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Effect of the degree of sensorineural hearing impairment on the results of subjective evaluations of a noise-reduction algorithm

Jinryoul Kim [a,c,1], Kyoung Won Nam [a,1], Sunhyun Yook [a,b], Sung Hwa Hong [c], Dong Pyo Jang [a], In Young Kim [a,*]

[a] *Department of Biomedical Engineering, Hanyang University, Seoul, Republic of Korea*

[b] *Department of Medical Device Management & Research, Samsung Advance Institute for Health Science & Technology, Sungkyunkwan University, Seoul, Republic of Korea*

[c] *Department of Otorhinolaryngology-Head & Neck Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea*

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Abstract

Subjective evaluations of the perceptual effects of a specific noise-reduction (NR) algorithm for hearing-support devices have frequently been performed using normal-hearing (NH) participants because of financial, time, and ethical constraints. However, the perceptual effects of the same NR algorithm in a subjective evaluation may differ in accordance with the degree of hearing ability of the subjects. In this study, we performed subjective evaluations using 45 participants with different degrees of sensorineural hearing impairment to assess whether the perceptual effects of a certain NR algorithm in aspects of preference, quality, and intelligibility are affected by the degree of hearing ability. We recruited 15 NH subjects, 15 sensorineural hearing-impaired (SNHI) subjects with moderate hearing loss, and 15 SNHI subjects with moderately-severe hearing loss, and performed preference, intelligibility, and quality tests using three NR algorithms. Experimental results demonstrated that the perceptual effects of a certain NR algorithm were not significantly affected by the degree of hearing ability in regards to preference and improvement of speech intelligibility, but were significantly affected in regards to the improvement of speech quality.

Keywords: Hearing aid; Sensorineural hearing impairment; Noise reduction; Preference

1. Introduction

Frequency-selectivity deterioration and dynamic-range reduction due to damage of the cochlea in sensorineural hearing-impaired (SNHI) persons can induce several abnormal auditory symptoms, including loudness recruitment, and can also result in decreased speech intelligibility in noisy environments (Moore, 2003). To compensate for these abnormal auditory senses, most hearing-support (HS) devices, such as digital hearing aids and cochlear

Abbreviations: SNHI, sensorineural hearing-impaired; HS, hearing-support; NR, noise-reduction; NH, normal-hearing; LogMMSE, log-scaled minimum mean-square error; MBSS, multi-band spectral subtraction; CMOS, Comparison Mean Opinion Score; SNR, signal-to-noise ratio; ISNR, input signal-to-noise ratio.

* Corresponding author at: Department of Biomedical Engineering, Hanyang University, Seoul 133-791, Republic of Korea. Tel.: +82 2 2291 1713; fax: +82 2 2220 4949.

E-mail addresses: jinryoul@bme.hanyang.ac.kr (J. Kim), kwnam@bme.hanyang.ac.kr (K.W. Nam), shyook@skku.edu (S. Yook), hongsh@skku.edu (S.H. Hong), dongpjang@gmail.com (D.P. Jang), iykim@hanyang.ac.kr (I.Y. Kim).

[1] Jinryoul Kim and Kyoung Won Nam contributed equally to this paper and should therefore be regarded as equivalent first authors.

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implants, have utilized various noise-reduction (NR) algorithms that can reduce the noise components in the speech-in-noise signals to improve the speech intelligibility of SNHI persons in noisy situations (Blamey, 2005). During the development of NR algorithms for HS devices, the most purposive way to evaluate the clinical efficacy is to perform various clinical tests using a large number of actual SNHI persons with various degrees of hearing impairment and various clinical symptoms (e.g., dead zone in a specific frequency range) in order to verify whether the speech quality and speech intelligibility of the SNHI patients are actually improved after applying the NR algorithm. However, there are many administrative, ethical, and financial barriers in performing large-scale clinical tests in accordance with the stages of the algorithm development; e.g., the application to, and approval of the local Institutional Review Board (IRB) and recruitment of SNHI patients with various symptoms and ages, which require full cooperation of the hospital and sufficient financial support. Therefore, as an alternative, many research groups have utilized various objective indices, such as the signal-to-noise ratio (SNR), perceptual evaluation of speech quality (PESQ), hearing aid speech quality indices (HASQI), and several composite indices (C_{sig}, C_{bak}, C_{ovl}), to quantitatively evaluate the performance of the algorithm, or have performed subjective evaluations using normal-hearing (NH) volunteers to indirectly estimate the clinical effects of the algorithm on actual SNHI persons (ITU-T P.862, 2000; Rix et al., 2001; ITU-T P.835, 2003; Kates and Arehart, 2010). However, the clinical effects of a certain NR algorithm with SNHI persons may be different than with those of NH persons and may even be different among the SNHI persons, depending on the degree of hearing ability. For example, Hilkhuysen et al. commented that the actual clinical benefits of the same NR algorithm may differ in accordance with whether or not the hearing ability of the person is impaired (Hilkhuysen et al., 2012). There have been several studies that evaluated the differences of the subjective performance of NR algorithms between NH and SNHI subjects (Marzinzik, 2000; Luts et al., 2010; Houben et al., 2011); however, there have been few studies that further evaluated the differences in the subjective satisfaction of the same NR algorithms between SNHI subjects with different degrees of hearing ability.

In this study, we evaluated whether the perceptual effects of a certain NR algorithm in aspects of preference, quality and intelligibility are affected by the degree of hearing ability by performing subjective evaluations with 15 NH and 30 SNHI subjects.

2. Materials and methods

2.1. Participants

Fifteen NH volunteers and 30 SNHI persons (15 with moderate hearing loss and 15 with moderately-severe hearing loss) participated in this study. Detailed protocols for participant recruitment and clinical evaluation adhered to the tenets of the Declaration of Helsinki and were also approved by the local IRB of Samsung Medical Center (SMC IRB approval 2012-05-086). The contents of the study were explained to each participant before the study began; informed consent was acquired, and each participant was paid about 45 USD (50,000 KRW) as a reward. Among the NH applicants, 15 applicants were recruited (G_NH), whose audiogram values were less than 20 dB HL at all testing frequency bands and whose word recognition scores (WRS) were 100% (eight males and seven females, age range: 23–46 years, median age = 27 years, average age = 30.3 years). In addition, among the SNHI applicants, 15 applicants (G_ML) with moderate hearing loss, whose average audiogram values over 500, 1000, 2000, and 4000 Hz were in the range of 41–55 dB HL (nine males and six females, age range: 23–74 years, median age = 55 years, average age = 50.1 years, group average = 50 dB HL) and 15 applicants (G_MSL) with moderately-severe hearing loss, whose average audiogram values over the same frequencies were in the range of 56–70 dB HL (six males and nine females, age range: 20–77 years, median age = 52 years, average age = 45.4 years, group average = 61 dB HL), were selected as SNHI participants (Clark, 1981). Fig. 1 represents the average hearing thresholds of the participants and Tables 1 and 2 demonstrate the detailed characteristics of the SNHI subjects (acquired from each subject before the clinical test using questionnaires).

2.2. NR algorithms used

In this study, three established NR algorithms with different basic mechanisms were selected: (1) a statistical model-based log-scaled minimum mean-square error (LogMMSE), (2) a spectrum subtraction-based multi-band spectral subtraction (MBSS), and (3) a Wiener filtering based on a priori SNR estimation (Wiener-as) (Ephraim and Malah, 1984, 1985; Scalart and Filho, 1996; Kamath and Loizou, 2002).

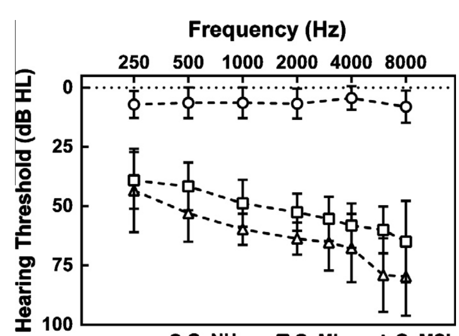

Fig. 1. Hearing thresholds of the participants (average and standard deviation).