Biomedical Signal Processing and Control 45 (2018) 91–97

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Technical note

Scalp tapping-based protocol for adjusting the parameters of binaural hearing aids

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ARTICLE INFO

Article history:
Received 5 June 2017
Received in revised form 26 March 2018
Accepted 27 May 2018

Keywords:
Acoustics
Hearing aid
Tapping
Control

ABSTRACT

Hearing aids (HAs) are used in everyday life. To improve the subjective satisfaction of HAs, a simple and comprehensive means to adjust the internal parameters to accommodate various situations is required. In this study, we propose a new scalp tapping-based protocol for controlling the parameters of binaural HAs. We then demonstrate the reliability, benefits, and clinical feasibility of the protocol via subjective evaluations from 11 volunteers. In the reliability test, the implemented scalp-tapping detection algorithm showed accuracies above 95.0% in various conditions and no false adjustment of internal parameters occurred from motions or other artifacts. In the benefit test, improvements of signal-to-noise ratio (SNR) and segmental SNR were 2.42–4.04 dB and 1.22–3.95 dB on average for serial connection of beamforming and noise-reduction algorithms. In the feasibility test, the range of control accuracy was 66.67–100% (88.06 ± 10.19%), and the range of latency time was 5.03–22.27 sec (7.25 ± 1.73 s). We expect that the proposed protocol can provide a simple and convenient way to adjust internal parameters of HAs without additional hardware changes and with short-term training.

1. Introduction

Hearing aids (HAs) are used in normal daily life, and the internal parameters of the device sometimes need to be adjusted in various situations in accordance with the user's needs or preferences. For example, there are situations in which the direction of the beamforming algorithm and the direction of user-interested sound are not identical, though the HA user should not turn his/her head for safety, e.g., when driving a car [1,2]. In order to tune HAs, the HA user generally needs to 1) go to the hospital or company and ask a trained audiologist to tune the device; or 2) self-adjust the device using dedicated controllers, such as SoundGate (Sonic, NJ, USA) and ComPilot Air II (Phonak, Stäfa, Switzerland), or smartphone applications, such as HearPlus (Beltone Electronics, IL, USA) and Trulink (Starkey Hearing Technologies, MN, USA) [3]. All of these models to tune the HAs induce a time and financial burden, are inconvenient, and there is a risk of losing the controller.

Recently, several technical options that can overcome these detriments have been proposed. For example, Phonak proposed an Autozoom control scheme that relays the input of a near-speech device to a contralateral device [4], and Lee et al. [2,5] proposed a binaural beamforming algorithm that can automatically adjust the direction of beamforming focus to the direction of maximal spectral power in speech area [5]. Those techniques do not request additional devices for device tuning, but the accuracies of target detection or environment classification are not always 100% and they cannot be applied when the user-interested target is not speech. In addition, Yoon et al. [6] proposed an eye-blink-based hands-free beamforming adjustment scheme for HA that can also focus to non-speech signals; however, it requests additional electrodes for the eye-blink detection, which can induce user inconvenience and performance degradation during long-term use. To overcome the limitations of the previous studies, several requirements should be satisfied: 1) no additional device should be required, 2) non-speech-targets should be able to be focused upon, and 3) control accuracy should be high regardless of the ambient circumstances.

In this study, we propose a new tuning protocol for binaural HAs that adjusts the internal parameters of the device using scalp-tapping. We evaluated the reliability, benefit, and clinical feasibility

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https://doi.org/10.1016/j.bspc.2018.05.018
1746-8094/

of the proposed protocol via subjective evaluations from 11 volunteers.

2. Materials and methods

2.1. Scenarios and setup

In this study, we selected as a representative situation that requires manual adjustment of the device a binaural HA user driving a car and listening to ambient sounds from non-forward directions. To record sound clips for the algorithm development, an examiner sat on a chair in the center of a sound-proof room in Hanyang University (Left/Right/Height = 300 × 300 × 200 cm) with two behind-the-ear type HA mock-ups (Canta7 housing; GNReSound A/S, Ballerup, Denmark) on his or her ears. Eight loudspeakers (HS50M; Yamaha Corp., Hamamatsu, Japan) were placed around the chair (100 cm distance, 45° spacing). Outputs of the four microphones in the mock-ups were recorded via an interface device (Fast Track Ultra; Avid Technology Inc., MA, USA) with 16 bits and 16,000 Hz (Fig. 1a). Recordings were made with two ambient sound scenarios as follows.

2.1.1. Driving with conversation (DWC)

Engine sound at 0°, traffic noise at 90° and 270°, a female voice at 45° (car navigation), and a male voice at 180° (requires adjustment of beamforming focus).

2.1.2. Driving with no conversation (DNC)

Engine sound at 0°, female voice at 45° (car navigation), and traffic noise at 90°, 180°, and 270° (requires adjustment of the output volume).

Speech signals were randomly selected from the Texas Instruments/Massachusetts Institute of Technology corpus [7], and car engine and traffic noises were selected from the Phonak database [8]. Before the recording, the amplification constants of each loudspeaker at 60/70/80 dB sound pressure level (SPL) were manually recorded using a 1000 Hz sine wave and a sound level meter (SC-30; CESVA, Barcelona, Spain) at the chair location. In addition, the volume of the interface device was adjusted so that no clipping was detected in the microphone outputs at both the DWC and DNC scenarios when all speakers were played at 90 dB SPL. During the recording, for each of the DWC and DNC scenarios, the volume of the speakers was adjusted to 60/70/80 dB SPL and, at each volume setting, the examiner tapped the scalp area near the HA mock-up (around T3/T5 for left-tapping and around T4/T6 for right-tapping in 10–20 international [9]) for 120 s (0–10 sec: no tapping, 11–110 sec: 1 tap/sec, 111–120 sec: no tapping; denoting by the NTN protocol) (Fig. 1b). Then, six recordings for each condition (2 scenarios x 3 sound levels) were utilized for the algorithm development.

2.2. Scalp tapping-based HA control protocol

Fig. 2 shows the schematic of the implemented scalp tapping-based HA control protocol. Similar to the general processing sequence of HAs, it was assumed that input signals ($M_{L,F}$ and $M_{L,R}$ for the left mock-up and $M_{R,F}$ and $M_{R,R}$ for the right mock-up) are processed with a sequence of beamforming, noise reduction, and wide dynamic range compression and fitting. The proposed protocol was composed of three operation states: 1) a fixed-operation state, 2) a target-selection state, and 3) a parameter-adjustment state. In the fixed-operation state, the device operates based on the previously-determined beamforming parameter and output volume amplification constant, and waits for the advent of a predetermined triggering pattern. When the triggering pattern is detected, the device enters into the target-selection state and waits for the input of an additional tapping pattern that specifies either the beamforming or the output volume. When a specific target for adjustment is selected, the device enters into the parameter-adjustment state and again waits for the input of an additional tapping pattern that specifies one of the possible parameter settings (focusing direction for beamforming, or amplification constant for output volume). When the target parameter is updated by the user input, the device returns to the fixed-operation state and waits for an additional triggering pattern.

To detect the scalp-tapping patterns, inputs of two rear microphones were pre-processed as follows: 1) filter the signals using a third order Butterworth low-pass filter (cut-off frequency = 100 Hz); 2) calculate absolute waves of the filter outputs; and 3) filter the difference between two absolute waves (left – right) using the same low-pass filter. Then, the scalp-tapping detection process was activated using the pre-processed input signals. The recorded signals for six conditions elucidated the following characteristics of the scalp-tapping patterns: 1) the spectral power of the tapping signal is relatively even in the range of 0–8,000 Hz in the frequency domain; and 2) the duration of the tapping peak is approximately 0.02 – 0.1 s in the time domain (Fig. 3). On the basis of these characteristics, the scalp-tapping detection was performed as follows: 1) input the width of the tapping pattern (TW), positive threshold (THR_P), and negative threshold (THR_N) for each individual from the results of a prior tapping test; 2) store four recent input packets of the absolute waves, x[n], x[n-1], x[n-2], and x[n-3], (1024 length per each) in buffer; 3) calculate the amplitude and position of the maximal (A_{MAX}, P_{MAX}) and minimal (A_{MIN}, P_{MIN}) values in x[n-1] and x[n-2]; 4) assume scalp-tapping occurred on the left if the value of A_{MAX} is greater than THR_P and, at the same time, there exists no absolute value whose amplitude is greater than A_{MAX} x 0.3 in the [P_{MAX} - (TW + 300), P_{MAX} – TW] and [P_{MAX} + TW, P_{MAX} + (TW + 300)] intervals; and 5) assume scalp-tapping occurred on the right if the value of A_{MIN} is smaller than THR_N and at the same time, there exists no absolute value whose amplitude is smaller than A_{MIN} x 0.3 in the [P_{MIN} - (TW + 300), P_{MIN} – TW] and [P_{MIN} + TW, P_{MIN} + (TW + 300)] intervals.

In this study, we utilized three algorithms: 1) forward/backward beamforming (bilateral): focuses in the 0° or the 180° direction (implemented based on Teutsch and Elko [10]); 2) diagonal beamforming (binaural): focuses in the 45° or the 135° direction (implemented based on Lee et al. [2,5]), and 3) noise reduction: a multi-band spectral subtraction algorithm (implemented based on Yook et al. [11]). The pattern for triggering (fixed-operation state -> target-selection state) was set as two scalp-taps within 1 s. In addition, patterns for target specification were set as follows: 1) beamforming: one scalp-tap within 1 s; 2) output volume: two scalp-taps within 1 s. In addition, patterns for parameter adjustment were set as follows: 1) beamforming: one/two/three scalp-tap(s) within 3 s for 0°/45°/180° focusing; 2) output volume: one/two/three scalp-tap(s) within 3 s for low/mid/high sound level.

2.3. Evaluation of the proposed protocol

A total of 11 healthy volunteers (3 for the reliability test and 10 for the feasibility test; 2 participated in both) were recruited based on a protocol that was approved by the local Institutional Review Board of Hanyang University (9 males and 2 females, age range: 18–29 years, median age = 26 years, average age = 25.45 years). Written agreements were acquired and each participant was provided monetary compensation. The environment for the experiments had the same recording setup described above. Before the subjective experiments, each participant was given a pre-training phase to familiarize him or her with the basic requirements for the scalp-tapping control (e.g., position, rhythm, and strength of