Loudness Recruitment

What's in a Name?

BY JONATHON P. WHITTON

The exact definition of the term *loudness recruitment* differs among hearing health-care professionals. This is not surprising as the denotation of the term has changed markedly since its origin.

Loudness recruitment is the term that many audiologists currently use to explain the phenomenon of normal or near-normal loudness perception in response to high sensation levels by individuals with sensorineural hearing loss. The implications of this physiologic property are reflected in the treatment of hearing impairment during hearing instrument fitting, one of the most fundamental practices of the field of audiology. However, the exact definition of the term *loudness recruitment* differs among hearing health-care professionals. This is not surprising as the denotation of the term has changed markedly since its origin.

The genesis of this term dates back to 1928 when Fowler first noted equivalent loudness perception at five sensation units in an impaired ear and 10-25 sensation units in a non-impaired ear in the case of a patient with unilateral hearing loss. In 1936, Fowler described such normal loudness perception of high intensity stimuli by individuals with cochlear hearing loss as the "boosting effect." In a later article, he coined the term *loudness recruitment* and put forth the following physiologic model to explain this phenomenon:

> In the cochlea, each nerve fiber comes in contact with a number of cells of the sensory end-organ (the internal and external hair cells), and therefore, even if only a few of these cells are strongly stimulated, the same number of impulses will proceed from the ear with a number of hair cells missing as from the normal ear. (Fowler, 1937a, p. 516)

Fowler then explained a similar process occurring at the synapses between the auditory nerve fibers and the brainstem nuclei. According to this definition, an abnormal growth of loudness occurs near threshold in individuals with sensorineural hearing loss as a result of neuronal "boosting."

The term *loudness recruitment* would seem appropriate for this proposed model; however, the contemporary reader likely realizes that Fowler's physiologic explanation of loudness recruitment pre-dates discoveries in the realm of cochlear anatomy and physiology such as differing physiologic properties of outer and inner hair cells, outer hair cell motility, and the efferent auditory system. In 1970, Spoendlin discovered a disparity between inner and outer hair cell innervation. This anatomical difference between inner hair cells and outer hair cells fostered interest in associated physiological differences between the two cell types (Dallos, 1985 and 1992; Kim 1986). After outer hair cells were shown to possess electromotile properties in vitro, research involving the active properties of the cochlea grew steadily (Brownwell, Bader, Bertrand, and de Ribaupierre, 1985; Dallos, 1992; Zenner, Zimmermann, and Schmitt, 1985). More recently, much attention has been paid to the ability of the efferent auditory system to modulate the function of the peripheral auditory system via direct connectivity to outer hair cells (for review see Sahley, Nodar, and Musiek, 1997).

Fowler's physiologic definition did not involve an active cochlea, differentiation between connectivity and functions of outer and inner hair cells, or the possibility of modulation of the peripheral auditory system by central processes via the efferent auditory system. Furthermore, as sensorineural hearing loss has been shown to create morphological and physiological changes within the central auditory nervous system, the possibility of central involvement (reduction of central inhibition and synaptic gain and/or connection strength) further complicates Fowler's original physiologic definition of loudness recruitment (Hardie and Shepherd, 1999; Heinz, Issa, and Young, 2005). Accordingly, Fowler's physiologic model of loudness recruitment has been abandoned; however, while current research focuses on the loss of compressive characteristics within the cochlea as they relate to loudness recruitment, the basic principle of abnormal loudness growth near an elevated threshold has survived for seven decades.

Oxenham and Bacon (2003) recently reviewed the body of research that supports the loss of cochlear compression as the impetus for a number of impairments associated with sensorineural hearing loss, including loudness recruitment. In this article, the authors attribute the compressive qualities of the cochlea to outer hair cell motility and basilar membrane mechanics. As hearing impairment is generally considered to be the product of a combination of inner and outer hair cell loss, the effects on cochlear compression are variable (for review see Moore, 2007).

A simplified model of the relationship between loss of compressive qualities within the cochlea and loudness recruitment can be described as follows:

> Due to the fact that a portion of the threshold elevation associated with sensorineural hearing loss can be attributed to outer hair cell loss, mechanical gain for low-level tones and cochlear compression are reduced (for review see Moore, 2007).

This results in a more linear response from the cochlea. This is to say that in a normal cochlea soft sounds are amplified (near linear response from basilar membrane) and louder sounds are attenuated, much like a wide dynamic range circuit in a hearing instrument (which is meant to artificially reproduce this property) while a more linear response is produced for all inputs by a

damaged cochlea. Remember that *loudness recruitment* is defined as an abnormal growth of loudness near an elevated threshold, but the response of the basilar-membrane is approximately linear near threshold regardless of whether that threshold is normal or is elevated by a pathologic cochlea (Buus and Florentine, 2001). So insomuch as growth of loudness perception and cochlear compression reflect basilar membrane mechanics, Fowler's classic definition of *loudness recruitment* would seem inappropriate (Buus and Florentine, 2001; Schlauch, Digiovanni, and Ries, 1998; Yates, Winter, and Robertson, 1990).

Using loudness matching tasks between pure tones and four- or 10-tone complexes, Buss and Florentine showed that loudness grows at similar rates near threshold for listeners with cochlear hearing loss and normal hearing sensitivity. This finding raises the following question: How do individuals with sensorineural hearing loss perceive loud sounds normally if loudness judgment does not grow abnormally near an elevated threshold? The answer is that Buus and Florentine additionally demonstrated that loudness at threshold was higher for individuals with hearing loss than those with normal hearing thresholds. In fact, loudness at threshold doubled for every 16 dB of hearing loss. This phenomenon was termed *softness imperception*. Their data showed that *softness imperception* coupled with normal loudness growth near threshold (as opposed to abnormal loudness growth near threshold) can account for the relatively normal perception of very intense stimuli by individuals with elevated thresholds due to sensorineural hearing loss. Incidentally, Fowler also recognized that threshold stimuli were more distinct for individuals with cochlear hearing loss than conductive pathology or normal hearing simply by observing patients as they were undergoing audiometric testing (1928 and 1937b).

Buus and Florentine's model of recruitment as normal loudness growth near an abnormally loud, elevated threshold is consistent with current models of basilar membrane mechanics and basic knowledge of inner and outer hair cell physiology (Buus, Florentine, and Poulsen, 1997; Schlauch, et al, 1998). This physiologic definition has little in common with the original definition of *loudness recruitment* put forth by Fowler in 1937, so the question remains as to whether loudness is in fact recruited. The *Oxford English Dictionary* (1989) lists the first usage of the verb *to recruit* to indicate the action of strengthening or reinforcing (with men or troops). The definition was originally associated with the military but also applies to the various modern employments of the term that typically refers to the enticement of individuals to join an organization for the purpose of strengthening that organization (e.g., college athletics or academics, social clubs, etc.), but also represents the physiologic phenomenon of the involvement of successively more motor neurons (innervating muscle fibers) in response to an unchanging, continuous stimulus. In view of this definition, to say that loudness is recruited in the case of cochlear hearing loss would seem appropriate considering Fowler's original, incorrect physiologic and psychological definitions of the term. However, would another term that reflects current physiological research be more appropriate?

Transparent terminology affords clarity and uniformity to the clinician as well as the student. If in view of the current physiologic models that have been put forth in this article, it cannot accurately be said that loudness is recruited in the case of the pathologic cochlea, a transparent term is needed to reflect the loss of compressive characteristics within the active cochlea that lead to softness imperception and normal or near normal loudness perception at high sensation levels. One solution would be to simply apply the prefix *de* to the already accepted verb *compress*. This prefix when attached to a verb has the function of undoing or reversing the action of the verb (*Oxford University Press*, 1989). The term *decompression* is currently used in the English language to indicate a release of pressure or even stress. The fields of computing and electronics have adopted the term *decompression* to reflect a returning of a compressed file or digital signal data to its original size. *Cochlear decompression* would serve as a transparent term that would reflect the physiologic pathologies associated with the psychological findings of softness imperception and normal or near-normal loudness perception at high sensation levels. However, regardless of the acceptance of the proposed term *cochlear decompression*, current scientific evidence, as presented in this article, argues for the abandonment of the term *loudness recruitment*. **AT**

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