31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Development of a portable A-ABR screener using a microprocessor

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Abstract—**Hearing loss is one of the most common birth defects among infants. Most hearing-impaired children are not diagnosed until one to three years of age, which is too late to treat for normal speech and language development. If hearing impairment is identified and treated in its early stage, a child's speech and language skills could be comparable to his or her normal-hearing peers. Auditory brain-stem response (ABR) is nowadays one of the most reliable diagnostic tools in the early detection of hearing impairment. In this study, we applied the 'Fsp' method to distinguish between normal and impaired hearing. We have developed a battery-operated portable automated auditory brainstem response (A-ABR) system that automatically detects hearing impairment in neonates or infants. We partially validated the accuracy of this system in twenty normal-hearing adults.**

I. INTRODUCTION

HEARING impairment is one of the most common birth defects among infants. Significant permanent hearing impairment affects 1 to 1.5 per 1000 live births [1], [2]. This is more frequent than any other disease for which newborn screening occurs [3]. If significant bilateral hearing impairment is undetected, it can have profound effects on speech, language, and cognitive development, and thus emotional and social well-being [4]. All infants must receive hearing screening within the first three months of age and appropriate intensive intervention within six months, because babies who have hearing impairment and receive appropriate and consistent early intervention have significantly better language levels than those children identified after the age of six months [5], [6].

Recent improvements in hearing screening standards have led to the advancement of hearing screening technology. The auditory brainstem response (ABR) test has become the standard of care for hospital newborn hearing screening programs. In addition, more and more physician's offices are using the technology to screen children of all ages and throughout adolescence. ABR measures objective hearing threshold levels by acquiring electric evoked potentials emanated from the auditory nerve system as it responds to auditory stimulation [7]-[9]. The obtained potentials that occur among large electric interferences have extremely low signal to noise ratio (SNR). Therefore, an ensemble averaging is generally used. However, ABR needs to be carried out in a sound-proof room and takes a long time to perform. Furthermore, the interpretation of conventional ABR should be done by a trained audiologist. The expense, time, and necessity of interpretation by trained personnel negate the use of conventional ABR as a useful hearing-screening tool.

Therefore, in this study, we have developed the automated-ABR (A-ABR) system, which objectively assesses the hearing threshold levels of patients, and interprets the brainstem response resulting from the clicking stimuli. This system is simple to operate for non-professionals and reduces the time necessary to implement the test. Moreover, it has been constructed as a portable system, which makes it an effective method to screen for hearing impairment in newborns, even in nursery rooms.

II. SYSTEM CONFIGURATIONS AND METHODS

A. Hardware

The A-ABR system consists of an amplifier, microprocessor, and LCD as shown in Figure 1. We chose the MSP430 FG4619 (TI, USA) as a microprocessor because of its multiple tasking ability, low price, and low power consumption. This chip includes 4 KB flash memory, direct memory access (DMA), and 12-bit ADC. The microprocessor converted analog evoked potentials to digital signals and performed several algorithms. ABR signals have a principal amplitude of 0.1 to 1 μV and a signal frequency range of 100 Hz to 3 kHz. Amplifiers were designed to handle extremely

Fig. 1. Photo of a hardware;
(a) Microprocessor, (b) Amplifier, (c) LCD

This study was supported by a grant of the Korea healthcare Technology R&D Prpject, Ministry for Health, Welfare and Family Affairs, Republic of Korea (No.A040032).

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Fig. 2. Photo of the developed A-ABR.

low potentials with good quality. To meet this strict amplifier requirement, we constructed a cascade circuit, which consisted of a differential amplifier, a gain stage, 3 kHz low pass filter, and 100 Hz high pass filter to remove AC power line noise. We used a touch-screen based LCD (Micro Control Pia, Korea) that included an ARM9 embedded controller. Finally, we developed a portable A-ABR system with battery power as shown in Figure 2.

B. Software

The flowchart of the A-ABR system is shown in Figure 3. When the start button is pressed, the microprocessor starts taking measurements while generating click stimuli. The generated click stimuli were pulse trains of 0.1 ms duration, with a repetition frequency of 10.1 Hz. The microprocessor syncronously averaged electric potentials, which were generated by auditory nerve systems in response to auditory stimuli. As the obtained potentials have extremely low SNR, an ensemble average was performed. This method is based on the fact that randomly distributed noise components are cancelled out provided that a sufficiently large number of measurements are taken. In this study, we performed 1500 iterations. The ensemble average procedure is shown in Figure 4.

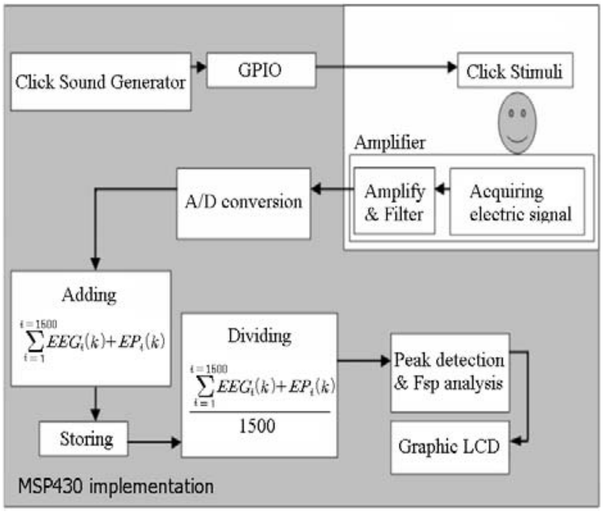

Fig. 3. Flowchart of the A-ABR system.

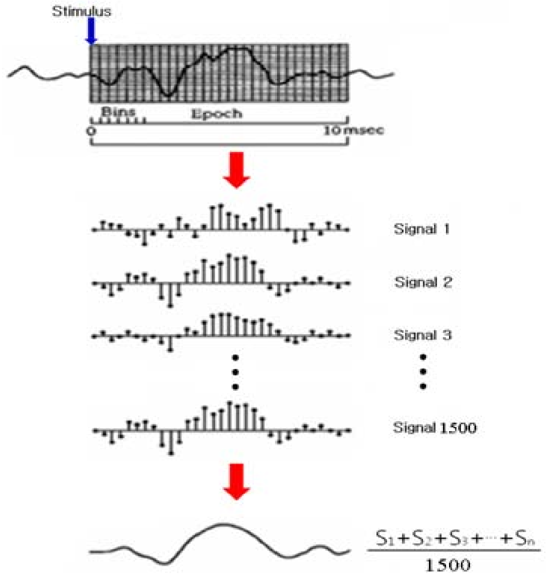

Fig. 4. The ensemble average algorithm procedure.

For automatic diagnosis of hearing impairment, we used an equation of ‘Fsp’ algorithm shown in Figure 5. Figure 5 (a) represents the level of background noise with each sweep fluctuation. To get a clear ABR signal, the single point should not vary from sweep to sweep. Figure 5 (b) is the averaged signal that represents the neural response amplitude to the stimuli [10]-[12]. In our previous study, we performed ABR tests for 50 infants who had normal hearing to obtain an optimal value of ‘Fsp’. As a result, the test accuracy was 95% when the value was 1.77 as shown in Figure 6. Therefore, we have constructed a system that automatically determines whether a subject has hearing impairment by applying this value.

$$Fsp = \frac{VAR(\bar{S})}{VAR(\overline{SP})} \quad (1)$$

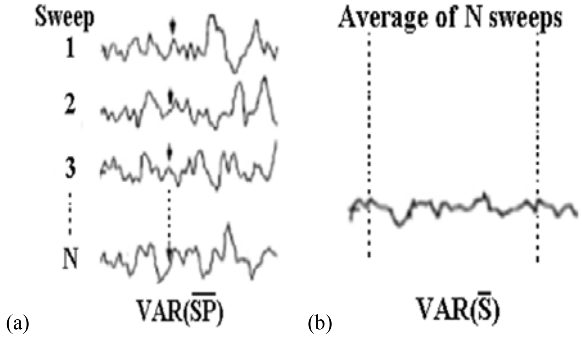

Fig. 5. ‘Fsp’ algorithm:
(a) Variance of a single point from sweep to sweep.
(b) Variance of successive points in window of average.

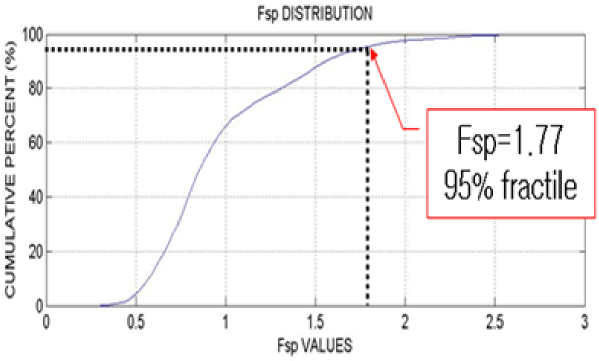

Fig. 6. Cumulative percent as a value of 'Fsp.'

C. *Experimentation*

For the purpose of validation of this system, the test was performed for 2.5 minutes on twenty healthy adults, using 40 dBnHL (normal hearing level) click stimuli as shown in Figure 7. To avoid background noise, we used an inserted earphone, EAR-3A (Ear Auditory System, UK). Before inserting the earphone, the external ear canal was checked for any easily removable debris or blockage. An active electrode was placed on the mastoid area of the test ear, a passive electrode was placed on the opposite side of the mastoide, and a ground electrode was attched on the forehead as shown. A total of 1500 stimuli were averaged while each subject was lying on bed. Also, we performed the test without sound stimuli. The result was shown on the LCD screen as either 'Pass' or 'Fail', in Figure 8.

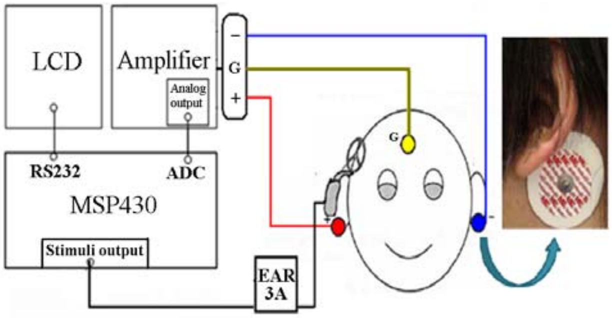

Fig. 7. Experimental setup.

III. RESULTS AND DISCUSSION

If a test result is 'fail,' another test is supposed to be repeated. If either of the next two tests is 'pass', the subject is considered to have normal hearing. All tests for twenty normal hearing adults resulted in 'pass.' We validated the accuracy of this system only for normal-hearing adults. The test results are presented on the screen as shown in Figure 8. Peak5 is normally the most robust in ABR signals and has latency between 4 and 6 ms in healthy adults. The peak5 in Figure 8(a) was the largest and latency time was approximately 5 ms. In contrast, when we performed the test without sound stimuli, 'Fail' was displayed on the screen.

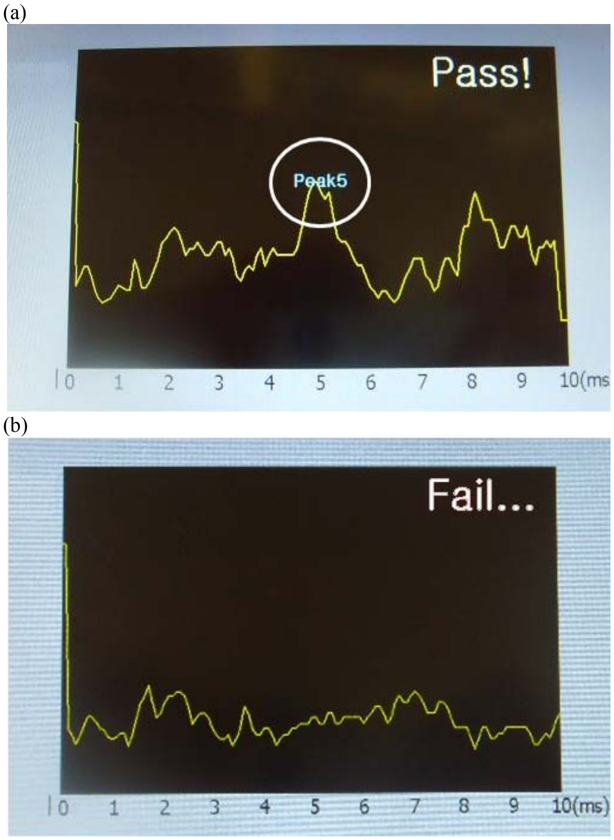

Fig. 8. The test results screen:
(a) A case in which the subject heard the click stimuli.
(b) A case in which the subject heard nothing.

IV. CONCLUSION

In this study, we have developed a battery operated portable A-ABR screener using a microprocessor. Since this portable system was made compactly and in light weight, so it might be helpful in virtually any environment, including Neonate Intensive Care Unit (NICU), Intensive Care Unit (ICU), and doctors' offices. Especially this system can be used even by the patients themselves. Furthermore, as it has also been programmed to save the signal data, the abilities to review and edit screening results are readily available.

For future studies, we will perform sufficient additional tests with subjects including hearing-impaired adults, newborns, and babies to assess and validate the accuracy of the system.

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