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Possible Joint Involvement of the Cochlea and Semicircular Canals in the Perception of Low-Frequency Tinnitus, Also Called “The Hum” or “Taos Hum”

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Abstract

Introduction: “The hum” or “Taos hum” are common terms of a tinnitus with three remarkable features. **Objective:** A possible common background is reevaluated for the three features of the hum: being sensitive on sound, head rotation, and long-distance air travel. **Material and Methods:** Questionnaires that were originally developed by Frosch were recalculated concerning the question of hum interactions with sounds. The question was split into the two affirmative answers a) “masking”, which corresponds to the overrule of the hum by a sound, and b) “beats”, which correspond to a nonlinear interaction with the hum as a Van der Pol-like oscillator. **Results and Conclusions:** When interacting with sounds as beats the hum resulted in completely different dependencies with the other two features than when masked by sounds. The simultaneous features of the hum to generate beats and to be removed during head rotation are strongly dependent at an error below 0.1%. The simultaneous features to mask the hum with sounds and to experience a time-lag of its reappearance after long-distance air travel are dependent at an error below 1%. These two pairs of features have no overlapping dependencies. The term hum can be expected to be a collective term for at least two independent manifestations.

Keywords: theoretical models, tinnitus, statistical analysis, perceptual masking, nonlinear dynamics.

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INTRODUCTION

An annoying and rare form of a low-frequency tinnitus that is perceived as mixed monaural and/or binaural low frequency sounds or noises in the range between 30 Hz and 80 Hz may provide useful insights into the mechanism of hearing. This kind of tinnitus, often called "the Hum" as we refer to it in this paper, affects approximately 2% of the population, called hearers[1]. Hearers report three curious observations. Their perception of the hum may get influenced by external sounds (ESs), hearers may notice a time lag of two to three days until their hum reappears after long-distance air travel, or they may prevent their hum during purposeful head movements, predominantly horizontal head-rotations above a certain rotation speed. All observations come from trusted and respected people. The observations are not simultaneously present in the hum of all hearers, but their occurrences are interdependent and demonstrate the variety of the manifestations of the hum[2].

Interactions of the hum with ESs usually are assigned to receptors of hair cells in the cochlea and with head rotations to those in the semicircular canals (SCs). Because of the interdependence of these observations, the cochlea and the SCs seem to be interconnected in the generation of the hum. The question of what actually causes the stochastic dependences of these three remarkable features of the hum and whether this interconnection can be merged into one common mechanism are the topics of this paper.

MATERIAL AND METHODS

The frequency distributions of the hum, being a sound-interacting hum (SIH), and/or a time-lag hum (TLH), and/or a head-rotation stopped hum (HRH), as described in Frosch[2], were statistically reevaluated in pair-wise comparisons, using the chi-squared (Chi^2) test of independence in fourfold contingency tables. The data from questionnaire surveys published by Frosch in 2008[3] and 2016[2] were used to reanalyze. All 22 questions of the 179 questionnaires were asked in the German language in written form in a manner that allowed written answers in a standardized format. The English wording of the three questions regarding SIH, HRH and TLH is presented in Table 1.

Table 2 summarizes the distributions of the three features that are the basis of the current pairwise investigations.

The Chi^2 test of independence set out in a "fourfold table" is a statistical test that was used to determine the independences of the hum features of Table 2 by pairwise comparisons. Each pair allows 1 of the 4 possible answers for each hearer: Yes/Yes, Yes/No, No/Yes and No/No. The answers were summed up at the relevant positions in the fourfold table and tested for independence, that is, the degree of dependence of their combined occurrence by calculating the numerical value of Chi^2. A Chi^2 value of < 3.84 is an indicator for the independence of the pair; when $3.84 < Chi^2 < 6.64$ there is a dependence on the 5% level, when $6.64 < Chi^2 < 10.83$ there is a dependence on a 1% level, and when $Chi^2 > 10.83$ there is a dependence of the pairs at an error below 0.1%.

The frequency distributions of SIHs, HRHs and TLHs are examined in pairwise tests on the question of whether they occur randomly and independently from each other in the hum or whether dependent and related appearances exist.

RESULTS

The two possible Yes answers to the SIH question (seen in Table 1) are split into (SIH a), which corresponds to masking, and (SIH b), indicating a beat generation. These were found to be independent of each other, as shown in Table 3, indicating that the question SIH contains "masking" and "beat generation" as two independent features.

As a consequence of this finding, the questions concerning SIH were split into (SIH a) and (SIH b) and compared separately in pairs with HRH and TLH. (SIH a) and HRH were compared first; the calculated Chi^2 test in Table 4 shows that this pair is independent.

The second split compares answer "b", written as (SIH *b), with HRH. Answer "b" is marked with an asterisk, because it additionally may contain answer "a", which is seen in the 12 Yes/Yes answers in Table 3.

Table 1. The questionnaire questions on SIH, HRH and TLH.

Question on SIH: Is your hum influenced by existing tones/words/music/noises or similar?

Yes, a) □ my hum sometimes disappears, when they get louder,

b) □ my hum starts to beat with similar tones/noises,

No, c) □ I have not observed any such influences on my hum.

Question on HRH: Does your hum change due to head movements like rotation (1), nodding (2) or posture changes (3)?

a) □ No,

b) □ Yes, and definitely due to.….

I observe…..

Question on TLH: Have you been on any flights lasting over 4 hours in duration since you have experienced the hum?

Yes, and after my return

a) □ my hum was always present again immediately after my return,

b) □ my hum sometimes reappeared at home only after several days,

No, c) □ I did not make any such air travels.

Table 2. Answers of 179 hearers when asked about the three features SIH, HRH and TLH of their individual hum.

Hum	Yes	No	No answer
SIH	102	69	8
HRH	109	62	8
TLH	39	32	108

Table 3. The number of (Yes) and (No) answers to the SIH question when divided into (SIH a) and (SIH b).

Test of independence: $Chi^2 = 0.19$, n = 171			
	Yes	SIH a	No
Yes	12		13
SIH b			
No	77		69

Table 4. Total of (Yes) and (No) answers for the combination (SIH a) and HRH.

Test of independence: $Chi^2 = 0.09$, n = 169			
	Yes	SIH a	No
Yes	28		33
HRH			
No	47		61

Table 5. Total of (Yes) and (No) answers for the combination (SIH *b) and HRH.

Test of independence: $Chi^2 = 12.95$, n=169			
	Yes	SIH *b	No
Yes	17		44
HRH			
No	8		100

Table 6. Total of (Yes) and (No) answers for the combination of (SIH a) and TLH.

Test of independence: $Chi^2 = 7.68$, n = 70			
	Yes	SIH a	No
Yes	22		16
TLH			
No	8		24

Table 7. Total of (Yes) and (No) answers for the combination of (SIH *b) and TLH.

Test of independence: $Chi^2 = 0.15$, n = 70			
	Yes	SIH *b	No
Yes	6		32
TLH			
No	4		28

Answer “*b” can clearly be attributed to interactions that are known for forced nonlinear oscillators like Van der Pol oscillators. When (SIH *b) is combined with HRHs as in Table 5, a dependence at an error below 0.1% results, which indicates an extreme interdependence between both features.

When (SIH a) was combined with TLH, the pair was noted to have a dependent distribution with an error < 1%, as shown in Table 6.

The combination of (SIH *b) and TLH, as shown in Table 7, was not noted to be dependent on each other.

The occurrence of both TLH and HRH has already been found to have an independent distribution ($Chi^2 = 1.01$ in Frosch[2]), confirming the findings of this study.

TLH and HRH do not seem to be related in any manner.

DISCUSSION

The stochastic dependences of the three features of the hum that were focused on in this study have been already reported[2]. SIH was found to appear significantly more often with TLH and HRH, while TLH and HRH were independent from each other. The significant dependence of SIH when paired with TLH or HRH suggests that SIH could have a crucial role in integrating all three features into one common principle.

Unexpected new information

In this study, novel data were collected after the SIH question was split into the two parts of Yes (answers “a” and “b” to the question on SIH in Table 1). Hearers clearly distinguished between the two parts of the SIH question: (SIH a) that corresponded to masking and (SIH b) that signified beat generation. Both parts appeared independently, as shown in Table 3, indicating that SIH contains masking and beat generation as two independent features.

The answers for (SIH a) and (SIH b) showed opposite dependencies when compared with HRH and TLH. (SIH a) and TLH were found to be significantly dependent and simultaneous in the hum, whereas (SIH a) and HRH were independent from each other. The opposite is true with regard to (SIH b). The combination of (SIH b) and TLH appeared to be independent, but (SIH b) and HRH were found to be highly dependent, with an error < 0.1%. It seems obvious that the two pairs of dependent features - beats and head rotations, and masking and time lag - are firmly linked but that they are not cross-linked. SIH should therefore be regarded as an umbrella term for the two completely different and independent features: masking (SIH a) and beat generation (SIH b).

Unknown information in the scientific literature

When we try to determine explanations for the different behaviors of the pairs of dependent features, we must emphasize that SIH, HRH, and TLH are not common knowledge in science, which complicates each observation. The conclusions from this study are therefore hypotheses, for which a match in current scientific evidence may be difficult to find. Due to a lack of data, several reports from reliable single hearer sources are utilized to further discuss on this topic and to gain a better insight into these unusual observations.

Beats and head rotations

The high mutual dependence between (SIH b) and HRH in Table 5 indicates a close connection between these two features. Both features may interact in some manner. Beats (SIH b) can clearly be attributed to forced nonlinear oscillators, like Van der Pol oscillators[4], and their place to hair cells in the cochlea or in the SCs of the ear, where ESs may affect these hair cells. Beat interactions have been reported between ESs and nonlinear internal oscillators, such as those that generate otoacoustic emissions[5].

Beat-interaction between the hum and an ES is reported to take place as if both signals are close to each other. Below the hearing level (HL) an ES no longer interacts with the hum like a forced Van der Pol oscillator. The ES then is inaudible, even though the hum still is audible. It may therefore be concluded that the hum oscillation, and parts of its perception, are independent of the individual's hearing ability, suggesting that the location of the hum oscillation is not the same as that of the SIH volume perception, which is presumably the cochlea.

Self-sustained oscillations may occur in the SC, but this is the only place where interactions with head rotations are possible. According to the superposition principle, the oscillations of the hum and its interactions with ESs and head rotations should occur at the same place. In this case, it was expected that the hum-oscillation was located in the SC. A self-sustained oscillation of hair cells in the SC is suppressed above a certain pressure, a pressure that is induced during head rotations above a certain velocity.

An undisturbed hum that is perceived in the head has been reported to move towards the ear that is exposed to a sound. A traveling wave seems necessary to make the sound interactions of the hum audible in the ear. The merged volume information of the hum and the ES, therefore, has to be transmitted from the SC into the cochlea, and to interact with this travelling wave.

Hearers who experience HRH and (SIH b) report that their hum not only is removed above a certain rotation speed, but that simultaneously generated beats then also stop. Beats may stop because the spike in the HL is reported to disappear during head rotation, which deteriorates the hearing ability of an ES.

We hypothesize that the Van der Pol-oscillation of a hum may interact with ESs in the SCs by means of longitudinal sound pressure waves; shortly following this, a volume-dependent beat interaction with the travelling wave may be perceived in the cochlea. The hum oscillates independently of the hearing ability. The HL limits the extent by which the Van der Pol interactions of the hum with ESs can become audible in the ear (see Tables 2 and 7 of Frosch[4]). Hearers in unison report that hum interactions with ESs occur without delay. The signal interactions therefore can be calculated to occur below one half of a cycle of a hum oscillation. With a hum of 70 Hz this would be below approximately 7 ms.

The efferent inhibition of first-order auditory afferents by two-tone stimuli has been demonstrated to occur at the level of primary neurons themselves, because the latency of inhibition was found to be almost identical to that of excitatory responses to single tones of less than 2 ms. Fibers of the vestibulocochlear anastomosis were excited with latencies from 5 to 40 ms[6]. A fast mechanism that detects binaural time differences of a few μs[7] may be another example[8] that the hearing process seems to be more sophisticated than generally assumed. The route for the transport of the volume information from the SC to the cochlea is unknown.

Masking and time lag

Another notable finding in this paper was that (SIH a), which corresponded to a masking, was significantly correlating with TLH, as shown in Table 6. In this case, masking[9] indicated that the perception of the hum was suppressed by an ES of higher volume. Surprisingly, the hum is not always masked by an ES. When taking into consideration that the volume information of the hum is transmitted from the SCs into the cochlea to obtain the sound impression, the masking of the hum seems to represent a reverse signal flow of the volume information, from the cochlea into the SC, to influence the hum-oscillation there.

During the time lag, when no hum is audible, the spike in the HL still exists and can be measured without a beat interaction[4]. This confirms that TLH and HRH are not dependent on each other, as head rotation is reported to remove the HL spike located at the same frequency of the hum.

It cannot be ruled out that these processes occur under normal hearing conditions. If the assumptions formed in this study prove correct, the current theories of hearing may be overturned. Further controlled studies are needed to provide better knowledge of the currently inexplicable features and dependencies.

CONCLUSION

The SIHs that either are generating beats with ESs or are masked by them resulted in completely different dependencies, when they were compared with the features TLH and HRH. The first paired features to generate beats with ESs and to suppress the hum during head rotation, as shown in Table 5, were significantly dependent at an error below 0.1%, which indicates a common origin in the semicircular canals. The second paired features to mask the hum with sounds and to generate a time lag of its reappearance after long-distance air travel (Table 6) were also significantly dependent at an error below 1%.

The two paired features however indicate different common origins, because they are not interdependent. There exist at least two independent pairs of dependent features that interact in the hum through two different mechanisms at different locations.

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