CPs already in their early lives) were randomly categorised into late deprivation control (n = 4) and late deprivation study (n = 4) groups. The neonatal rats were housed with their dam until weaning (P21) and the litter-mates were housed in pairs and fed a standard diet. The adult rats were also fed a standard diet and were maintained on a 12:12 h light–dark cycle. Transient hearing loss was induced from P10 to P28 in the neonatal rats assigned to early deprivation study group, and the ears of four 6-week-old rats were plugged with silicone (Late deprivation study group) for 20 days, which was the same duration as in the neonatal rat experiment.

All animal experiments in the present study were approved by the Institutional Animal Care and Use Committee (IACUC) of Dankook University (14-024) and all procedures were carried out in accordance with their regulations. A schematic schedule of the experiments is plotted in Fig. 1.

2.2. Induction of transient conductive hearing loss

In the present study, hearing loss was induced by plugging bilateral ear canals with silicone elastomer (Kwik-Sil, World Precision Instruments, Inc.; Sarasota, FL, USA) on P10 when the ear canal

opening became evident. The fast-drying silicone elastomer was expected to provide a secure and tightly-sealed earplug that could not be removed by the rats. During insertion of ear plug, rats were anesthetized with Zoletil (Virbac Laboratories, France) and Rumpun (Bayer, Korea). The earplugs were checked every day to confirm the proper position and were reinserted if needed. The induction of hearing loss and recovery of hearing were confirmed with the ABR test and, after removing the earplug, the ear canal and tympanic membrane were examined with an otoscope to identify possible infections or retained material present in the canal.

2.3. ABR test

Hearing was evaluated by measuring the ABR threshold and latency values on P8, P27, and P31 at frequencies of 4, 8, 12, 16, and 32 kHz. A sound field speaker (ES1; Tucker-Davis Technologies, Alachua, FL, USA) was placed 10 cm from the rat and used as a transducer to measure hearing in the silicon-filled ear canal. Tests were performed using a Smart EP high-frequency software/hardware package (System III; Tucker Davis Technologies, Alachua, FL, USA), as previously described [20]. During ABR, rats were anesthesized with Zoletil (Virbac Laboratories, France) and Rumpun (Bayer, Korea).

2.4. GPIAS test

GPIAS tests were performed at P10, 31, 45, and 60, as previously described [16,20]. Briefly, each rat was placed in an acoustically-transparent, unconstrained-type enclosure that was set in a soundproof chamber (Fig. 2A–C); a diagram of the GPIAS measurement system is provided (see Supplementary Fig. S1 online). An accelerometer was installed on the base of the enclosure to measure the startle reflex. One session of GPIAS consisted of 10 gap trials and 10 no-gap trials (Fig. 2D–E). A 60-dB sound pressure level (SPL) continuous white noise was employed as background noise and a single white noise of 120 dB SPL (duration: 20 ms) was used as the main startle stimulus; this stimulus was presented with a variable inter-stimulus interval ranging from 17 to 23 s to prevent anticipation of its presentation.

Gap detection ability was assessed by determining the level of inhibition of the acoustic startle reflex produced by a short silent gap inserted in a continuous background sound prior to a loud startling stimulus. GPIAS (%) was calculated as:

$$\text{GPIAS } [\%] = \frac{\text{No gap SR} - \text{Gap SR}}{\text{No gap SR}} \times 100$$

SR, startle reflex

The GDT was defined as the minimum gap duration needed to induce a significant inhibition of the startle reflex [12]; this value was retrieved from the GPIAS data. If the GDT was not achieved at 80 ms, then 100 ms was assumed to be the GDT in that animal.