Errata to

Hearing: A 21st Century Paradigm

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Post Publication changes to page xiii

Figure 5.3.4-3 The response of one IHC to a series of tone pulses, missing, from List of Figures

Figure 7.4.4-5 The characteristic impedance and phase velocity along an axon, missing from List of Figures

Post Publication changes to page 4

Section 1.1.4.1 Cheveigne has provided a historical review of many of the concepts still being studied today. An 8-oage variant of the material is available on line at http://audition.ens.fr/adc/pdf/2004_ICA.pdf It draws no conclusions. The longer form will appear inPlack & Oxenham, ed. (2004) Pitch. NY: Springer-Verlag

Post Publication changes to page 27

Figure number should be Figure 2.4.2-1

Post Publication changes to page 41

In Section 2.3.3, second paragraph, change “inner” to “middle” in the first line

Post Publication changes to page 46

The endolymph call on the right in Figure 2.3.4-3 should point to the space between Reissner’s membrane and the basilar membrane as described in the caption.

Post Publication addition to page 61:

2.4.4 The signaling paths of hearing within the CNS (xxx May 2009)

Eggermont & Ponton[1] have described the elements of the hearing modality within the CNS. Their lateral and coronal views of the human brain demonstrate that many of the important CNS elements are not associated with the surface of the cerebral cortex but are buried in deep sulci or located on the insula, an interior element. Their block diagram showing the interconnections of the major processing elements remains incomplete (containing no elements more distal thatn the inferior colliculus and providing no input to the “supra geniculate” and medial pulvinar couple. The supra geniculate nucleus appears to be equivalent to the auditory portion of the perigeniculate nucleus of this work. The perigeniculate nucleus receives signals from the MOC and extracts tonal information that is processed further by the medial pulvinar being passed to their caudal and rostral parabelts located on the superior temporal gyrus of the cerebral cortex.

Many of their signal paths appear to be based on morphology and traffic analysis rather than functional significance.

Post Publication Change to page 109:

Heerens & de Ru have recently printed a 74 page description of “Applying Physics Makes Auditory Sense: A New Paradigm in Hearing” available at http://igitur-archive.library.uu.nl/med/2011-0204-200555/Book%20Heerens%20de%20Ru%20EN.pdf . It remains basilar membrane based but invokes Bernoulli’s Principle and an unsupported “square-law” mechanism. No figures are presented to explain their mathematical solution. They note their application of Bernoulli’s Principle has been disputed by several journal editors. Their application of the general wave equation appears to omit the velocity term. They appear to equate the velocity of an oscillatory transverse acoustic wave to the axial velocity of a compression wave.

Post Publication Change to page 110:

Added a citation to Patuzzi, Chapter 4 in Dallos, Popper & Fay (1996) The Cochlea. Patuzzi gives a comprehensive review of the mathematics of the cochlea under the conventional interpretation of its operation and notes the continued failure of the conventional model to accommodate the Kenp "Echo" and the need to employ separate short wavelength and long wavelength models to interpret the putative propagation of acoustic energy along the BM-scala vestibuli interface. It depends on gravity-type traveling waves but did not explain how hearing can be obtained with a person standing on their head. The figures on page 211 do not form a complete set (no capillary waves) and appear to focus on the wrong portion of the dispersion relationship. His page 212 is less than convincing concerning the stalling of acoustic waves within the cochlea as developed by von Bekesy. It incorporates an "anomalous dispersion" and then uses the word "explain" in quotation marks to introduce the subsequent discussion. His figure 4.8, explaining the stalling, remains entirely in caricature.

While Patuzzi does not cite Lighthill as an expert in "Waves in Fluids," he does cite an easier to read textbook by Main (1993), "Vibrations and Waves in Physics, 3rd Ed." Patuzzi's figures are not found in Main, 2nd Ed. I did not locate the third edition. Patuzzi does not address capillary-type waves. The final comments on page 212 are strange.

Patuzzi does note the "resistive" character of the cochlea input impedance on page 244 and calls it "amazing." This is assured by two mechanisms, the dispersion of energy by the Marcatili Effect and the long delay associated with the Kemp "Echo" caused by any discontinuity prior to energy dispersion from Hensen's stripe.

The equations of Lighthill and of Main only apply to a fluid with a free surface and gravity participating as a restoring force. The equations do not apply to an immersed interface. The actual case of a immersed surface is addressed by Biryukov et al. with significantly different results. See Appendix M. Ghaffari et al. obtained data for a Lamb wave at a surface since gravity does not affect a Lamb wave. They could not measure a Rayleigh wave that was not immersed.

Post Publication Change to page 111:

Mammano & Nobili have presented an undated summary of the historical explanations of the operation of the Organ of Corti and then presented an alternative similar to the 1990's proposals of Neely & Allen at http://147.162.36.50/cochlea/index.htm . The alternative is a floating model. They do not discuss the slow-wave character of the acoustic energy flowing along their basilar membrane, although one of the caricatures suggests it, nor how it is created from the fast-wave structure associated with the compression wave generated in the vestibule of the labyrinth. Their set of web pages related to cochlear mechanics includes the nearly obligatory page in such floating model solutions, the *paradox page* that highlights the inconsistencies of their proposals and the measured performance. It is interesting that although they speak of the Fourier components of the acoustic energy being isolated at different locations along the basilar membrane, and suggest a slow wave structure of acoustic energy transmission along the basilar membrane, they continue to show the round window operating in perfect synchronism with the movements of the oval window (http://147.162.36.50/cochlea/cochleapages/overview/index.htm). Their explanation appears to require the basilar membrane to consist of radial planks tuned to different frequencies with distance along the cochlea but having negligible connectivity between the planks that is necessary to support longitudinal transmission. They do offer a colorized, and possibly more detailed version of Noback, 1967 used as Figure 2.2.3-1, page 37, in this work at http://147.162.36.50/cochlea/cochleapages/overview/index.htm . It shows the position of the cochlear nucleus specifically. See hearing art/mammano_wb_site.wpg

Post Publication Change to page 120:

Added a brief note concerning a loaded interface between a fluid/fluid or fluid/gas interface in acousto-mechanical models leading to surface acoustic waves in the OC. It supports figure 4.1.5-1. While mentioning Patuzzi, I did not add a footnote at this time.

Post Publication Change to page 122 (shown within square brackets):

> Beginning at least with Hunt (1894), the hearing community has conceptualized a slowly propagating acoustic wave associated with the cochlear partition. Wever & Lawrence reviewed these theories in 1954 without introducing any mathematics[2]. Lighthill noted the true slow wave of acoustics became known in hearing as a traveling wave[3]. This occurred in spite of the fact that the pressure wave propagating at the speed of sound in a fluid is also a traveling wave by definition outside the field of hearing. Any solution of the GWE consists of one or more traveling waves[4]. The only propagating (traveling) waves known to exhibit a propagation velocity on the order of six meters per second as measured by Bekesy, [and nearly zero attenuation as measured by Tasaki,] are the surface acoustic waves. The "traveling wave" of hearing research is described here as a surface acoustic wave in accordance with all more recent theoretical texts on acoustic and/or elastic waves. Surface acoustic waves always involve an interface between two materials of different elastic properties.

Post Publication Change to page 124 (shown within square brackets):

> Add a citation to a followup paper to Chadwick et al. by Manoussaki et al. (2008).

Post Publication Change to page 139, adding the description of the cochlea as a dispersive transversal filter

> As shown in figure 4.3.2.2(B), the active part of the cochlea forms a bilateral transversal filter. It is bilateral but not opposed.

In the physical situation, the hair cells are arranged like the toes of a bilateral human. They all point in the same direction.

As also noted in the figure, when unwound, the bilateral transversal filter is not frequency selective. Only when the filter is curved does it become dispersive and thereby frequency selective, based on the Marcatili Effect.

Post Publication Change to page 149, Figure 4.3.3-6

Changed shape of "gel surface" to emphasize the extension of Hensen's stripe below the inner surface of the tectorial membrane into contact with the inner hair cells.

Post Publication Change to page 152 involving the replacement of the earlier paragraph beginning with "Ghaffari. . ."

Research within the cochlea has begun to focus on the tectorial membrane. Ghaffari et al. have recently reported important inforemation concerning the bulk properties of the TM in mice[5]. They demonstrated the ability of the TM to propagate a bulk shear wave at velocities near the Rayleigh velocity proposed in this work. They demonstrated velocities in the 3-7 m/sec range as shown in Figure 4.3.3-8. The figure also shows their bulk shear waves exhibited dispersion on the order of 0.1 m/s/kHz. They also demonstrated the waves could propagate bidirectionally across the bulk TM independent of the microfibril structure defined by Kronester-Frei. The TM shear viscosity encountered by these waves was measured at 0.11 to 0.26 Pa•s (100 to 200 times that of water). They also demonstrated a space constant for the waves of 237 microns. The slow propagation velocity, high viscosity, dispersion and short space constant of the propagating bulk waves demonstrated that the TM was acting as a solid or liquid-crystal and not as a fluid, even though it consists of approximately 95% water.

Even though the measured space constant for the bulk shear wave is much lower than the expected space constant for a surface acoustic wave, it was high enough to cause Ghaffari et al. to make the following statement. "This finding counters a fundamental assumption made in classical cochlear models: that adjacent longitudinal sections of the cochlea are uncoupled."

While addressing a bulk shear wave is not of immediate interest in this theory, it is hoped their research will be continued in order to demonstrate the ability of the same structure to propagate a surface acoustic wave (preferably of the Rayleigh type) with a similar Rayleigh velocity, lower dispersion and a much larger space constant at the TM/endolymph interface. This space constant would be nominally infinite as suggested by the texts of Morse & Ingard and Biryukov et al. cited below (Section 4.4.1.1), and in accordance with the gross measurements of Tasaki in 1952 (Section 9.3.1.3).

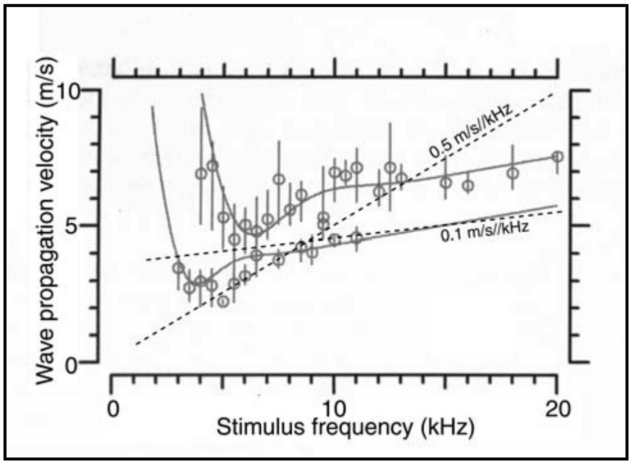

Figure 4.3.3-8 Propagation velocities of Lamb-type traveling waves on the TM of a mouse presumably at room temperature. Upper group, basal region. Lower group apical region. Potential group velocities shown dotted. Modified from Ghaffari et al., 2007.

Post Publication Change to page 154 involving the addition of the line in brackets to the earlier paragraph:

Hashimoto has provided a fundamental tutorial on surface acoustic wave devices[6]. Oliner has provided a much more important and broader book[7]. Datta has also provided an important work for the current purpose[8]. The mathematics in Datta have been limited to simple calculus but the descriptions of phenomena are clear. [Morse & Ingard have addressed surface acoustic waves briefly, by noting their lack of attenuation[9].] Biryukov et al. have provided an extensive mathematical analysis of surface acoustic waves in more complex situations, also noting their lack of attenuation[10].

Post Publication Change to page 168

Added citation to Lyon as a source of studies on multistage RC filters to account for the bandpass characteristics of the cochlea that do not meet the attenuation characteristics measured in the laboratory.

Post Publication changes to page 181

Heading 4.5.4.4, fourth paragraph, should end with, "moved horizontally to overlay the theoretical curve quite well."

Post Publication changes to page 188

Added several citations to recent Finite Element Modeling (FEM) activity that will grow to include the liquid crystalline tectorial membrane surface in the future.

Post Publication changes to page 288

The saggital plan in the figure should be labeled the medial plane

Post Publication changes to page 300

The figure number and call to it on this page should be Figure 7.1.4-1.

Post Publication changes to page 309

The vertical scale label should read "Voltage rel. to quiescent level, mV"

Post Publication changes to pages 335 & 337

The value of 0.19 msec on these pages should be 0.019 msec. The calculations based on this number leading to a avg velocity of 44. m/sec. are correct.

Post Publication changes to pages 386, 2nd paragraph, next to last line

The line should read, "The right side shows only the two nerves emanating . . . "

1. Eggermont, J. & Ponton, C. (2002) The Neurophysiology of Auditory Perception: From Single Units to Evoked Potentials *Audiol Neurootol* 2002;7:71–99

2. Wever, E. & Lawrence, M. (1954) Physiological Acoustics. Princeton, NJ: Princeton Univ Press pp 248-293

3. Lighthill, M. J. (1981). "Energy flow in the cochlea," *J. Fluid Mech.* 106, 149-213.

4. Kraus, J. (1953) Electromagnetics. NY: McGraw-Hill pp 347-358

5. Ghaffari, R. Aranyosi, A. & Freeman, D. (2007) Longitudinally propagating traveling waves onf the mammalian tectorial membrane *PNAS*, vol 41, pp 16510-16515

6. Hashimoto, K-Y. (2000) Surface Acoustic Wave Devices in Telecommunications. NY: Springer

7. Oliner, A. ed. (1978) Acoustic Surface Waves. NY: Springer-Verlag.

8. Datta, S. (1986) Surface Acoustic Wave Devices. Englewood Cliffs, NJ: Prentice-Hall

9. Morse, P. & Ingard, K. (1986) Theoretical Acoustics. Princeton University Press pp 624-627 634 & 641

10. Biryukov, S. Gulyaev, Y. Krylov, V. & Plessky, V. (1995) Surface Acoustic Waves in Inhomogeneous Media. NY: Springer-Verlag