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A Hybrid Trial To Trial Wavelet Coherence and Novelty Detection Scheme for a Fast and Clear Notification of the Uncomfortable Loudness Level

Mai Mariam and Izadora Mustaffa
Universiti Teknikal Malaysia Melaka, Malaysia

Abstract. To determine the uncomfortable loudness (UCL) level is not an easy task, especially in children. A need to objectively measure this level is crucial as the age of hearing devices candidates is getting younger. Previous studies have shown that the feasibility of habituation correlates in late auditory evoked potentials for a measurement technique of UCL identification is promising. Nevertheless, a scheme that could provide a fast and clear notification of the UCL level is desirable. The present study has introduced a hybrid trial to trial wavelet coherence and novelty detection scheme to analyze the habituation in late auditory evoked potentials (LAEPs) i.e., relative changes within trial sequences. In 10 normal hearing subjects, a clear discrimination between 50 decibel (dB) sound pressure level (SPL) stimulated LAEPs and 100 dB SPL stimulated LAEPs. In addition, the proposed scheme is able to highlight the presence of habituation and the number of stimuli could be reduced up to 60% percent for meaningful results. Therefore, the proposed approach provides an encouraging foundation for a fast and reliable scheme in developing an objective loudness scaling measurement, in particular to determine the UCL level.

Keywords: habituation, wavelet coherence, novelty detection, late auditory evoked potential.

1. Introduction

Hearing plays a huge role for oral communication skill. An excellent performance in speech perception and production are found in children who received cochlear implantation at a younger age in comparison to the children at an older age [1].

To fit a hearing device to a young child is not an easy task. The behavioural observation audiometry which estimates loudness perceptions by physical or emotional responses of the child has limited application and could not reliably estimate auditory sensitivity [2]. A simple behavioural audiometry observation in children can be misleading and ultimately leads to mismanagement [3] especially in determining the uncomfortable loudness (UCL) level. Surveys have shown that many hearing aid users are dissatisfied with the loudness of their hearing aid [4] especially with the UCL level. In subjective measures, a patient has to decide whether a particular sound is loud enough for him/her. If an adult finds this task difficult, much less to an infant.

We have introduced an electrophysiological technique in [5] which applies the phenomenon of response reduction due to repeated stimulation to differentiate between a high intensity responses of 100 decibel (dB) sound pressure level (SPL) and 50 dB SPL. We found that a unique signature (insignificantly habituate) of large--scale neural correlates of habituation in late auditory evoked potentials (LAEPs) when stimulated with 100dB SPL. In contrast to 100dB SPL stimulated response, 50dB SPL stimulated responses shows clear habituation behaviour.

+ Corresponding author. Tel.: + (606-5552156); fax: +(606-5552121).
E-mail address: (maimariam@utem.edu.my).

The feasibility of habituation correlates in LAEPs as an objective measurement of loudness scaling has been shown to be promising. However, a scheme that could provide a fast and clear notification of an UCL level reached is desirable.

In this paper, the post-processing in [5] is modified by combining the **SSTC** scheme with the novelty detection approach in order to achieve a fast and a reliable identification scheme for habituation extraction. Similar data from [5] is used and the comparison between the previous and present of post processing results in made. The details of the present technique and a brief review of data acquisition are discussed in the following sections.

2. Methodology

2.1. Data Acquisition

We collected data from 10 normal hearing subjects (4 female and 6 male; mean age: 30 years and 11 months with a standard deviation of 3 years and 9 months) with no history of hearing problems with a normal hearing threshold (below 15dB hearing level) were participating in this study. Each subject received an audiogram test before and immediately after the experiment to ensure post-experimental effects does not occur, as the stimulation intensity level (100dB SPL) is too high. The auditory stimuli were pure tones of 1 kHz with a duration of 40 ms and a constant interstimulus interval (ISI) of 1s. The auditory stimuli were presented monaurally to the right ear via a headphone. The electroencephalographic (EEG) recordings were performed in a sound proof room. Subjects were lying on an examination bed and relaxing.

Stimuli were presented at two stimulation levels; 50dB SPL (lower sound) and 100dB SPL (higher sound) consecutively with 3 minutes break in between. The signals were recorded using surface electrodes (Ag/AgCl) which were placed at the left and right mastoid, the vertex and the upper forehead. The EEG was sampled at 512 Hz and filtered using a digital filter (bandpass 1Hz-30Hz). Trials that contained artefacts were rejected using threshold detection (amplitude larger than 50μV). At least 800 single sweep LAEPs of each subject were obtained in this way. See [5] for the details explanation of data acquisition.

2.2. Habituation

In [5] and [7], we have found that insignificant or absence of habituation behavior responses when subjects were stimulated by a high stimulation level or UCL perceived intensity level in comparison to lower level of stimulations. Our results are supported by a few other previous findings such as more rapid habituation with stimuli of lower intensity [8] and strong stimuli may yield no significant habituation as reported by [9]. Moreover, [10] and [11] have observed that habituation is shown to be less and slower and when a subject pay attention to the stimuli.

2.3. Trial-to-trial wavelet coherence

Let $(\Omega^{\varphi,t}a,b)$ be the wavelet cross spectrum between signal a and b, where φ and t represent the wavelet and window to calculate wavelet coherence, respectively. With scale, s and translation parameter, n, the wavelet coherence of two signals a and is defined as

$$(W^{\varphi,t}a,b)(s,n) = \frac{\left|(\Omega^{\varphi,t}a,b)(s,n)\right|}{\sqrt{(\Omega^{\varphi,t}a,a)(s,n)(\Omega^{\varphi,t}b,b)(s,n)}} \;. \tag{1}$$

To capture the correlation between two consecutive trials, T over the experiment (M trials), equation (1) is modified to

$$Z_m^T(s,n) = \left(W_{T_{m-1},T_m}\right)(s,n), \tag{2}$$

and Z is referred to as trial-to-trial wavelet coherence with m = 2,…,M.

Habituation is defined as reduction of response over repeated stimulations. When habituation is observed in a trial, but not in the preceded trial, the obtained coherence in between trials is zero as both trials are not correlated. See [5] for detailed explanation of trial-to-trial wavelet coherence and references therein.

Trial-to-trial observation provides informative features describing habituate response or non-habituate response. In order to extract the presence of habituation, we further analyze the wavelet coherence results with novelty detection. We have observed in [5] that the reduction of wavelet coherence (i.e., presence of habituation) occurs after several trials after the experiment began. Therefore, we take these first η trials (training set) to train a classifier. This classifier is generated by all information of η trials which forms a hypothetical sphere with center *c* and radius *K.* To minimize this sphere so that the learning machine is free from false negative errors, the problem is solved by

$$\min_{c\in F, R\in\Re, \phi\in\Re^{\eta}} K^2 + \alpha\sum_{i=1}^{\eta}\phi_i \tag{3}$$

where, α is the trade-off which allows a balance of space volume and number of false positive errors and ϕ is the slack variables introduce in [13] to reduce classifier sensitivity. (3) has to be optimized under the limitation given by

$$\|W_i - c\|^2 \le K^2 + \phi_i \qquad (i = 1, \ldots\ldots, \eta),$$

$$\phi_i \ge 0 \qquad (i = 1, \ldots\ldots, \eta) \tag{4}$$

The generated classifier has all the information of insignificant habituate trials. Should the consecutive trial (test trial) after η trials habituates; the generated novelty measure equals to 1 as it shows a highly different information. In other words, the more novelty measure occurs in an experiment, the higher the degree of habituation.

3. Results

In [5], we have shown that that habituate responses (low sound) produce a continuous reduction of wavelet coherence in comparison to response of higher sound (insignificant changes of wavelet coherence over time), see [5] for details implementation of trial to trial wavelet coherence and the obtain results. To determine a suitable and reasonable number of trials to be used to train the classifier, based on the results in [5], we applied three training sets consisting of different numbers of trials, i.e., 50, 100 and 200 trials. In the following figures, we illustrate all trials including the training set.

Fig. 1(a) and Fig. 1(b) show the grand average novelty measure of 10 subjects for both low and high sound, respectively with training set of 50 trials. We observe that low sound produce more novelty than high sound. The frequency of trials of the novelty measures equal to 1, is 17 trials within the first 150 test trials (including the 50 training trials). In contrast to low sound, high sound produced less novelty measures which is 32 trials.

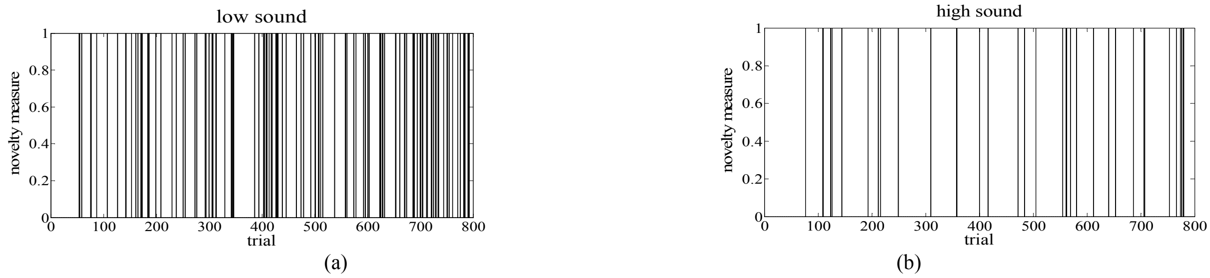
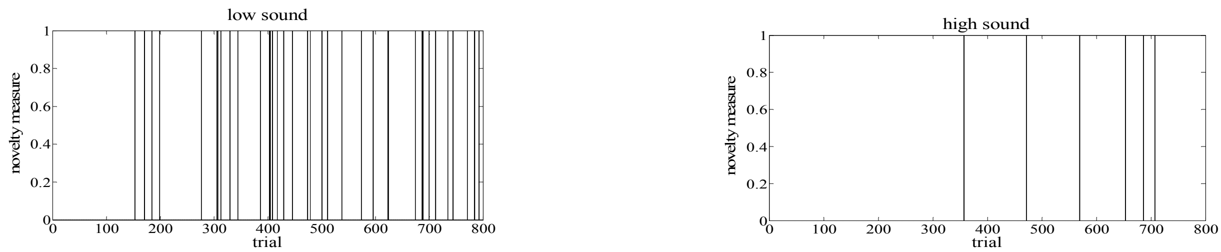


Fig. 1: The novelty measures of low sound (a) and high sound (b) with 50 trials for training set. (A grand average of 10 subjects)

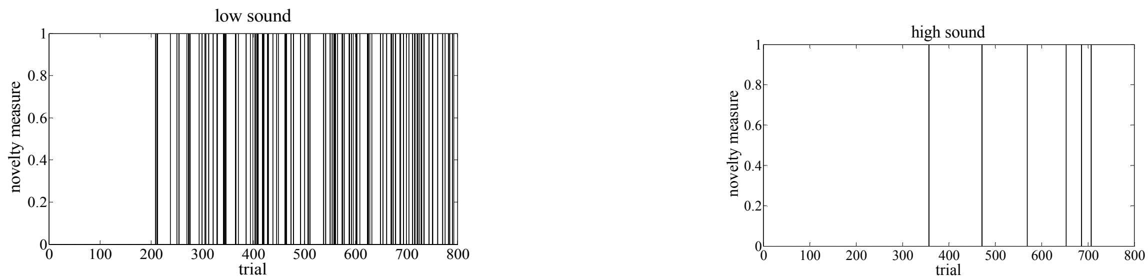
Fig. 2(a) and Fig. 2(b) show the grand average novelty measure of 10 subjects for both low and high sound, respectively with 100 trials for training set. The frequency of novelty measures presence is 20 trials within first 100 test trials. Interestingly, with 100 training trials to train the classifier, high sound produced zero novelty measures in first 157 test trials and only 8 novelty measures over the experiment which shows that habituation is considerably less in comparison to low sound.



(a) (b)

Fig. 2: The novelty measures of low sound (a) and high sound (b) with 100 trials for training set. (A grand average of 10 subjects)

Fig. 3(a) and Fig. 3(b) show the grand average novelty measure of 10 subjects for both low and high sound, respectively with 200 trials for training set. A major habituation is clearly shown has occurred after approximately 220 trials after experiment began. In contrast, high sound produced novelty measure after 157 trials (same as with the 100 training trials) and the number of novelty measures is 95 % lower than the low sound.



(a) (b)

Fig. 3: The novelty measures of low sound (a) and high sound (b) with 200 trials for training set. (A grand average of 10 subjects)

4. Discussions

In the present study, we further analyze the results in [5] in order to achieve a fast and reliable identification of habituate response. With a combination of trial-to-trial wavelet coherence and novelty detection schemes, identification of habituation moment is clearly highlighted. Trial-to-trial wavelet coherence is a reliable method to extract habituation and novelty detection analysis is able to highlight the abnormality in a train of data which provide a suitable method for identifying a reduction of response in real time.

Not all sampling data (512) from wavelet coherence analysis are used in novelty detection analysis. As the measurement is based on the analysis of the neurophysiological effects of auditory habituation reflected in a LAEP component, namely the N100 wave as well as N100 wave may jitter between 80 ms to 120 ms, we used the sampling data from 40 to 60 (signal is sampled at 512 Hz). The N1 wave is generally assumed to reflect sensory processing as in selective attention as well as physical attributes of a stimulus such as intensity [12]. The LAEP can be elicited from the cochlear implant patients [13] and offer technical, physiological, medical and psychological advantages in comparison to early potentials such as auditory brain response [14].

Three training set were applied and the training set with 200 trials has been shown to be more suitable to train the classifier. We also show that the frequencies of novelty measures of the two sound levels are clearly differentiated. Based on Fig.3(b), it shows that the present approach enables us to estimate the absence of habituation earlier in the UCL level. In addition, the proposed approach offers a reduction of stimuli needed for meaningful results up to 75% as high habituation behaviour is observed at approximately 200 trials (including training set) .

5. Conclusions

In the present study, we show an improved post processing technique to extract habituation in LAEPs by combining trial-to-trial wavelet coherence with novelty detection. The identification of habituation presence is faster and clearly highlighted in comparison to the previous study. These findings demonstrates a promising technique for objectively determine UCL procedure and analysis.

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