Hearing Research 308 (2014) 2–12

Contents lists available at ScienceDirect

Hearing Research

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

Review

Some characteristics of amplified music through hearing aids

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ARTICLE INFO

Article history:
Received 3 December 2012
Received in revised form
24 June 2013
Accepted 1 July 2013
Available online 20 July 2013

ABSTRACT

Hearing aids are a relatively non-invasive means of reducing the negative effects of hearing loss on an individual who does not require a cochlear implant. Music amplified through hearing aids has some interesting characteristics but high fidelity is not typically one of them. This poses a serious problem for the investigator who wants to perform research on music with hearing impaired individuals who wear hearing aids. If the signal at the tympanic membrane is somewhat distorted then this has consequences for the assessment of music processing when examining both the peripheral and the central auditory system. In this review article on the subject of hearing aids and music, some of the acoustical differences between speech and music will be described. Following this, a discussion about what hearing aids do well and also less well for music as an input will be presented. Finally, some recommendations are made about what can be done for hearing-impaired individuals who wear hearing aids to listen to music.

This article is part of a Special Issue entitled <Music: A window into the hearing brain>.

1. Introduction

Sensorineural hearing loss has many negative effects on auditory perception. The result is that hearing-impaired individuals face numerous challenges which include decreased audibility, decreased dynamic range, decreased frequency resolution and decreased temporal resolution (Moore, 1996, 2007). Additionally, they often experience negative social effects such as increased isolation and withdrawal from social situations (Dalton et al., 2003; Strawbridge et al., 2000; Weinstein and Ventry, 1982). Amplification with hearing aids can address many of these concerns and has been shown to reduce the negative effects of hearing loss for those individuals who do not require a cochlear implant (NCOA, 1999; Chisolm et al., 2007; Kochkin, 2011).

Sensorineural hearing loss is most often described in terms of the effects it has on the perception of speech since difficulties with communication are a key reason why many hearing-impaired individuals, or their families, seek amplification or other rehabilitative interventions (Kochkin, 2012; Laplante-Lévesque et al., 2011, 2012). Hearing aids are therefore designed to amplify speech signals well, and this is of primary importance for the manufacturers of these devices. Amplification schemes for hearing aids are derived in terms of both audibility and comfort for speech (Cox and Moore, 1988; Keidser et al., 2011; Moore et al., 2010; Scollie et al., 2005). However, does this focus on speech really reflect the way that all hearing aid users live? There are many hearing aid users and potential users who require their hearing aids to amplify music well regardless of genre (Killion, 2009; Revit, 2009; Rutledge, 2009; Uys and van DijK, 2011; Uys et al., 2012), be they musicians or even enthusiastic concert goers.

Successful listening to music by a person with hearing loss involves many factors, including the nature of the input signal, the hearing aid processing, the signal at the output of the hearing aid, the auditory system (both peripheral and central) and the person's personal attributes such as musical training and experience. The focus of this review is on the music input signal and the hearing aid processing.

When exploring the subject of hearing aids and music it is important to first look at some of the acoustical differences between speech and music. After this, a discussion about what hearing aids do well and also less well for music as an input is necessary. Finally, some improvements and suggestions are made regarding adjusting hearing aids so that they can perform better for the hearing aid wearer when listening to or performing music.

2. Acoustic properties of music versus that of speech

2.1. Sound levels of music

Many hard-of-hearing consumers of hearing aids are requesting, and in some cases, demanding, improved fidelity of amplified music

Abbreviations: A/D, Analog-to-Digital; AGC, Automatic Gain Control; ANSI, American National Standards Institute; dB, Decibel; MPO, Maximum Power Output; msec, millisecond; OSPL90, Output Sound Pressure Level with a 90 dB SPL input; SPL, Sound Pressure Level; WDRC, Wide dynamic range compression

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0378-5955/$ – see front matter
http://dx.doi.org/10.1016/j.heares.2013.07.003

(Chasin, 2003; Revit, 2009). These requests may come from those people who like to listen to music on occasion, or those who actually play music. There may even be an audiological requirement to amplify the softer elements of music, and attenuate the higher levels of music, but in a pattern that amplifies music in a manner which the hard-of-hearing person remembers as being of high fidelity.

Whatever the audiological requirements, the hearing aid fitting goal remains the same: a musical signal that is both audible but not too intense, and one that has sufficient fidelity. This goal is not unlike that for speech, however, with music there are some additional aspects that need to be addressed. These additional requirements are based on the spectral nature of music and how it differs from that of speech.

Table 1 is adapted from Chasin (2006a) and is based on the spectral assessment of the musical instruments from over 1000 musicians. In all cases but one, the level measurements were made from a distance of 3 m on the horizontal plane. The one exceptional case is an additional set of measurements made at the left ear meatal opening for the violin players. In all cases, the average level of the musical instrument is far in excess of that which would be produced during normal conversational speech.

There are two issues that arise when considering the greater spectral levels of music versus those of speech. One is whether the music can produce hearing loss in the same vein as industrial noise can result in hearing loss. Speech – even shouted speech – does not achieve a level that can be damaging to one's own hearing. The same cannot be said of music and many studies have demonstrated the potential for permanent hearing loss from long term exposure (see for example, Axelsson and Lindgren, 1981; Behar et al., 2006; Camp and Horstman, 1991; MacDonald et al., 2008; Phillips and Mace, 2008; Poissant et al., 2012; Royster et al., 1991; Schmidt, 2011). These examples are from classical non-amplified music and the deleterious situation can be further enhanced with amplified music (see for example, Axelsson and Lindgren, 1978; Clark, 1991; Flugrath, 1969; Hart et al., 1987). The situation may be further complicated if the music has significant mid-and-high frequency sound energy. Furthermore, in cases such as playing a violin one ear may be exposed to a different level than the other because of head shadow effects. This may lead to an asymmetrical sensorineural hearing loss with the left ear being worse than the right ear (Schmidt, 2011) and this would be a complicating factor for providing amplification to these individuals via hearing aids.

The second issue related to the higher sound levels of music than speech is the capability of the hearing aid to transduce the higher input levels without significant distortion. As will be discussed in subsequent sections, this has direct ramifications for current hearing aid technology.

2.2. Spectral shape

There are differences in the spectral shape between speech and music that need to be accounted for when comparing these two signals. The spectral properties of speech are typically defined according to the long-term average speech spectrum (LTASS) (Dunn and White, 1940). The LTASS is defined in terms of a sample of natural running speech which contains all of the natural pauses between syllables and sentences. The measurement period of the LTASS is generally accepted as being more than a minute, as defined by Dunn and White (1940) or, more precisely, 64 s by Byrne et al. (1994). The LTASS is well defined and is relatively consistent between languages (Byrne et al., 1994). This is understandable because speakers of all languages have similar vocal tract lengths, similar oral and nasal cavity volumes, and similar mechanical and surface features. There is no inherent reason why a speaker from Japan should have a LTASS that is significantly different than that of a speaker from Peru. There are differing linguistically distinctive (phonemic) characteristics of various languages and these would direct a change in the amplification parameters of speakers of different languages (Chasin, 2012), however the input to a hearing aid microphone would be similar from language to language.

Table 1
Average sound levels of a number of musical instruments measured from 3 m. Also given is the sound level for the violin measured near the left ear of the players. Adapted from Chasin (2006a). Used with permission.

Musical instrument	dBA ranges measured from 3 m
Cello	80–104
Clarinet	68–82
Flute	92–105
Trombone	90–106
Violin	80–90
Violin (near left ear)	85–105
Trumpet	88–108

The spectral shape of the LTASS has a peak in the 500 Hz region and falls off at about 5–6 dB/octave above that. Low frequency sonorants (vowels, nasals, and liquids) have greater sound pressure levels than the higher frequency obstruents (affricates, fricatives, and stop consonants). Again this is true of all languages of the world. In contrast, the spectral shape of music can be similar to the LTASS or it can bear no resemblance. Non-vocal music is not constrained by the mechanical and physical characteristics of the human vocal tract. The shape of a music spectrum can be low-frequency emphasis, high-frequency emphasis, and anything in between. While vocal music has much of its spectral content in the lower and mid-frequencies, percussion instruments would generate primarily mid- to high-frequency energy. There is no single long-term average music spectrum that can be used for hearing aid fitting formulas. Because some sources of music have significant mid to high frequency content, the sound levels that reach each of the musicians' ears can be quite different.

2.3. Crest factor

Another difference between speech and music as an input to a hearing aid is the crest factor of the input signal. The crest factor is the difference between the average or RMS (Root Mean Square) amplitude of the signal and the instantaneous peak of the signal. The crest factor that is commonly used in the hearing aid industry is defined by the American National Standards Institute (ANSI) for testing hearing aids with a broad-band signal (ANSI S3.42, 1992). The studies on the levels of speech, from where the crest factor was derived, used analyses windows of 120 msec (Cox et al., 1988) and 125 msec (Dunn and White, 1940). This makes sense in that the time constants (temporal limitations) of our auditory systems are assumed to be on the order of 125 msec so shorter temporal analysis windows would not make sense.

Although highly modulated compared to steady state noise, human vocalizations are significantly damped within the vocal tract and this is independent of frequency. There are substantial constrictions in the oral and nasal cavities, a narrow opening in the velo-pharyngeal port (connecting the oral and nasal cavities), a significant amount of tissue in the turbinates of the nasal cavity, and soft buccal walls and lingual structures (Johnson, 2003). In short, the human vocal tract is highly damped such that the difference between the RMS of a generated signal and its instantaneous peak is relatively small. In contrast, the output waveform of music is "peakier" relative to speech because of the lower level of damping inherent in most musical instruments, therefore, the crest factor for music can typically be on the order of 16–18 dB whereas that for speech is assumed to be only about 12 dB (Cox et al., 1988).