# OVERCOMPRESSED SOUND, A NEW AUDITORY RISK AND A WINDOW ON NEW PATHOPHYSIOLOGICAL MECHANISMS

**Thamara dos Santos**[1,2], **Christian Hugonnet**[3], **Paul Avan**[1, 4*]
[1] Neurosensory biophysics, Université Clermont Auvergne, France
[2] Audiology, UFMG, Belo Horizonte, Brazil
[3] Association La Semaine du Son, Paris, France
[4] Institut de l'Audition, Institut Pasteur, Paris, France

**ABSTRACT**

Current standards for the prevention of hazard due to sound overexposure apply the isoenergy rule according to which the risk to hearing is determined by the total amount of sound energy. New sound processing methods allow sound manipulations that lead to deeply unusual situations. The best example is offered by over-compression of the dynamic range that erases even the shortest silent intervals of a sound file. Over-compressed sound dynamics protocols are extensively used by radio stations, music providers and videoconference platforms. The present experiment tested awake guinea pigs, with an audible frequency range approaching that of humans, exposed to natural or over-compressed music for 4 hours at the same doses close to the legal ceiling. Otoacoustic emissions and stapedius-reflex tests were performed before and just after exposure, then 1, 2 and 7 days after exposure. No significant change in cochlear sensitivity occurred. In contrast, after exposure to over-compressed but not natural music, the stapedius-muscle reflex lost half its effectiveness for a week. The stapedius reflex may signal failure of auditory brainstem circuits yet to be identified. This is the first evidence of the importance of short silent windows whose quantitative evaluation is under way. Funding: Fondation Ecouter-Voir AP-VIS-19-001.

**Keywords:** *compressed sound, auditory hazard, sound overexposure.*

[*] ***Corresponding author***: paul.avan@uca.fr.



## 1. INTRODUCTION

Music to which strong dynamic intensity compression has been applied remains perfectly identifiable but deprived of nuances. This aspect could be minor for a main objective of intensity compression, which is to allow sound broadcast in noisy places to always dominate competing sounds. Nonetheless, listeners increasingly complain of a subjective impression of increased fatigue. To determine whether these complaints are purely qualitative or highlight particular physiological aspects, and above all a particular hearing hazard, a specific study was carried out to compare the effects on hearing of a single intense exposure to the same music (pop/soul style) in an original vs. overcompressed version. To avoid any risk related to possible toxicity, with reference to the discovery of hidden hearing damage (hidden, that is, not detectable by noninvasive standard audiological means, yet revealed by postmortem microscopy) to laboratory animals after a single exposure of 2 hours around 100 dB and a permanent loss of synapses [1], we chose to work on an animal model, i.e., the guinea pig that shares with humans its frequency range of best hearing sensitivity and that easily accepts auditory tests while awake. This eliminates any interference from anesthesia or strict restraint, confounding factors for fatigue measurements.

## 2. METHODS

### 2.1 Acoustic characteristics

The guinea pigs, once accustomed, were placed in pairs in a cage with wide-mesh walls to influence the spatial distribution of the acoustic levels as little as possible. The cage itself was placed in a small soundproof enclosure,

itself in an anechoic cabin 2.5 x 2.5 m wide. In the small enclosure, two loudspeakers (alpha 80 Focal®) connected to the sound card of a computer broadcast the music at the chosen average level, 40 cm from the cage. Sound level was calibrated using a 2250 Light - Brüel & Kjær® sound level meter placed next to the cage, after checking that the level inside the cage was uniform to within < 1.5 dB. The original, uncompressed and overcompressed versions were adjusted so that the average level measured by 15-minute sequences was in both cases 102 dBA, not exceeding 118 dBC, in accordance with the current limits in France for concert halls (decree 2017-1244).
The chosen music was song 'I miss you', by Adele, 4.5 minutes played in a loop without any break for 4 hours at constant average level. The various spectral bands of the song all contained a high energy: there was no band in which temporary pauses would be provided.

### 2.2 Auditory monitoring

Auditory tests were performed in awake animals before, just after a single 4-h music exposure, then 1, 2 and 7 days later. Objective testing probed the cochlea, using distortion-product otoacoustic emissions (DPOAEs) [2] and the neural loop of the stapedius muscle reflex, triggered by a brief broadband noise applied in the left ear while the DPOAEs in the right ear served as a marker of sound transfer function through the stapes ossicle.
When the stapedius muscle undergoes a reflex contraction, the DPOAE elicited at 2 x 6.6 – 8 = 5.2 kHz by a pair of pure-tone stimuli at 8 and 6.6 kHz is phase shifted in proportion to the reflex strength [3].
The decrease in DPOAE levels at frequencies between 2 and 20 kHz and the percentage of reflex strength with reference to the strength before music exposure served as markers of cochlear and neural reflex fatigue, respectively. The time course of these markers were compared in samples exposed to original and overcompressed songs.

## 3. RESULTS

### 3.1 Cochlear status

After exposure, the DPOAE thresholds measured at days 1, 2 and 7 after the single exposure session were normal, whereas those measured just at the end of exposure could be elevated, by 10 to 15 dB at 2 kHz and slightly more than 5 dB at 3 kHz, for animals exposed to the original music. Threshold elevation might reach 20 dB at these two frequencies in the overcompressed music sample. Above 3 kHz, which corresponds to the most sensitive part of the human and guinea pig cochleae, neither type of exposure had any effect, even immediate.

### 3.2 Stapedius reflex strength

The effects of stapedius-muscle contraction were most robust for contralateral noise set at 70 dB SPL. This level allowed a clear activation of the reflex, well above its threshold, in all ears. Immediately after exposure, regardless of the type of music, the average strength of the reflex was reduced to about 40% of its pre-exposure reference value. At 24 hours and later, the behavior of the stapedius reflex differed completely according to the type of music. For the original music, the recovery was almost total at 24 hours with a reflex close to 100% of its initial strength, maintained at 48 hours and after 7 days.
In sharp contrast, for overcompressed music, the average strength of the reflex, also around 40% of its pre-exposure value just after the end of exposure, remained at this level after 24 hours, and hardly changed even after one week. A control sample of unexposed, repeatedly tested animals showed perfect stability of the reflex strength.
Two-way ANOVA on repeated measurements (with type of music and time as factors) showed a highly significant difference among samples ($p<0.001$, $F=16.41$; $n = 6$, 14 and 11, in control, original and overcompressed samples respectively), driven by the protracted loss in reflex strength of the overcompressed-music group.

## 4. DISCUSSION

This experimental work designed for establishing a proof of concept led to two results, with regard to a single 4-hour exposure to music in accordance with French decree 2017-1244 whose goal is the auditory protection of the public exposed to amplified sounds at high sound levels in concert halls. Here, no exposure exceeded the equivalent continuous levels of 102 dBA and 118 dBC over 15-minute intervals. The first result is comforting in that such an exposure had no cochlear effect apart from an immediate one just at the end of the exposure session.
The second finding is that despite a level exactly matching that of original music, overcompressed music, induced a protracted fatigue of the strength of the stapedius reflex, a marker of one of the multiple circuits of the auditory brainstem activated by sound exposure. The isoenergy rule used by regulatory texts to set an upper exposure limit is therefore at fault in a situation which admittedly differs from natural occupational noise for which this rule was designed. When sound is digitally processed so that its

microstructure eliminates any pause during which competing sounds might mask the sound of interest.

The idea that the isoenergy rule may not cover all situations, and in particular exposure to intense sounds with skewed statistical distribution of intensities, has been raised for several decades, in particular to better manage the risks associated with impact noise from high peak intensity. The case treated here corresponds to the reverse situation when intensities are always kept near the maximum allowed by an electroacoustic system.

Up until now, most of the studies addressing these atypical aspects of intense sound were based on the evaluation of the permanent elevations of auditory-sensitivity thresholds and the losses in cochlear sensory cells as a benchmark. Thus, they did not take into account the new data mentioned in the introduction that relate to hidden hearing damage, which by definition cannot be described by these indicators.

Some authors have recommended the use of the stapedius reflex to access the function of one neuronal auditory pathway, rather than the cochlea as assessed by permanent elevations of hearing thresholds. This work led the Institut National de Recherche sur la Sécurité (INRS, Nancy, France) to develop the patented EchoScan test based on the use of DPOAEs to detect changes in the strength of the stapedius reflex induced by exposure to intense sound during a day of work [4]. The present work proposes an extension of this method to the exploration of the effects of overcompressed amplified music.

Incidentally, the discovery of a prolonged impairment of the stapedius reflex one week after a single exposure raises a question of terminology: can such a protracted impairment be considered as fatigue? And does this fatigue affect only the stapedius reflex loop or other auditory circuits? The current study monitored the stapedius loop for one practical reason, the ease with which this monitoring can be achieved in guinea pigs. This choice is suitable for a proof of concept, but not for a comprehensive study of the potentially harmful effect of compressed sound on auditory function. It is widely thought that the stapedius reflex mainly acts as a protective device against sound overexposure, a function that the auditory system may not critically need for everyday life.

In conclusion, the present work leads to a series of as yet unaddressed issues that should kindle further studies. One of them pertains to the mechanism at play in 'fatigued' auditory neurons. These neurons have particularly intense energetic needs due to their extremely high rate of activity. They can deliver several hundred action potentials per second, thus at a rate more than ten times higher than neurons coding for other sensory or motor modalities. It might be that the filling-in effect associated with compression and the attending suppression of silent parts threatens the mechanisms that allow auditory neurons to attend to their metabolic needs during pauses in their activity. The second question is whether the fatiguing effect of overcompressed sound extends to sound (not only music) exposures at less than 102 dBA. Most videoconference platforms currently make abundant use of compressed dynamics of intensity, for sound levels often set by users between 75 and 80 dBA. Their growing importance by students and many professionals means that more attention should be paid to the specific auditory risks that they may experience, not taken into account by current standards.

## 5. REFERENCES


[1] Kujawa SG, Liberman MC. Synaptopathy in the noise-exposed and aging cochlea: Primary neural degeneration in acquired sensorineural hearing loss. *Hear Res* **2015**, *330*, 191-199.

[2] Avan P, Buki B, Petit C. Auditory distortions: origins and functions. *Physiol Rev* **2013**, *93*, 1563-1619.

[3] Avan P, Buki B, Maat B, Dordain M, Wit HP. Middle ear influence on otoacoustic emissions. I: noninvasive investigation of the human transmission apparatus and comparison with model results. *Hear Res* **2000**, *140*, 189-201.

[4] Venet T, Campo P, Rumeau C, Eluecque H, Parietti-Winkler C. EchoScan: a new system to objectively assess peripheral hearing disorders. *Noise Health* **2012**, *14*, 253-259.