Feasibility of N1-P2 Habituation to Differentiate Loudness Levels

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Abstract— **In the present study, the feasibility of habituation correlates of N1-P2 component of late auditory evoked potential to differentiate loudness levels was investigated. In ten normal hearing subjects, it was shown that habituation correlates of N1-P2 is able to differentiate between acceptable loudness levels (comfortable loudness and comfortable but loud) and strong and high loudness levels (loud, upper level and uncomfortable loudness level (UCL)). Therefore, the proposed approach is promising for the development of objective setting method for hearing devices, especially to estimate the level of UCL.**

Keywords-habituation; Late Auditory Evoked Potential; N1-P2

I. INTRODUCTION

In terms of hearing rehabilitation devices, over the last 200 years such devices have evolved from being bulky instruments based on basic sound amplification to small sophisticated devices that can be implanted in our auditory organ and enable hopelessly profound deaf people to recover their hearing capability. In parallel, as the technology of hearing devices becomes more sophisticated and with high demands of efficiency of then constrained by the type of patient being treated, fitting of such devices becomes more and more challenging. In this respect, available subjective procedures require a total cooperation of the patient (to voluntarily assess the loudness of the stimulus), which represents a big challenge when dealing especially with young patients. For these candidates, a hearing device is recommended before the age of six months, or even three months as recently suggested, for an optimal outcome in terms of speech development [1], hence, developing an objective fitting procedure has become fashionable among researchers [2], [3].

During the setting of a hearing device on a patient, two levels of loudness perceptions are important i.e., hearing threshold (THR: the level of which a listener begins to hear the sound) and uncomfortable loudness (UCL: the highest sound that makes the listener uncomfortable over a period of time) level. UCL level is important to be set correctly during the fitting of a hearing instrument because this value has a larger impact in speech understanding in comparison to a reduction in THR level [4].

Hence, the objective of the present study is to study the practicability of natural human response, i.e., we finally habituate when repeatedly stimulated by a same stimulus to estimate loudness levels. In [5], the differentiation between two distinct intensities was possible by using habituation approach. The UCL level is commonly perceived as too loud until we feel uncomfortable to it. For a level that is too loud or perhaps a little painful, it is hard to ignore or to draw away our attention from it. Previous studies such as [6] and [7] have observed that habituation was shown to be slower and less significant when a subject pays attention to the stimuli. Groves and Eason [7] have reported that more rapid habituation with low intensity stimulation and [8] have stated that a strong stimulus was found to yield no significant habituation.

The habituation phenomenon will be studied on the electrical activity of the human brain is known as electroencephalography (EEG), especially the late auditory evoked potential (LAEP). The focus analysis will be the neurophysiologic effects of auditory habituation reflected in a LAEP component, namely the N1-P2 wave. In the auditory modality, P2 often occurs together with N1 and shares many characteristic of the preceding component, yet the two peaks can be dissociated experimentally and developmentally [9]. P2 is sensitive to physical parameters of the stimuli, such as pitch [10]. The amplitude of the auditory N1 is enhanced by increased attention to the stimuli [10]. Naatanen [11] proposed that the N1 wave reflect sensory and physical properties such as intensity. Soininen et. al [12] have reported, habituation of the NI wave does not depend on age.

II. METHODOLOGY

A. Experimental Setup and Preprocessing

The EEG recording is conducted by using BIOPAC System Inc, MP150 EEG 100C and computer software (Acknowledge 4.2). In all experiments, the auditory stimuli were generated by a computer and presented monaurally to the right ear via a headphone. The EEG was sampled at 512 Hz.

The electrophysiological recordings were performed in a sound proof room. The subject was lying on an examination bed. He/she was instructed to relax with the eyes closed and ignore the stimuli during the experiment. The subject was monitored through the entire experiment in order to aware any signs of sleeping such as snoring and rapid eye movement. If the subject was found asleep during the experiment, the data will be discarded. He/she was instructed to relax during the experiment, to keep his/her eyes closed, and to ignore the stimuli. The single--sweeps, i.e, the responses to the individual tones, were recorded using surface electrodes (Ag/AgCl) which were placed at the right mastoid, the vertex (reference) and the upper forehead (ground). The electrodes impedances were ensured to remain below 5kΩ during the measurements.

B. Subjects, Stimuli and Experimental Paradigm

Ten volunteers (three females and seven males) participated in this study. All subjects were healthy and had no history of hearing problems with a normal hearing threshold (below 15dB hearing level). The experiments were performed after the subjects were informed about the procedure and signed an informed consent form. Each subject received an audiogram test before and immediately after the experiment to ensure post-experimental effects occurred.

For the electrophysiological measurements, the 1000 Hz trapezoidal shape pure tones with duration of 40 ms, 10ms rise/fall and an ISI of 1s stimuli were presented at four stimulation levels, began with 60 dB, 70dB, 80dB, and 90dB SPL consecutively with 3 minutes break in between. Before the EEG recording was conducted, the aforementioned auditory stimuli were presented briefly to the subject (about 30 s) at random intensity level (between 0 dB to 90 dB with increment of 10 level dB at every scale). The subject was asked to scale the given stimuli within 10 categories (NOTHING (N), THRESHOLD (TH), VERY SOFT (VS), SOFT (S), COMFORTABLE BUT SOFT (CBS), COMFORTABLE LOUD (CL), COMFORTABLE BUT LOUD (CBL), LOUD (L), UPPER LEVEL (UL), and TOO LOUD (TL or UCL)) by indicating the corresponding loudness on a scaling tableau.

A total of 400 stimulations were applied for each stimulation level in every subject. Only the ipsilateral (on the right mastoid) data were analyzed in this study. The electroencephalographic recordings were segmented to sweeps ranging from 0 to 1s post-stimulus. They were filtered using a digital filter (bandpass 1Hz-30Hz). Sweeps that contained artifacts were rejected using the threshold detection (amplitude larger than 50μV).

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III. RESULTS

To analyze the LAEPs over trials, groups of 20 trials are averaged in order to reduce signal to noise ratio and produce a clear LAEP as shown in Fig. 1. Fig. 1 shows the LAEP of Subject 1 at 60dB stimulation intensity. In this figure, three consecutive LAEPs (each LAEP is an average of 20 trials. The LAEP 1 is the mean of trial 1- 20, LAEP 2 is the mean of trial 21- 40 and LAEP 3 is an average of trial 41– 60) in an experiment are illustrated in a graph. From this figure, the negative amplitude of N1 and positive amplitude of P2 are decreasing over trials. For this case (subject 1, intensity 60dB), such decrements continue throughout the experiment, see Fig. 2.

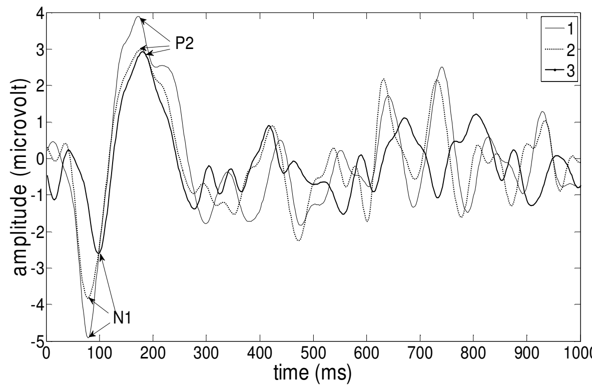

Fig. 1 The LAEP of Subject 1 at 60dB stimulation intensity. Each LAEP is an average of 20 trials. The LAEP 1 is the mean of trial 1- 20, LAEP 2 is the mean of trial 21- 40 and LAEP 3 is an average of trial 41 – 60.

In the following, the results of each subject are presented individually as each individual perceived differently and to analyze the relationship between one's perception of intensity (loudness) and the degree of amplitude decrement (habituation). In Fig. 2 to Fig. 11, the different between the peak of N1 and P2 is illustrated over trials (average of 20 trials). The range of N1-P2 is represented by the dots. In order to show the degree of the decrements (if occurs), regression analysis was done and illustrated by the solid line. Each subfigure shows the N1-P2 range over trials at respective stimulation intensity and subject's perception.

At 60dB, 9 out of 10 subjects perceived this intensity as CL and the decrement of N1-P2 range show a significant (Wicoxon test, significant level $p<0.05$) decrement of N1-P2 range over trials when stimulated at 60dB intensity level.

At 90dB, 6 out of 10 subjects perceived this intensity as TL and the degree of habituation was insignificantly, except subject 7. Some of them show an increment of N1-P2. Subject 8 perceived 90dB intensity level as UL and the decrement of N1-P2 range was significant.

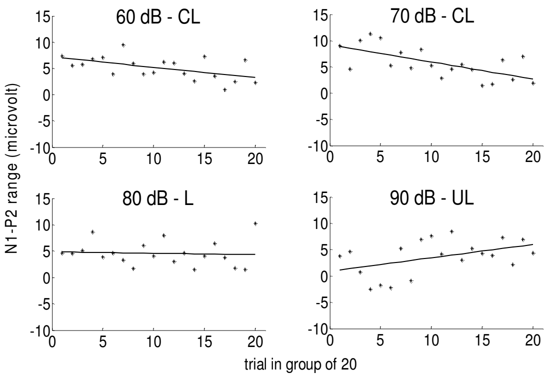

Fig. 2 Subject 1

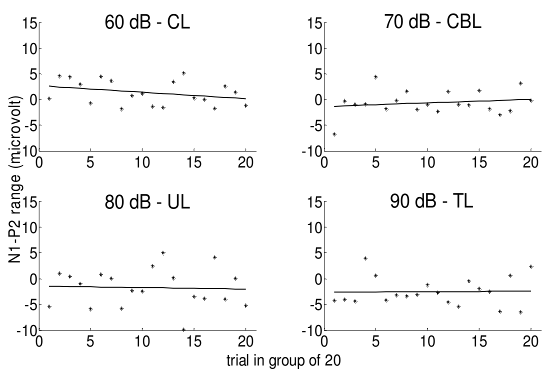

Fig. 3 Subject 2

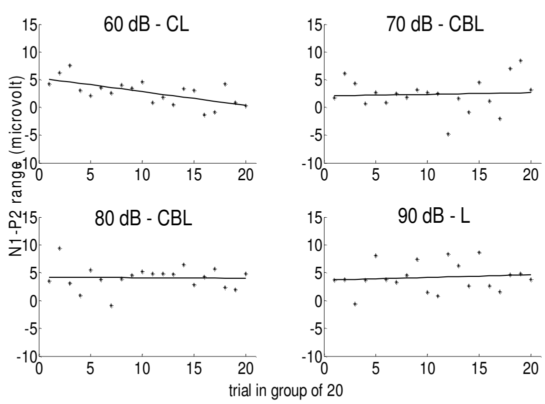

Fig. 4 Subject 3

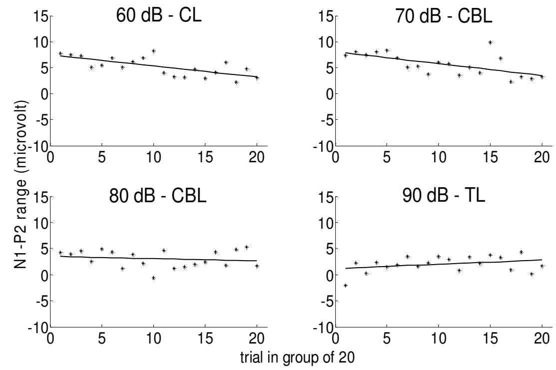

Fig. 5 Subject 4

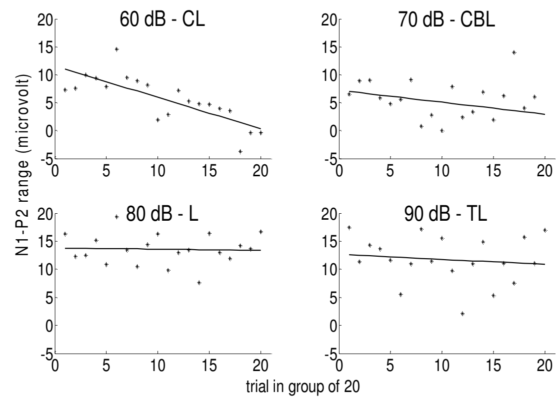

Fig. 6 Subject 5

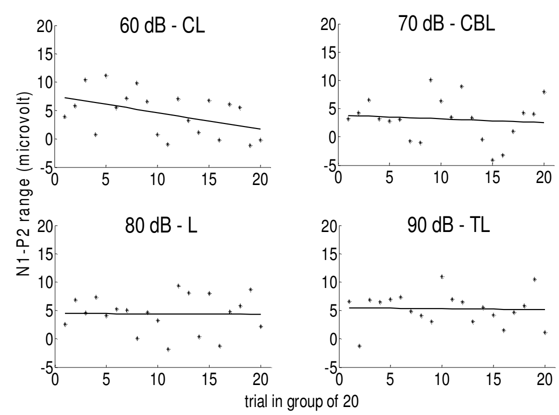

Fig. 7 Subject 6

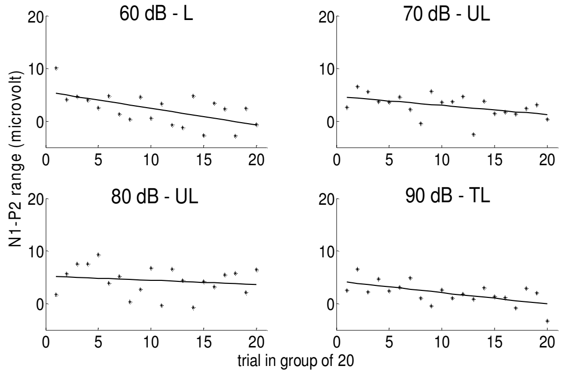

Fig. 8 Subject 7

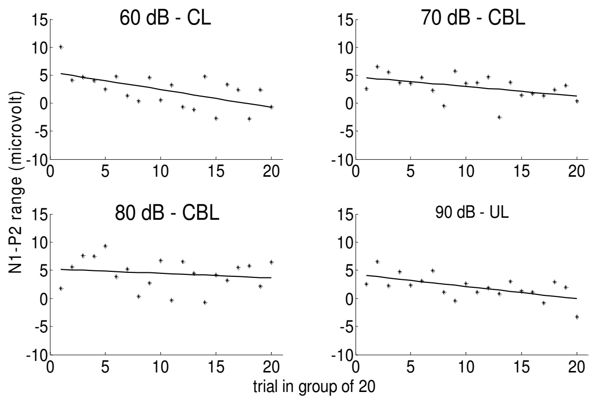

Fig. 9 Subject 8

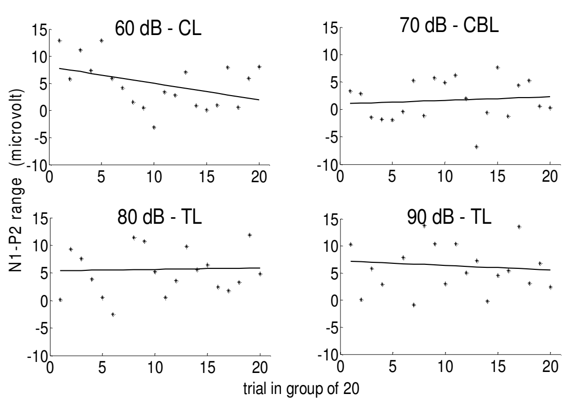

Fig. 10 Subject 9

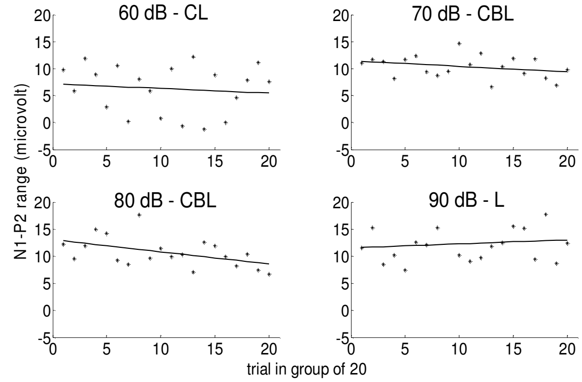

Fig. 11 Subject 10

For the intensity of 70dB, 8 of them perceived as CBL with 4 of them show a significance habituation of N1-P2 and the other 4 were insignificantly habituated. In case of 80dB, majority of the subjects (40%) perceived this intensity as CBL and show insignificant habituation except subject 10. 30 % of the subjects show insignificant habituation of N1-P2 and they perceived this intensity as L. The other 2 subjects have classified 80dB as UL and 1 subject perceived it as TL. Their responses showed insignificant habituation.

IV. Discussions and Conclusions

In this study, the relationship between the degree of habituation of N1-P2 and loudness was investigated. Based on the results, it was shown that the habituation of N1-P2 was significant when the intensity of the sound was CL and CBL. This finding correlates with [13] whereby in normal-hearing subjects, the loudness adaptation increases with decreasing level and increasing frequency.

Different observations were found when the intensity or the loudness increased. In a recent computational model of habituation, by using a large-scale model for simulating auditory evoked cortical potential, [14] was able to show a significance change in the synchronization-stability of the N1-P2 wave of LAEP during habituation towards stimulus novelty. A high intensity stimulus is assumed to activate additionally brain structures for the processing of aversive stimuli. In terms of their model, these result in an imbalance of exogenous and endogenous weights and thus in the inability to habituate to excessive loud tones. Hence, when the sound becomes loud and too strong, the amplitude of N1-P2 was significantly steady over time. In a number of the subjects we could see that the amplitude was increasing over trials when stimulated by a high intensity or when they perceived the stimuli as L, UL or TL. Too loud sound is hard to ignore. Therefore, the aforementioned observation is correlated with the attention phenomenon, where several studies have shown that the amplitude of the LAEP increase when the subject pay attention the stimuli [6], [7], [10]. In addition, electrical stimulated LAEP reflects electrical activation of the cortex as a response to stimulation of the auditory system. The integration and synchronization of the auditory neurons at all stages of the auditory pathway increases as the stimulation increases and may result in hearing sensations. The higher the stimulus level the larger the cortical activation [15]. As shown by Hoppe et. al [15] and Butler et. Al [16], the LAEP amplitude increases when the stimulation intensity increases.

In conclusion, this study has shown that two major categories of acceptable loudness as in CL and CBL, and strong and high loudness as in L, UL and TL were able to be differentiated by the habituation of N1-P2 wave. Hence, we have shown that N1-P2 habituation behavior could be used for an objectives measurement to estimate UCL level.

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