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# Tuning and sensitivity of the human vestibular system to low-frequency vibration

Neil P. McAngus Todd<sup>a,\*</sup>, Sally M. Rosengren<sup>b</sup>, James G. Colebatch<sup>b</sup>

<sup>a</sup> Faculty of Life Science, Jacksons Mill, University of Manchester, Manchester M60 1QD, UK

<sup>b</sup> Prince of Wales Clinical School and Medical Research Institute, University of New South Wales, Randwick, Sydney, NSW 2031, Australia

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## ABSTRACT

Mechanoreceptive hair-cells of the vertebrate inner ear have a remarkable sensitivity to displacement, whether excited by sound, whole-body acceleration or substrate-borne vibration. In response to seismic or substrate-borne vibration, thresholds for vestibular afferent fibre activation have been reported in anamniotes (fish and frogs) in the range  $-120$  to  $-90$  dB re 1 g. In this article, we demonstrate for the first time that the human vestibular system is also extremely sensitive to low-frequency and infrasound vibrations by making use of a new technique for measuring vestibular activation, via the vestibulo-ocular reflex (VOR). We found a highly tuned response to whole-head vibration in the transmastoid plane with a best frequency of about 100 Hz. At the best frequency we obtained VOR responses at intensities of less than  $-70$  dB re 1 g, which was 15 dB lower than the threshold of hearing for bone-conducted sound in humans at this frequency. Given the likely synaptic attenuation of the VOR pathway, human receptor sensitivity is probably an order of magnitude lower, thus approaching the seismic sensitivity of the frog ear. These results extend our knowledge of vibration-sensitivity of vestibular afferents but also are remarkable as they indicate that the seismic sensitivity of the human vestibular system exceeds that of the cochlea for low-frequencies.

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The middle organs, the saccule, utricle and selenia, primarily respond to whole-body acceleration or tilt in gravity [1]. In fish, there are also important auditory structures for acoustic near field (particle motion) sensing [1,2]. Several studies have determined behavioural particle motion thresholds for non-species-specific fish, e.g. the cod, plaice and dab [3]. These have indicated that the maximal best sensitivity lies between 30 and 120 Hz, with threshold acceleration values of about  $-120$  dB re 1 g at 80 Hz. During the course of evolution the amniote ear developed the structures for far-field (sound pressure) hearing in air, including the basilar papilla and the mammalian cochlea [4].

It has been established, however, that the middle organs in terrestrial vertebrates have conserved a particular sensitivity to substrate- or bone-conducted sound [2,15,16,22] consistent with their function as near-field sound sensors in fish [5]. In some species of frog the saccule shows a fish-like band-pass response to a displacement with best frequencies between 20 and 100 Hz and thresholds between  $-90$  and  $-120$  dB re 1 g, while others show a low-pass response with best frequencies at 10–20 Hz [16]. Sensitivity to audio-frequency vibration has also been demonstrated in many mammalian species. In the monkey [27], best frequencies were

between 125 and 177 Hz with phase locking threshold as low as  $-30$  dB re 1 g, and in the guinea-pig at 50 Hz thresholds were 10 dB above the ABR threshold [23]. At present, however, no such threshold measurements have been obtained for the human vestibular system and this was the aim of our study.

Non-invasive assessment of human vestibular sensitivity can be accomplished by measurement of the powerful vestibulo-ocular reflex (VOR) to head acceleration. The VOR normally serves to maintain eye gaze with head tilt or rotation and its main effects are mediated by a simple reflex: neurons are connecting the vestibular portion of the eighth nerve to the motor neurones of the extraocular muscles [1]. In response to stimuli such as head movements, reflex activity occurs in the extraocular muscles, producing a compensatory eye movement. By placing surface electrodes around the eyes, synchronous muscle activity can be recorded in the form of ocular vestibular evoked myogenic potentials (OVEMPs) [24]. These responses are vestibular rather than cochlear in origin as they are present in deaf patients but are absent in patients with loss of vestibular function [18,24]. We aimed to measure the tuning and sensitivity of OVEMPs to whole head vibration in the transmastoid plane.

Four volunteers (2 females and 2 males between 17 and 32 years of age) with no auditory or vestibular deficits were stimulated using sinusoidal accelerations between 12.5 and 800 Hz (1/5, 1/3, 1/2, 100, 200, 300 and 800 Hz). The subjects were seated

\* Corresponding author. Tel.: +44 161 306 5770; fax: +44 161 306 3887. E-mail address: neil.todd@manchester.ac.uk (N.P.M. Todd).

In an article titled "Tuning and sensitivity of the human vestibular system to low-frequency vibration,"<sup>1</sup> three British scientists have demonstrated that the inner ear is "extremely sensitive" to extremely low levels of low frequency noise, indeed "approaching the seismic sensitivity of the frog ear." They go on to wonder about the "behavioral consequences" of such sensitivity—a degree of sensitivity, they make clear, that is found even in normal human subjects.

This is precisely what Nina Pierpont has been talking about. This new research offers substantial support for her claim that a *perturbed vestibular apparatus* is one of the keys to explaining Wind Turbine Syndrome.

"Mechanoreceptive hair-cells of the vertebrate inner ear have a remarkable sensitivity to displacement, whether excited by *sound, whole-body acceleration or substrate-borne vibration*....In this article we demonstrate for the first time that the human vestibular system [inner ear] is ... extremely sensitive to low-frequency and infrasound vibrations." "Human [inner ear] receptor sensitivity is probably ... approaching the seismic sensitivity of the frog ear" (emphasis added, Abstract).

"The very low [noise] thresholds we found are remarkable as they suggest that humans possess a frog- or fish-like sensory mechanism which appears to exceed the cochlea for detection of substrate-borne low-frequency vibration and which until now has not been properly recognised.... A fundamental question is also raised as to the possible behavioral consequences ... such a mechanism may have" (p. 41).