Changes in clinical and instrumental vestibular parameters following acute exposition to auditory stress

Valutazione di parametri clinici e strumentali vestibolari in seguito ad esposizione acuta a stress uditivo

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Key words

Tullio's phenomenon • Vestibular function • Saccular activation • VEMPs • Sound hypersensitivity • Acoustic stress

Parole chiave

Fenomeno di Tullio • Funzione vestibolare • Attivazione sacculare • VEMPs • Ipersensibilità al suono • Stress acustico

Summary

Besides Tullio's phenomenon, resulting from anatomic changes in the labyrinth, a hypersensitivity to acoustic stimuli of the saccular structures appears to be the underlying cause of the vestibular responses detected in some patients. In order to evaluate the incidence of vestibular symptoms triggered by acute exposure to auditory stress (disco music), 40 subjects aged between 18 and 26 years, with no audiological and vestibular disorders, were submitted to otoneurologic tests. Subjects were exposed to disco music [intensity 128 dB (C)], for 3 hours. Tests have been carried out before and immediately after exposure. Canalar and macular functions have been evaluated using vestibular investigation techniques and vestibular evoked myogenic potentials. When compared to baseline data, post-exposure test results did not reveal any canalar damage. Pre- and post-exposure recordings of the vestibular-oculomotor reflex threshold have shown no significant changes. Conversely, post-stimulus recordings have shown a significant increase in the amplitude of the vestibular evoked myogenic potential response, thus indicating a possible irritative involvement of the macular receptor. This result suggests a direct action upon the receptor by acoustic stimulation which could, therefore, be the underlying cause of vestibular symptoms reported by patients following exposure to sufficiently intense acoustic stimuli. Prior to this study, a questionnaire concerning the relationship between habitual disco visiting and audio-vestibular symptoms has been completed by 310 students at the University of Catanzaro. This survey revealed a significant incidence of vestibular symptoms due to acoustic stress (Tullio's phenomenon) which led us to hypothesise that balance disorders due to auditory stress are much more frequent than commonly held, particularly since, in many cases, diagnoses is unknown or not easy due to the difficult procedures by which these conditions are diagnosed.

Riassunto

Al di là del fenomeno di Tullio basato su alterazioni anatomiche del labirinto, una particolare sensibilità delle strutture sacculari agli stimoli acustici sembra essere alla base delle risposte di tipo vestibolare che si osservano in alcuni pazienti. Per valutare l'incidenza di sintomi riferibili ad interessamento vestibolare in seguito ad esposizione acuta a stress uditivo (musica da discoteca) sono stati esaminati con una batteria di test otoneurologici 40 soggetti di età compresa tra i 18 e i 26 anni, esenti da problematiche di tipo audiologico e vestibolare. I soggetti sono stati esposti a musica, in discoteca, per tre ore, a un'intensità di 128 dB(C). I controlli sono stati effettuati prima e subito dopo l'esposizione. Allo scopo di indagare oltre che la funzione canalare anche quella maculare sono state utilizzate tecniche di esplorazione vestibolare e la registrazione dei potenziati evocati vestibolari miogenici. I risultati degli esami da noi effettuati post-esposizione rispetto ai dati rilevati in condizioni di base indirizzavano verso una sostanziale indennità canalare. Lo studio della soglia del riflesso vestibolo-oculomotore, registrata pre- e post-esposizione, non rivela variazioni significative. È stato invece individuato un significativo incremento dei valori di ampiezza della risposta ai potenziati evocati vestibolari miogenici nelle registrazioni post-stimolo che segnala un verosimile coinvolgimento di tipo irritativo del recettore maculare. Il dato è suggestivo di un'azione diretta sul recettore da parte della esposizione a stimoli sonori di entità sufficiente. In una fase precedente a questo studio era stato somministrato un questionario di valutazione delle relazioni tra frequentazione di discoteche e sintomi audio-vestibolari a 310 studenti della nostra Università. Tale indagine ha rilevato una significativa incidenza di sintomi riferibili ad interessamento vestibolare da stress acustico (fenomeno di Tullio) che ci ha consentito di ipotizzare che i disturbi dell'equilibrio in conseguenza a stress uditivo abbiano un'incidenza più rilevante di quanto venga ritenuto comunemente, soprattutto in relazione al fatto che la loro diagnosi è, in molti casi, misconosciuta o, comunque, difficoltosa a causa dell'indaginosità delle procedure diagnostiche capaci di individuarli.

Introduction

It is now known that appropriate audible vibrating energy is able to activate the vestibular system. This phenomenon, known as Tullio phenomenon, consists in the onset of vestibular signs and symptoms in response to a sufficiently intense auditory stimulus [1]. Patients presenting Tullio phenomenon report oscillopsia or lack of balance if exposed to acoustic stimuli (even if not particularly intense) such as city noise or, sometimes, their own voice. Healthy patients, instead, show vestibular signs and symptoms only if exposed to excessive sound energy. According to the various aetiopathogenetic hypotheses formulated, Tullio phenomenon is associated with the following disorders: superior semicircular canal dehiscence or other anatomic changes in the temporal bone [2], congenital infections [3], congenital hearing loss, direct vestibular trauma during otosurgery or endolymphatic hydrops, cholesteatoma associated with erosion of the bony wall of one of the semicircular canals. Backous et al. [5] and, even earlier, Anson et al. [6] specified the values of the distance between the stapes footplate and the utricle and saccule. The shortest distance (mean) between the stapes footplate and the utricle has been estimated to be 0.58±0.10 mm, at the posterior third of the oval window. When measured at the front third, this value reaches 1.51±0.20 mm. The distance between the stapes footplate and the saccule varies from 1.31±0.18 mm, if measured at the front third of the oval window, to 1.33±0.20 mm, if measured at the middle third. Moreover, these same Authors reported the presence of membranous connections between the utricle and the footplate in 26% of the patients examined. These structures, whether coexisting or not with other anatomic factors such as footplate hypermobility and/or bony labyrinth dehiscence, could be the predisposing factor to otolithic activation following sound and/or pressure stimulation.

Parker [7] reported the onset of nystagmus following exposure to pure tones within the range of 200-2500 Hz, at an intensity of 120-160 dB SPL. The onset of vestibular responses depends solely upon the integrity of the posterior labyrinth structures and indeed can be reproduced in animals following cochlear ablation. Colebatch et al. [8] report a decrease in the activation threshold of the vestibulo ocular reflex following acoustic click stimulation, in patients with Tullio phenomenon.

The present study on a group of normal volunteers with a negative otoneurologic history aimed at evaluating, by means of clinical instrumental tests, the incidence of objective vestibular signs following acute exposure to auditory stress caused by disco music.

At the same time, a large group of students at the University of Catanzaro were invited to answer a questionnaire in order to investigate the incidence of symptoms possibly related to frequency of exposure to disco music.

Patients and methods

A total of 40 volunteers (32 females, 8 males, age range 18 to 26 years) with a negative otoneurologic and drug history were enrolled in the study. These subjects have been exposed to disco music for 3 hours, at an intensity ranging from 110 dB (mean) (C), in the middle of the dance floor, to 128 dB (peak), near the loudspeakers. All subjects had been told to abstain from alcohol and other substances. The study protocol included: medical history, otolaryngological examination, tonal audiometry, timpanometry, videonystagmography (VNG), vestibular tests and vestibular evoked myogenic potential (VEMP) recording. Tests have been carried out before and immediately after exposure Vestibular function has been studied by detecting spontaneous and provoked nystagmus by means of position and positioning manoeuvres (Pagnini McClure, Dix Hallpike) and by evaluating the threshold of the vestibulo-oculomotor reflex (VOR) elicited by a growing-amplitude (max 30°) and 20''-steady-period sinusoidal stimulation. Kinetic tests have been carried out using a VNG Ulmer® system. Saccadic and smooth pursuit eye movements and posture have been evaluated by means of non instrumental tests (Romberg test, Tandem Romberg, Fukuda stepping test).

VEMPs have been recorded in an Amplaid MK 12-hyposonorised environment with the patient lying supine, head rotated contralaterally to the acoustic stimulus, and by using disposable, electroencephalogram (EEG)-like, self-adhesive surface electrodes. Electrodes were located at the medium third of the sternocleidomastoid (SCM) muscle (negative) half way along the clavicular body (positive) and in the middle of the episternum (ground). Monoaural stimulation was induced using a 500 Hz positive logon, with a 10 dB-step-decreasing intensity, from 120 dB SPL pe to threshold, and a 4 Hz rate. Recording has been carried out with the following parameters: 200 sweep acquisition, 100 ms-window, filter extension from 10 to 200 Hz and a 25 μV/div-amplitude scale.

TTS was evaluated by determining the tonal audiometric threshold in a noiseless environment immediately after exposure, with intensity decreasing at a rate of 1 dB.

The questionnaire, aimed at evaluating the correlation between habitual discofrequentation and audio-vestibular symptoms, has been submitted to 310 University students (aged 18-26 years), 214 of whom have been selected due to the presence of one or more of the following signs: audio-vestibular symptoms (vertigo, instability, oscillopsia, confusion, tinnitus, bilateral perceptive hearing loss at 4 and/or 6 kHz = 20 dB), neuro-vegetative symptoms and habitual disco frequentation.

Results

Spontaneous and elicited nystagmus evaluation as well as eye movement examination failed to reveal any significant changes. Romberg static posture test has revealed the onset of well balanced multidirectional oscillations in 64% of subjects. A drastic increase in the percentage of subjects having difficulty in performing the test was observed when the "tandem" test, was carried out with 87% of subjects tending to fall within the first 10''. Evaluation of dynamic posture by means of the Fukuda test showed comparable results even if greater difficulty was encountered in carrying out the test.

Detection of the mean threshold of VOR appearance (Table I) shows no statistically significant changes vs pre-exposure values (r=–0.117, p=0.85). Likewise, analysis of the VEMPs response threshold shows little change following exposure to noise. Indeed, this value remained at about 100 dB SPL pe in almost the entire study population. The study of VEMPs latency parameters also failed to offer any significant data (Fig. 1). As far as concerns the amplitude of the P1-N1 complex, a statistically significant increase has been observed post-exposure, particularly at stimulation of suprathreshold intensity (at 120 dB SPL pe r=0.98, p=0.0026; at 110 dB SPL pe r=0.96, p=0.007) (Fig. 2). In 8 of the 40 subjects examined, a direct correlation was found between a higher increase in VEMPs amplitude and a greater intensity of the symptoms reported. Tonal threshold variations following exposure appear to be quite limited, without exceeding 14 dB at frequencies from 3 to 8 kHz. The most significant changes affect the right ear.

Replies to the questionnaire showed that 194 of the 214 subjects selected habitually went to discos. Of these, 42 reported only hearing loss, while 41 reported at least one of the vestibular symptoms (21 of whom reported both vestibular symptoms and hearing loss). This result has shown a significant incidence of vestibular symptoms due to acoustic stress. Out of the 24 students who did not habitually go to discos, 11 reported only hearing loss and 9 reported at least one vestibular symptom (5 of whom both vestibular symptoms and hearing loss) (Fig. 3).

Table I. Mean (±SD threshold) vestibulo-oculomotor reflex.

	PRE (°/sec)	POST (°/sec)
Left ear	8.78 (2.03)	9.42 (1.85)
Right ear	10.96 (0.9)	10.78 (1.04)

Discussion

As shown by preliminary studies appearing in the literature [8] and by our questionnaire evaluation, the percentage of symptoms involving the vestibular system following acoustic stress, is significant.

Tullio phenomenon, based upon the presence of con-

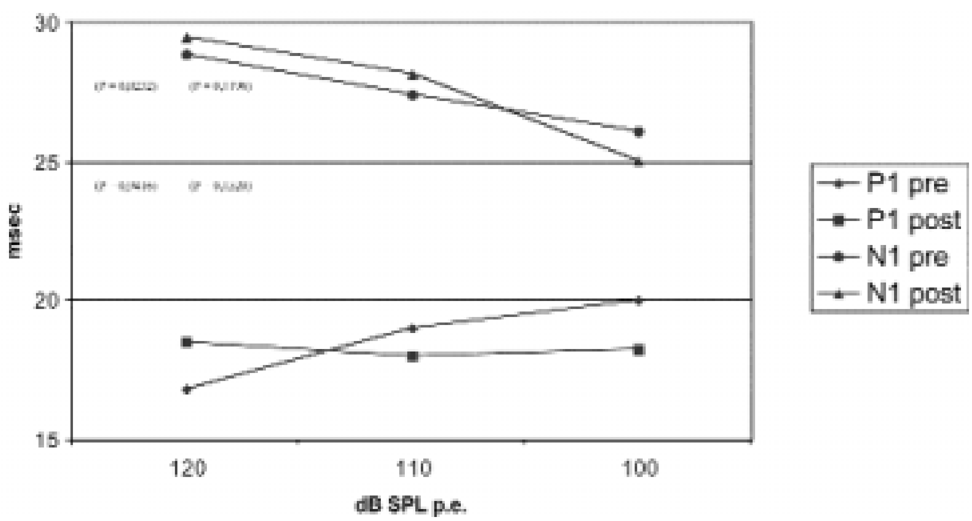

Fig. 1. Pre- and post-exposure to-noise. Mean latency values of the two main VEMP components.

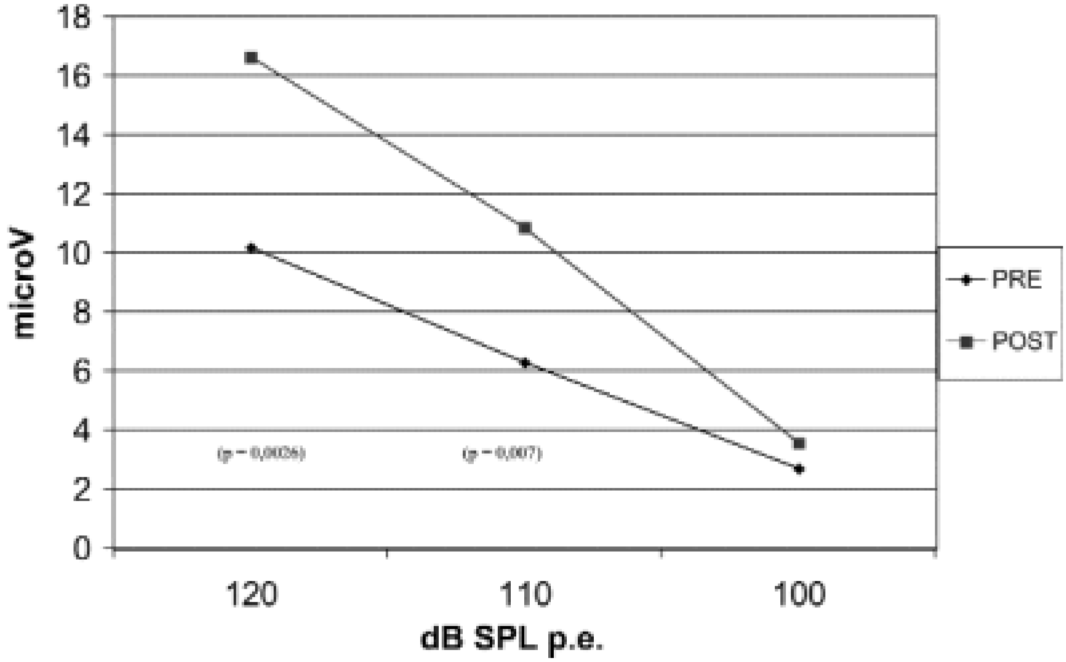

Fig. 2. Mean peak-to-peak values related to VEMP PI-NI complex.

genital or acquired anatomic abnormalities in the temporal bone [12], explains only limited percentage of cases. Also Backous [5] hypothesis, referring to the role played by hypermobility of the stapes within the oval window explains a further small percentage of cases. Of interest are data suggesting the existence of connective structures between the utricle and the stapes footplate and demonstrating the anatomic contiguity between footplate and macular structures. Even if controversial [10 11], this finding could explain the response of vestibular structures to acoustic stimuli, given the extreme proximity of the entrance point to the sound energy.

Furthermore, data reported in the literature show the true acoustic function of the macular receptors [13-15] and much evidence exists supporting this theory. Firstly, the common embryological origin of the cochlea and sacculus [16], the latter representing, moreover, a real auditory receptor, in the lower species [17]. Murofushi et al. [18] showed that some neurons of the

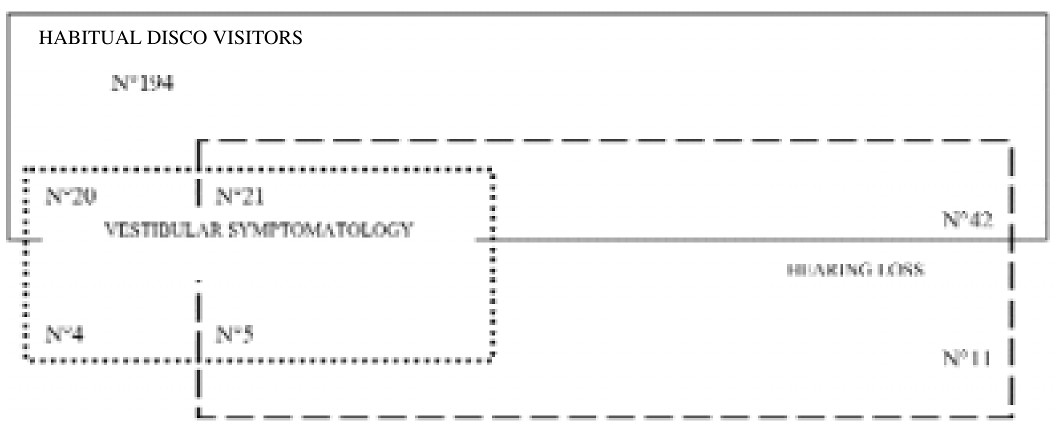

Fig. 3. Questionnaire: Individual symptomatology related to habitually frequenting discos.

vestibular nuclei and some primary vestibular afferent fibres, in guinea pigs and cats, are sensitive to intense sound. Finally, studies on VEMPs show the presence of the P1-N1 complex in patients with deep perceptive hearing loss and normal vestibular function. Conversely, in patients with normal hearing showing a highly reduced or absent vestibular reflexivity, the P1-N1 complex is not present [18-20].
Saccular activation following sufficiently intense acoustic stimuli is constantly detected. The presence of Tullio phenomenon, instead, is seen as hypersensitivity of the macular structures to sound energy resulting in a decrease in the stimulation threshold, i.e., the need for a lower quantity of sound energy in order to obtain a vestibular response following auditory stimulation [8 21]. The role this hypersensitivity to acoustic stimuli plays in the origin of vestibular symptoms is not yet clear. Also in this case, saccular involvement is not excluded by the presence of eye movements which could be related to the stimulation of the anterior semicircular canal (ASC) since studies on animals showed the presence of similar eye responses after ASC and otolith stimulation [22-24]. Oscillopsia is probably related to activation of saccular projections towards eye muscles [23 25].
Objectification of the above-mentioned symptoms still remains quite difficult since the possibility of exploring the vestibular system is limited, particularly the macular region. In this regard, the introduction of VEMPs, in clinical practice, has been particularly useful.
Analysis of the data obtained failed to reveal any apparent canalar involvement, as indicated by the onset of the VOR threshold which remains almost unchanged following exposure to the sound stimulus. Results of the static posture test revealed the presence of alterations in a percentage of patients varying from 64% (Romberg Test) to 87% (Tandem Romberg). This finding as in agreement with the results obtained by Russolo [21] with reference to postural responses following highly intense sound stimuli, even if not reproducing the side selectivity because of the type of stimulus. These postural changes may be related to the activation of macular receptors in response, to the intensity of the sound stimulus to which patients were submitted and, may, also in our opinion, be regarded as a true physiological Tullio phenomenon [21].
Data related to the VEMP recordings are the most interesting aspect emerging from the analysis. The latency parameter test does not show any significant change: it appears to be unsteady and cannot be supported from a statistical point of view. Similarly, concerning the threshold of the onset of the VEMPs response no difference is observed between pre- and post-stimulus recordings.
Conversely, the analysis of the amplitude parameter of the post-exposure response, showing a significant increase in the suprathreshold stimulation intensity, suggests a direct and irritative action of the sound stimulus upon the macular receptors. It is, therefore, feasible to assume, in our opinion, that, in the presence of an almost steady involvement of the macular function following acoustic stress, hypersensitive individuals can develop an irritative response leading to the appearance of vestibular symptoms. The mechanism triggering this symptomatology is not yet clear but, in the absence of evidence of anatomic changes, it is likely related to a direct action upon the receptor.
Acoustic stress revealed a TTS which, although significant, is lower than expected. This result could be due to the spectral aspect of disco music obviously less stressful than the white noise generally used in experimental tests.
The analysis of the questionnaire also suggests how balance disorders, following auditory stress are much more frequent than commonly believed, particularly if considering their often unknown or difficult diagnosis due to the complicated diagnostic procedures.

Conclusions

The percentage of symptoms in some way related to vestibular involvement due to acute acoustic stress is significant also in subjects without evident anatomic changes which way possibly be related to Tullio phenomenon. The physiopathologic mechanism underlying vestibular structure involvement remains unknown. Albeit, the sensory structures involved appear to be of the macular type, as suggested by the changes in VEMPs which appear to be sufficiently sensitive once the technique has been accurately standardised. Conversely, canalar structures do not appear functionally involved and, therefore, routine vestibular exploratory techniques are not suitable to evaluate the possible involvement of the posterior labyrinth due to acute acoustic stress.

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